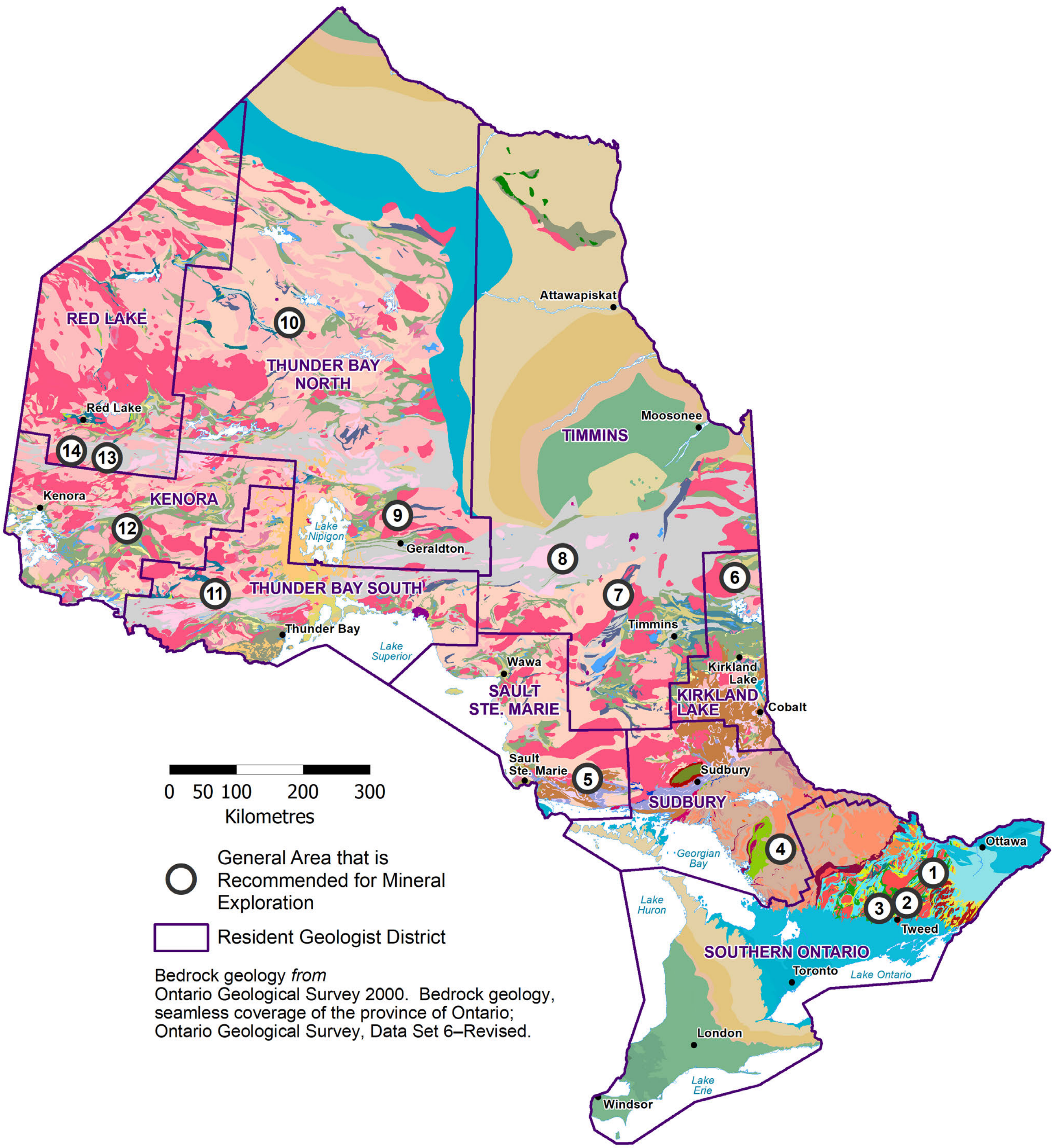
Recommendations for Exploration 2021–2022

Ministry of Northern Development, Mines, Natural Resources and Forestry
Ontario Geological Survey - Resident Geologist Program

Ontario

ONTARIO CANADA

Recommendations for Exploration
2021–2022



Ontario Geological Survey
Resident Geologist Program
Recommendations for Exploration 2021–2022

The Ontario Geological Survey (OGS) is pleased to issue its *2022 Recommendations for Exploration*. These recommendations are the product of the dedicated and knowledgeable staff located in the 8 Resident Geologist Program (RGP) offices across the province. They have been developed using existing OGS geological and exploration data, along with new information derived from the current year's activities.

This year our recommendations focus on the exploration potential for many of the critical minerals that appear on Ontario's Draft Critical Minerals List, as published in the *Critical Minerals Framework Discussion Paper* that was released by the Ministry of Northern Development, Mines, Natural Resources and Forestry in March 2021. Critical minerals can be defined as commodities that have specific industrial, technological, and strategic applications for which there are few viable substitutions. They are also at higher supply risk due to geopolitical considerations and market demand. As evidenced by this year's recommendations, Ontario's diverse geology provides excellent opportunities for the discovery and future development of new critical mineral deposits.

The RGP is also pleased to announce that we have implemented upgrades to the data entry and online posting components of our rebranded Ontario Mineral Inventory, OMI (formerly Mineral Deposit Inventory, MDI) database. These upgrades promise to provide users with more frequent updates and will allow for ongoing data quality improvements. The OMI is now accessible through our Geology Ontario (http://www.mndm.gov.on.ca/en/mines-and-minerals/applications/geologyontario) and OGSEarth (https://www.geologyontario.mndm.gov.on.ca/ogsearth.html) websites. Users of OGS publications will continue to find the database referenced by its former name, MDI, as in this compilation.

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

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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 www.mndm.gov.on.ca/en/mines-and-minerals/geology#simple-table-of-contents-2.

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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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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:

Mancini, L.M. 2022. Critical mineral molybdenum in the Grenville rocks of southern Ontario; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.4-9.

HIGHLIGHTS

- **Large portions of the Lavant gabbro complex remain underexplored**
- **Potential target for Ni and Co exploration**
- **Unexplained magnetic anomalies**
- **Abundant outcrop and easy access**

Also refer to Open File Report 6386, *Report of Activities 2021, Resident Geologist Program, Southern Ontario Regional Resident Geologist Report* (p.32-34), for an emended version of this article.

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The Lavant Gabbro Complex

The Lavant gabbro complex is the largest mafic body in the Grenville Province of Ontario and is found within the Central Metasedimentary Belt along the western margin of the Sharbot Lake domain, bound to the west by the Robertson Lake shear zone (Figure 1). According to Easton (1992), the complex is a differentiated igneous intrusion, locally layered and displaying a compositional range from ultramafic phases to gabbroic anorthosite and tonalite. In 2014, Magnus, Easton and Rainsford updated eastern Ontario's Precambrian geology from aeromagnetic and compiled geological data through a series of maps. From their interpretation and visible map anomalies, it appears that the complex is much more variable and heterogenous than current mapping indicates.

The Lavant gabbro complex is host to 2 main types of significant mineralization generally found on its margins, according to Easton (1992). Copper-gold-antimony-silver deposits hosted in mylonitized dolomite marbles within mafic mylonites derived from the complex, and several small, magmatic massive magnetite deposits occur in the Lavant gabbro, including the Yuill iron mine and the Darling and Lavant deposits (Easton 1992). According to assessment work and Mineral Deposit Inventory (MDI) data on file (Ontario Geological Survey 2021), there has been work completed on the complex (ranging from rock sampling and trenching, to geophysics and diamond drilling); however, exploration of the Lavant gabbro complex has been focused only on these 2 deposit types.

Sangster (2014) noted that several early reports by the Geological Survey of Canada (Table 1) reference 2 nickel occurrences "with a dark-gray, fine-grained diorite" in northeastern Dalhousie Township. Analysis of samples from the occurrences returned values of 0.165% Ni, trace cobalt with the "metalliferous portion of the ore" containing 0.23% Ni from first site and 0.09% Ni, trace cobalt from the second site. These results are unexplained and not documented in any published reports by the Ontario Geological Survey.

The north end of the of Lavant gabbro complex is crosscut by a splay of the Robertson Lake shear zone. This coincides with a magnetic map anomaly

Table 1. Selected historical Geological Survey of Canada reports citing nickel occurrences in northeastern Dalhousie Township, southern Ontario.

Year	Report
1898	Geological Survey of Canada, Annual Report Volume 11, Part R, p. 27
1897	Geological Survey of Canada, Annual Report Volume 10, Part A, p. 60
1896	Geological Survey of Canada, Annual Report Volume 09, Part R, p. 38
1892	Geological Survey of Canada, Annual Report Volume 06, Part R, p. 38

Dorado–Troughton, M. 2022. The Lavant gabbro complex; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.1-3.

near Pilons Lake, as noted by Easton and deKemp (1988, Figure 2). This area in Darling Township, as well as areas in Dalhousie and Lavant townships are open for registration as of October 2021.

Finally, line-1 of the Abitibi–Grenville Southern Ontario Seismic (SOS) Reflection survey intersects the Lavant gabbro complex as it was used to study the Robertson Lake shear zone and the boundary between the Mazinaw domain and the Sharbot Lake domain (Ouassaa, Forsyth and White 2007). Further analysis of this survey may yield further understanding of the shear zone, its associated splays, and the structures affecting the Lavant gabbro complex. The reader is referred to Lewis' recommendation in 2021, that the application of similar regional, seismic and long period magnetotelluric surveys in the Red Lake District to trace deep tapping seismic structures from their surface expressions as shear zones may lead to great success (Lewis 2021).

The Lavant gabbro complex has great road access and outcrop exposure, as well as land open for claim registration—making it an ideal area for exploration. Detailed geological mapping exploring the complex's magnetic anomalies and its apparent heterogeneity, further sampling with broader analyses and a thorough compilation and reinterpretation of historical data is recommended.

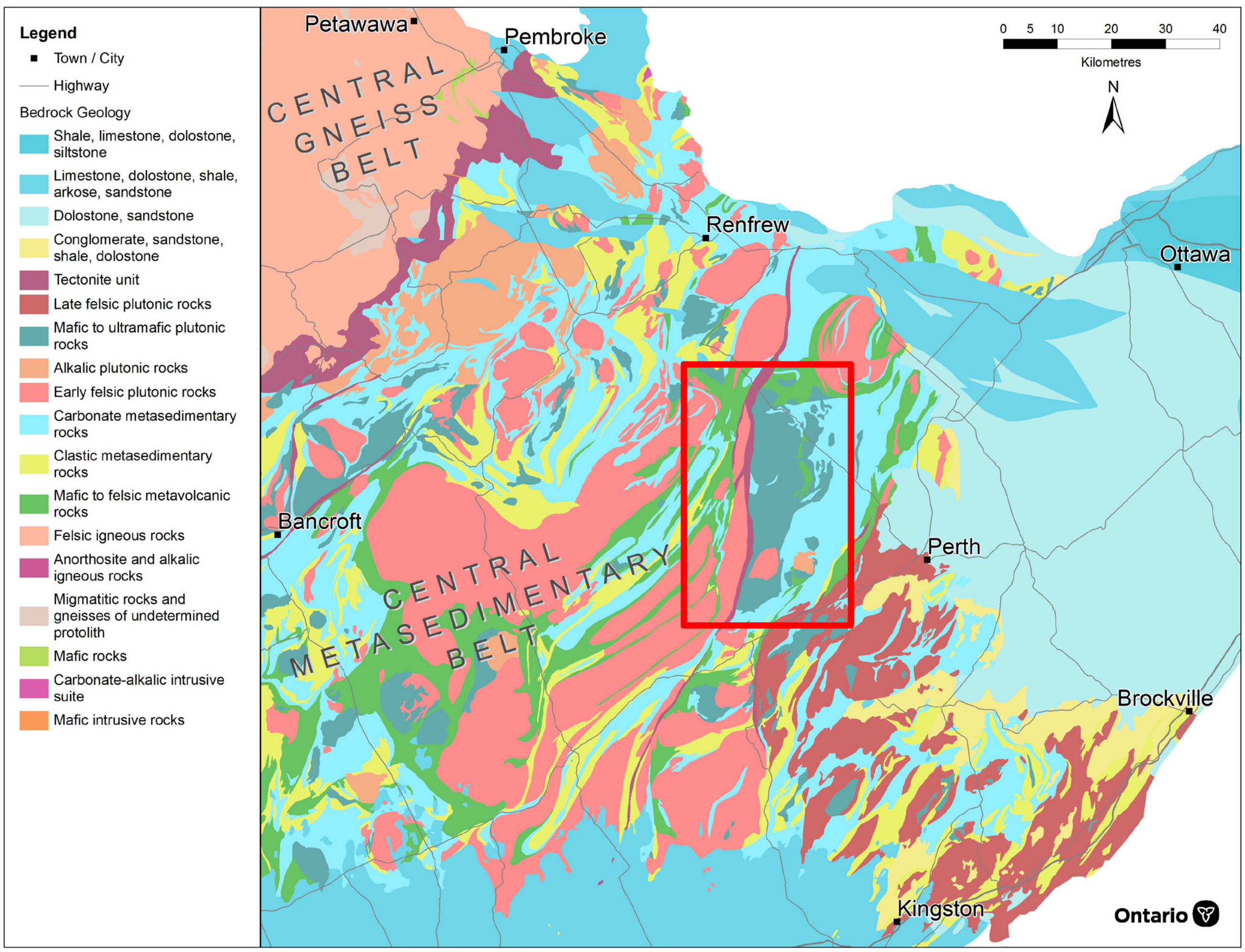

Figure 1. Bedrock geology map showing the location of the Lavant gabbro complex (outlined in red rectangle) in southern Ontario; geology *from* Ontario Geological Survey 2011.

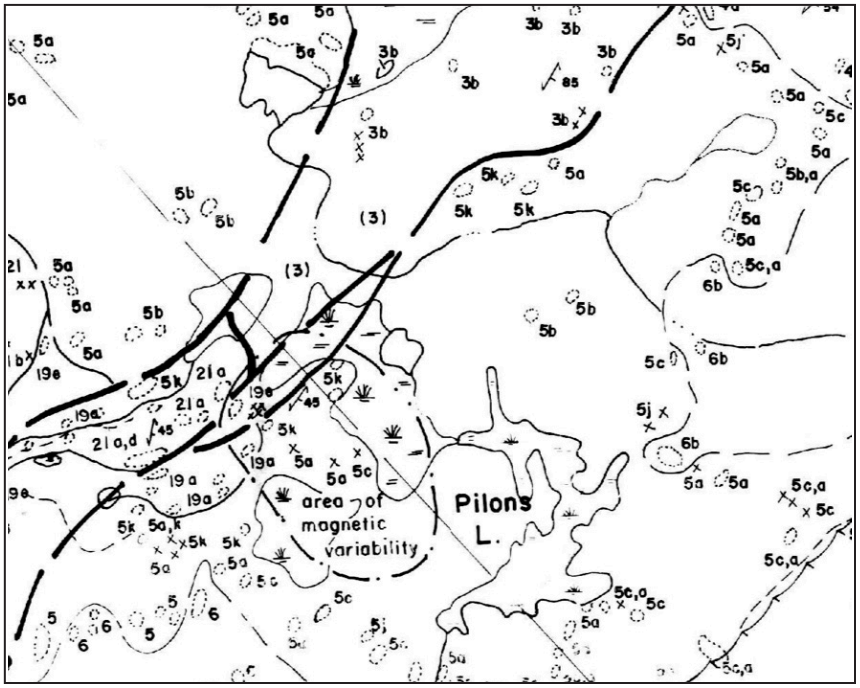

Figure 2. The unexplained magnetic anomaly near Pilons Lake in the northern end of the Lavant gabbro complex at the boundary between Lavant and Darling townships, is outlined with dot-dash lines (highlighted by Easton and deKemp 1988). Thick dashed lines indicate observed and assumed faults, splays off the Robertson Lake shear zone. Thin dashed lines indicate the interpreted positions of geological positions. Solid lines indicate observed geological boundaries. Dashed circles represent areas of bedrock outcrop and numbered with the following rock types: 21, carbonate rocks; 19, mafic ultra- and protomylonites; 5, mafic intrusive rocks; and 3, carbonate metasedimentary rocks. The centre of the magnetic anomaly can be found at NAD83, UTM Zone 18, 374545E, 5002028N.

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Lewis, S.O. 2021. Deep tapping seismic structure in the Red Lake District; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2020-2021, p.9-13.

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HIGHLIGHTS

- **Molybdenum is listed as a critical mineral in Ontario and globally**
- **More than 100 molybdenum occurrences are documented in southern Ontario**
- **Southern Ontario has excellent local, national and international transportation infrastructure**

Also refer to Open File Report 6386, *Report of Activities 2021, Resident Geologist Program, Southern Ontario Regional Resident Geologist Report* (p.35-38), for a revised version of this article.

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Critical Mineral Molybdenum in the Grenville Rocks of Southern Ontario

Molybdenum, considered a critical mineral provincially, nationally and globally, is used in many industries such as steel, oil and gas, automotive, aerospace, military, and energy. It is also used in electronics and medical equipment. Because of the multitude of large-scale industries that rely on it, the demand for molybdenum has the potential to increase significantly over the next few years (Molybdenum Market by Product Type (Steel, Chemical, Foundry, Molybdenum Metal, Nickel Alloy), and Application (Oil and Gas, Automotive, Heavy Machinery, Energy, Aerospace and Defense and Others): Global Opportunity Analysis and Industry Forecast, 2021–2030; Allied Market Research (2021) report available at https://www.alliedmarketresearch.com [accessed November 15, 2021]).

The global molybdenum market is predicted to grow at a compound annual growth rate (CAGR) of 2% from 2020 to 2027 with the market being worth US$319 billion by 2027. In Canada, the molybdenum market is forecast to grow between 0.9% and 1.4%, depending on the industry, from 2020 to 2027 (https://www.globenewswire.com/news-release/2020/08/24/2082764/0/en/Global-Molybdenum-Industry.html [accessed November 15, 2021]).

Molybdenum in Southern Ontario

Molybdenum mineralization in the Grenville Province rocks of southern Ontario occurs in 3 deposit types:

1. Stratabound in skarn lenses within segments of intercalated marble and paragneiss;
2. Unconformable and conformable pegmatite dikes and sills intruding intercalated marble, amphibole paragneiss and granite gneiss; and
3. Stratiform in amphibolite-hedenbergite paragneiss (Carter 1984).

In the early 1900s, a few tens to hundreds of kilograms of hand-picked molybdenum flakes were attained from several southern Ontario deposits (Carter 1984). Production of 43 844 kg of 95% MoS_2 from 8255 tonnes of ore is documented from the Hunt Mine in Brougham Township. Production of 4536 kg of MoS_2 is also documented from the Spain and Zenith deposits (Carter 1984).

Recommendations for Exploration

A quick search of the Mineral Deposit Inventory (MDI) online database revealed more than 100 documented molybdenum occurrences in the

Mancini, L.M. 2022. Critical mineral molybdenum in the Grenville rocks of southern Ontario; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.4-9.

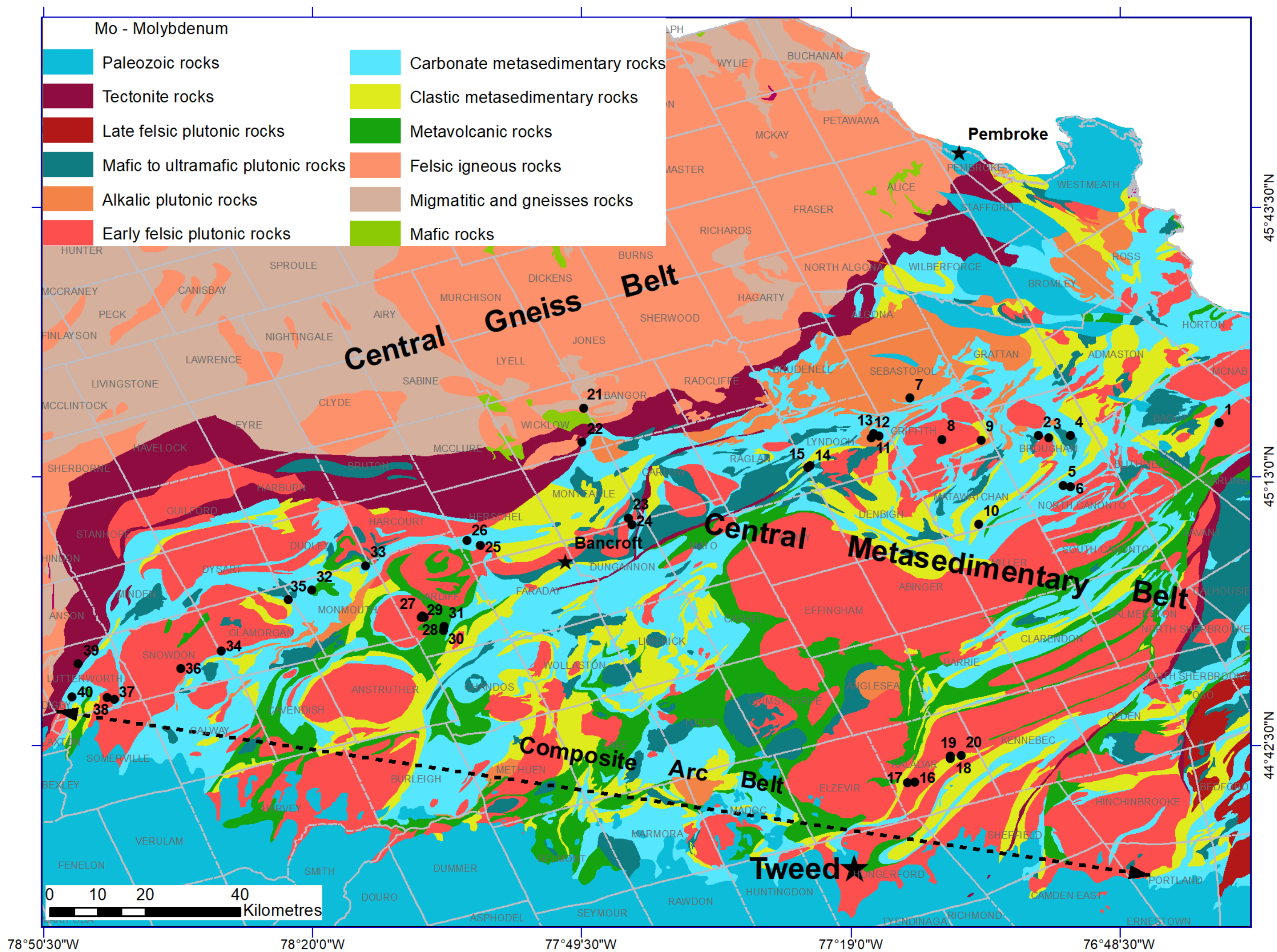

Figure 1. Simplified geological map of the Composite Arc Belt and Central Gneiss Belt of southern Ontario showing locations of molybdenum occurrences on crown land available for mining claim registration. Numbers on the map correspond to deposit names and the occurrence descriptions in Table 1 (data *from* the Mineral Deposit Inventory, Ontario Geological Survey 2021).

Table 1. Molybdenum occurrences in the Central Gneiss Belt and Composite Arc Belt of southern Ontario open for mining claim registration as of October 14, 2021. Data *from* MDI (Mineral Deposit Inventory), Ontario Geological Survey 2021. Numbers refer to occurrences in Figure 1.

No.	Deposit Name /Township	MDI File No.	Commodity Primary, Secondary	Mineralization Style	Rock Association(s)	Deposit Status
1	Stone Lake Bagot	MDI31F07SE00075	Mo	[1]Disseminated flakes in pegmatite stringers	[1]Marble, Sediments, Granitic Intrusion	Discretionary Occurrence
2	Bob Claims Brougham	MDI31F07SW00105	Mo Py	[10]In veins and seams in contact between marble and gneiss	[10]Marble, Amphibolitized Gneiss	Discretionary Occurrence
3	Ross-O'Brian Brougham	MDI31F07SW00017	Mo Py, Po	[1]Coarse flakes in gneiss	[1]Hedenbergite Gneiss, Marble	Prospect
4	Kennelly Lake No. 2 Brougham	MDI31F07SW00103	Mo	[3]Disseminated flakes in marble	[3]Marble	Discretionary Occurrence
5	Mountain Chute Brougham	MDI31F02NW00055	Mo	[4]Disseminated in marble	[4]Marble	Discretionary Occurrence
6	J.S. Box Brougham	MDI31F02NW00042	Mo Py, Po	[1]Disseminated in skarn	[1]Pyroxenite, Marble	Discretionary Occurrence
7	W. Felhaber Sebastopol	MDI31F06SE00093	Mo Cp, Py, Po	[1]Flakes of Mo associated with Cp, Py and Po disseminated in dikes	[1]Pegmatite	Discretionary Occurrence
8	Nelson-Lepine Griffith	MDI31F06SE00094	Mo, Th U	[1]Disseminated at contact between marble and pegmatite	[1]Marble, Pegmatite Intrusion	Occurrence
9	Spain Mine (J.R. Lill, J. Legree) Griffith	MDI31F06SE00013	Mo U, Th, Cu	[1]Flakes of Mo associated with Py and Po disseminated in stratabound lenses	[1]Pegmatite, Marble, Gneiss	Developed Prospect with Reserves
10	James Wilson Matawatchan	MDI31F03NE00014	Mo Py	[1]Flakes of Mo disseminated in pyroxenite	[1]Pyroxenite, Pegmatite	Discretionary Occurrence
11	Legree (Mining Mountain) Lyndoch	MDI31F06SW00073	Mo Po	[1]Patchy disseminated along contact between marble and pegmatite	[1]Marble, Pegmatite, Gneiss	Occurrence
12	Lyndoch Deposit (Mining Mountain SE) Lyndoch	MDI31F06SW00072	Mo Py, Po	[1]Patchy disseminated along contact between marble and pegmatite. Flakes of Mo up to 2.5 cm occur sparsely in Qtz in the pegmatite	[1]Marble, Pegmatite, Gneiss	Discretionary Occurrence
13	Jamieson Mine Lyndoch	MDI31F06SW00017	Mo, U, Th Ap, Py, Po, Ga, Spl	[1]Mo occurs as large crystalline flakes associated with disseminated Py and Po in the pegmatite	[1]Marble, Pegmatite, Gneiss	Prospect
14	North Bruceton Lyndoch	MDI31F03NW00052	Mo Po	[1]Mo and Po are contained in a wide band of biotite paragneiss	[1]Paragneiss	Discretionary Occurrence
15	Bruceton Deposit Lyndoch	MDI31F03NW00042	Mo Act, Po	[1]Mo found with Po and Act calcite stringers in a pyroxenite	[1]Marble, Pyroxenite	Discretionary Occurrence
16	Young Kaladar	MDI31C11SE00087	Mo Act	[5]Scattered flakes in pegmatite dikes	[5]Granite Gneiss, Pegmatite	Discretionary Occurrence
17	Marisette Kaladar	MDI31C11NE00100	Mo	[5]Scattered flakes in pegmatite dikes	[5]Granite Gneiss, Pegmatite	Discretionary Occurrence

Table 1. *continued*

No.	Deposit Name /Township	MDI File No.	Commodity Primary, Secondary	Mineralization Style	Rock Association(s)	Deposit Status
18	Kaladar North Kaladar	MDI31C11NE00152	Mo	[5]Scattered flakes in pegmatite dikes	[5]Pegmatite, Biotite Granodiorite	Discretionary Occurrence
19	Kaladar North Moly Kaladar	MDI31C11NE00156	Mo	[5]Scattered flakes in pegmatite dikes	[5]Pegmatite, Biotite Granodiorite	Discretionary Occurrence
20	Flinton Corner East Kaladar	MDI31C11NE00158	Mo	[5]Scattered flakes in pegmatite dikes	[5]Granite Gneiss, Pegmatite	Discretionary Occurrence
21	Papineau Shores Wicklow	MDI31F05SW00021	Mo	[6]Scattered flakes and aggregates in metasediments	[6]Metasediments, Amphibolite	Discretionary Occurrence
22	Davis Falls Wicklow	MDI31F05SW00018	Mo Sph	[6]Fine-grained disseminated Mo in sphene-diopside syenite	[6]Syenite	Discretionary Occurrence
23	York River Monteagle	MDI31F04NE00072	Mo Hbl	[1]Scattered flakes in narrow Qtz veins and fibrous hornblende	[1]Marble, Clastic Metasedimentary	Discretionary Occurrence
24	Stoughton Deposit Dungannon	MDI31F04NE00071	Mo	[1]Mo crystals up to 2.5 cm occur in pyroxenite	[1]Marble, Pegmatite, Pyroxenite	Occurrence
25	Williams Herschel	MDI31E01SE00240	Mo	[2]Disseminated and stringers in pyroxenite	[2]Pyroxenite	Occurrence
26	Baptiste Lake Herschel	MDI31E01SE00242	Mo	[2]Disseminated and stringers of coarse flakes in pyroxenite	[2]Marble, Pyroxenite, Pegmatite	Occurrence
27	Powell and Anderson Cardiff	MDI31D16NE00156	Mo	[7]Mo occurs in pegmatite dikes cutting granitic gneiss	[7]Granitic Gneiss, Pegmatite	Occurrence
28	North Eels Lake Cardiff	MDI31D16NE00244	Mo	[8]Mo occurs in pegmatite dikes cutting granitic gneiss	[8]Granitic Gneiss, Pegmatite	Occurrence
29	Moly Prospect Cardiff	MDI31D16NE00276	Mo	[7]Mo occurs in pegmatite dikes cutting granitic gneiss	[7]Granitic Gneiss, Pegmatite	Discretionary Occurrence
30	Orr-Kidd Cardiff	MDI31D16NE00240	Mo Py, Po, Bio	[2]Mo and Py occur in pegmatite dikes cutting paragneiss	[2]Paragneiss, Pegmatite	Occurrence
31	South Farrel Cardiff	MDI31D16NE00243	Th, U Mo	[8]Th, U and Mo occur in pegmatite intruding metasediments	[8]Amphibolite, Marble, Pegmatite	Occurrence
32	Affenby Monmouth	MDI31D16NW00292	Mo Py	[2]Mo, Py occur in pegmatite dikes cutting marble	[2]Marble, Hornblende Gneiss, Pegmatite	Discretionary Occurrence
33	P.J. Dwyer Monmouth	MDI31E01SE00328	Mo Py, Po	[2]Mo, Py and Po occur in pyroxenite	[2]Pargneiss, Pyroxenite, Marble, Pegmatite	Occurrence
34	Simmonds Glamorgan	MDI31D15NE00044	Mo, U Cu	[10]Mo, Cp and Po occur in several showings in pegmatite	[10]Gneiss, Pegmatite	Discretionary Occurrence

Table 1. *continued*

No.	Deposit Name /Township	MDI File No.	Commodity Primary, Secondary	Mineralization Style	Rock Association(s)	Deposit Status
35	Little Glamor Glamorgan	MDI31D16NW00214	Mo Py, Po	[2]Scattered coarse flakes of Mo associated with Py and Po	[2]Gneiss, Pegmatite	Past-Producing Mine without Reserves
36	West Bow Molybdenum Snowdon	MDI31D15SE00133	Mo Mag, U	[11]Disseminated flakes of Mo occur in a syenite pegmatite dike intruding the Glanmorgan Gneiss Complex. U occurs in Qtz dikes	[11]Glamorgan Gneiss Complex, Pegmatite	Occurrence
37	Hopkins, A.Y. Lutterworth	MDI31D15SE00088	Mo Qtz	[2]Mo occurs in Qtz vein in gneiss on a small island 100 m off west shore of Davis Lake.	[2]Glamorgan Gneiss Complex	Occurrence
38	Davis Lake Lutterworth	MDI31D15SE00113	Mo	[11]Disseminated Mo occurs in gneiss.	[11]Glamorgan Gneiss Complex	Occurrence
39	Hunter Lutterworth	MDI31D15SW00094	Mo	[12]Disseminated Mo occurs in gneiss.	[12]Porphyroclastic Gneiss	Discretionary Occurrence
40	H. Lundberg Lutterworth	MDI31D15SW00056	Mo, U Nb	[2]Mo occurs in marble tectonic breccia	[2]Marble	Occurrence

Sources for mineralization style and rock association(s) descriptions: [1]Carter, Colvine and Meyn 1980; [2]Satterly 1943; [3]Martin 1983; [4]Easton 1990; [5]Wolff 1982; [6]Breaks and Thivierge 1983; [7]Hewitt 1959; [8]Bright 1987; [9]Satterly 1957; [10]Johnston 1968; [11]Easton 1987; [12]Easton 2001.

Abbreviations: Act, actinolite; Ap, apatite; Bio, biotite; Cp, chalcopyrite; Cu, copper; Ga, galena; Hbl, hornblende; Sph, sphene; Spl, sphalerite; Mag, magnetite; Mo, molybdenum; Nb, niobium; Po, pyrrhotite; Py, pyrite; Qtz, quartz; Th, thorium; U, uranium.

Grenville Gneiss Belt and the Composite Arc Belt of southern Ontario, 41 of which are located on crown land and available for mining claim registration (Ontario Geological Survey 2021). Details of the 41 occurrences are listed in Table 1 and their locations indicated in Figure 1.

Southern Ontario remains an excellent location for mineral exploration and development, and production with its mineralogically diverse and complex geology. Excellent transportation infrastructure allows quick and efficient movement of products to local, national and international markets via roads, rail and Great Lakes shipping (Mancini 2021).

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HIGHLIGHTS

- **The Tweed Drill Core Library is a valuable resource for drill core from past exploration programs**
- **Overlooked rare earth element (REE) potential from former uranium–thorium exploration programs**
- **Use of UV-induced fluorescence is low-cost, portable, and highly effective in locating REE mineralization**

Also refer to Open File Report 6386, *Report of Activities 2021, Resident Geologist Program, Southern Ontario Regional Resident Geologist Report* (p.39-42), for a revised version of this article.

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REE Potential from Former U-Th Exploration Programs

On December 7th, 2020, the District Geologist examined drill core at the Tweed Drill Core Library donated from the former Jupiter project in Palmerston Township. Sample descriptions and photos were taken in the middle of the afternoon and fluorescence examination and sampling were conducted in the evening after dark.

Location and Access

The Tweed Drill Core Library (DCL) is located approximately 2 km south of Tweed and hosts more than 210 000 m of irreplaceable drill core from southern Ontario. Access to the drill core library can be granted by contacting the Southern Ontario Resident Geologist Office in Tweed.

The Jupiter project's former drill site is a 5.5 km drive down Robertsville Rd. off County Road 509 followed by a 500 m hike west through the bush.

Regional Geology

The Jupiter project is located in the Mazinaw terrane of the Central Metasedimentary Belt, Grenville Province. The Mazinaw terrane consists of basaltic–tonalitic basement which underwent a comparatively prolonged deformation history relative to the adjacent Frontenac Terrane (Easton 1992). Grenville Supergroup marbles and calc-alkalic metavolcanic rocks overly these basement units and are in turn overlain by deformed metasedimentary rocks (approximately 1155 Ma) belonging to the Flinton Group (Easton 1992). The Jupiter project mining claims overlie the Addington granite, north of an interpreted fault that trends roughly east.

Property Geology

Three main lithologies are predominant on the property as observed in donated drill core from the Jupiter project and in historic drill logs from Rexdale Mines described in their 1969 assessment filing (Baker 1969).

Pegmatite units consist of quartz, albite, and K-feldspar with minor biotite and trace uraninite. South of the Jupiter claims in the Frontenac Ventures East–Bancroft uranium project (Bottrill 2007), the grain size has considerable variation from equigranular granite to coarse-grained granite and locally to pegmatite. Foliation is present in quartz-feldspar dominated zones whereas coarser grained units maintain an equigranular fabric (Photo 1A).

Mafic gneiss and schist units are prevalent in areas directly to the south of the Jupiter claims (Bottrill 2007) as reported in previous field mapping; and in drill logs from Rexdale Mines (Baker 1969) as observed in donated drill core. Gneissic intersections consist of fine-grained amphibole and biotite. Garnet-biotite-amphibole schists are also present

Dorado–Troughton, M. and Meek, R.D. 2022. REE potential from former U-Th exploration programs; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.10-13.

Photo 1. Photographs of donated drill core from the former Jupiter project, stored at the Tweed Drill Core Library. **A)** Representative photograph of the pegmatite unit. **B)** Representative photograph of the garnet-biotite schist. **C)** Intercalated garnet-biotite schist and pegmatite unit. **D)** Representative photograph of the marble unit. Note: Drill core pictured are NQ sized and 47.6 mm in diameter.

intercalated between pegmatite units at the decimetre scale. Garnets, 2 to 20 mm in diameter, are present in distinct horizons (Photos 1B and 1C).

Marble units have been previously logged as crystalline limestone by Baker (1969) during the Rexdale Mines drill program. They consist of banded pink and white calcite and minor to trace pale green apatite, biotite, phlogopite, green pyroxenes, and local pyrrhotite (Photo 1D).

Sampling and REE Mineralization

The Jupiter project drill core was exposed to shortwave (265 nm) and longwave (320 nm) ultraviolet (UV) light to test for correlation between fluorescence, uranium-thorium-potassium content and REE mineralization. Fluorescing sections were sampled for spectrometer assay and rare earth element analysis. Under both shortwave and longwave UV light, sodic feldspars produced a faint pink response, micas a green response, and bands of pale green were observed from the marble (Photo 1D). Disseminated pink and yellow spots less than 5 mm in diameter were observed in samples RM-REE20-2 and RM-REE20-5 (Photo 2).

Uranium (U), thorium (Th) and potassium (K) measurements were taken using the RS-125 spectrometer's 120-second assay function and the results are noted in Table 1. Only drill core sections at or above background levels were sampled. Samples were processed at the Ontario Geological Survey Geo Labs in Sudbury, Ontario and were analyzed with inductively coupled plasma mass spectrometry (IMC-100) for minor and trace elements.

Table 1. Descriptions and assay results from selected Jupiter project drill core samples stored at the Tweed Drill Core Library.

Sample	Company Hole ID	Interval Start (m)	Interval End (m)	K (%)	U (ppm)	Th (ppm)	Fluorescence	Description
RM-REE20-1	Jup-08-03	12	12.08	2.1	6.8	7.7	Faint pink response on Fsp, moderate green response on micas (SW+LW)	Pegmatite, grades from pink Fsp at top to green Fsp at bottom, smoky qtz, varying amounts of biotite and phlogopite, trace ~3 mm elongate yellow minerals
RM-REE20-2	Jup-08-03	18.24	18.4	2.6	4.2	8.7	Disseminated pink and yellow spots, Fsp and mica?	Garnet-biotite schist with intercalated pegmatite. Gnt 2-20 mm in diameter, phlogopite and biotite present, pegmatite layers consist of coarse-grained pink and green Fsp and smoky qtz.
RM-REE20-3	Jup-08-03	31.8	32	2	9.2	6.7	White-green response from micas	Pegmatite. Coarse grained, albite and K-Fsp ± Hbl, Bt, Phlog. Trace pyrrhotite and pyrite.
RM-REE20-4	Jup-08-03	32	32.1	2	9.2	6.7	White-green response from micas	Contact between pegmatite described above and garnet-biotite schist, K-Fsp dominant in pegmatite in area closest to contact.
RM-REE20-5	Jup-08-03	45.5	45.65	2	5.9	5.3	Disseminated pink spots (Fsp?)	Biotite-feldspar gneiss, Fol. 25 deg. Trace calcite. Coarse grained diopside layers in coarse grained smoky qtz layers, biotite layers throughout ~ 2 mm thick, trace pyrrhotite
RM-REE20-6	Jup-08-03	50.5	50.6	1.6	6	5.6	Bands of pale green	Marble. Interbanding of pink and white calcite, minor pale green apatite, biotite and phlogopite, diopside, actinolite and trace pyrrhotite

Abbreviations: Bt, biotite; Fol., foliation; Fsp, feldspar; Gnt, garnet; Hbl, hornblende; K-fsp, potassium feldspar; Phlog, phlogopite; qtz, quartz; SW+LW, Shortwave and Longwave

Table 2. Selected elemental analysis results from sampling of donated Jupiter project drill core at the Tweed Drill Core Library. Sample descriptions are found in Table 1. Bolded samples indicate more notable results in the analyses.

Sample	Ce (ppm)	Dy (ppm)	Er (ppm)	Gd (ppm)	Ho (ppm)	La (ppm)	Lu (ppm)	Nd (ppm)	Pb (ppm)	Sc (ppm)	Sm (ppm)
RM-REE20-1	3.33	0.232	0.123	0.293	0.0453	1.8	0.015	1.45	35.17	0.4	0.308
RM-REE20-2	**115.66**	**9.144**	**4.712**	**10.863**	**1.6976**	**51.7**	**0.577**	**57.02**	**24.53**	**27.2**	**11.982**
RM-REE20-3	4.81	0.446	0.342	0.472	0.1029	2.6	0.091	2.14	28.53	1	0.457
RM-REE20-4	14.97	2.929	2.018	2.476	0.6417	7	0.318	7.74	78.73	7.5	1.974
RM-REE20-5	**76.61**	**9.391**	**5.546**	**10.114**	**1.8746**	**32**	**0.717**	**44.55**	**10.47**	**27.7**	**9.941**
RM-REE20-6	14.38	1.327	0.705	1.505	0.2712	8.8	0.067	6.39	1.28	1.6	1.277
RM-REE20-5 (duplicate)	**76.37**	**9.408**	**5.36**	**10.264**	**1.8809**	**31.8**	**0.706**	**44.37**	**10.34**	**27.5**	**9.621**
RM-REE20-6 (duplicate)	14.33	1.281	0.739	1.552	0.277	9.1	0.067	6.43	1.25	1.7	1.317

Selected sample results are presented in Table 2 with notable results bolded. Samples RM-REE20-2 and RM-REE20-5 clearly show the most significant REE mineralization. These samples are both classified as a part of the mafic units (a gneiss and a schist respectively). The 2 samples also notably displayed disseminated and spotty pink fluorescence, and some of the lowest uranium assay results (*see* Table 1). Pegmatitic samples (RM-REE20-1 and RM-REE20-3) displayed higher U, Th and K assay results, as well as white to pale green fluorescence, yet their results show very little REE mineralization. Finally, samples with intermediate REE results include RM-REE20-4 and RM-REE20-6, representing a pegmatite–schist contact and the marble unit respectively.

While the original target of the Jupiter project's exploration was U–Th mineralization hosted within pegmatite units, it is clear that there is notable and overlooked REE mineralization present within the project's mafic gneiss and schist zones—likely concentrated and enriched by the emplacement of the pegmatites.

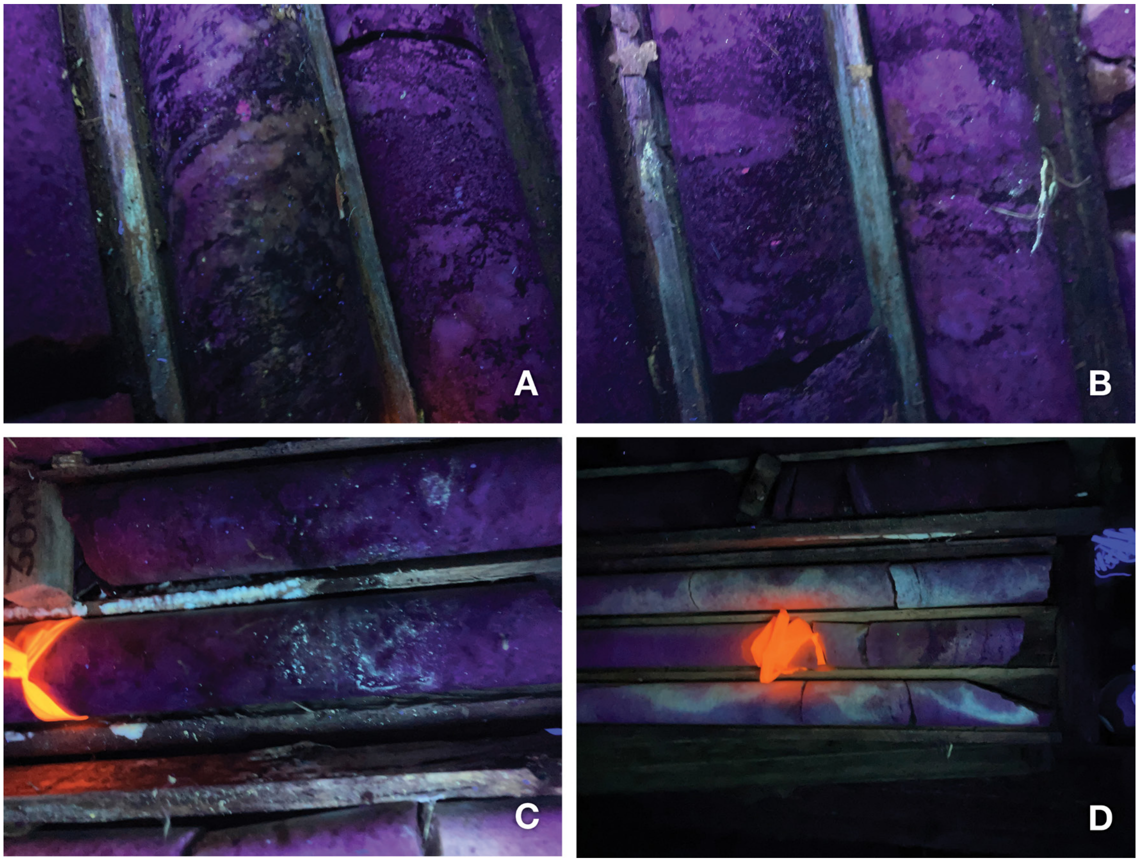

Photo 2. Photographs of donated drill core from the former Jupiter project exhibiting fluorescence under UV light. Note: The bright orange bands are flagging tape and the pictured core is NQ sized and 47.6 mm in diameter. **A)** Sample RM-REE20-5. Note the disseminated pink spots. **B)** Sample RM-REE20-5. Note the disseminated pink spots. **C)** Sample RM-REE20-2. Note the disseminated yellow zone and minor pink spots. **D)** Sample RM-REE20-6. Note the bands of pale green.

Summary

These initial results highlight the Tweed DCL's utility as a resource of archived drill core that can be accessed early in exploration making available core samples from historical programs that may have not considered REE mineralization during their initial exploration efforts. The use of UV-induced fluorescence as a preliminary method to analyze drill core highlights an often ignored, low-cost prospecting tool to assist with locating REE mineralization.

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HIGHLIGHTS

- **Graphite is classified as a critical mineral in Ontario, as well as nationally and internationally**
- **The Bissett Creek graphite deposit occurs in graphitic gneisses in the Grenville Province**
- **Additionally, there are 5 prospects and 13 occurrences in the Grenville Province, Sudbury District**
- **The majority of the occurrences are in paragneisses (gneisses of sedimentary origin)**

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Graphite in the Grenville Province, Sudbury District

Graphite is defined as a critical mineral by Ontario, as well as by Canada, and internationally. Specifically, it is critical in the production of batteries, essential to a green economy (Simandl, Simandl and Paradis 2021). However, natural graphite has many other uses: in refractory bricks, crucibles and crucible linings, brake linings, lubricants, paint coatings, steel industry, carbon brushes and in electric arc furnaces (Robinson, Hammarstrom and Olson 2017; Simandl, Simandl and Paradis 2021). Natural graphite occurs in 3 forms: amorphous, flake and vein (Robinson, Hammarstrom and Olson 2017; Table 1). The graphite currently produced in Canada is flake graphite. Canadian graphite production in 2020 was 10 000 tonnes, accounting for approximately 1% of world production and placing it tenth in the world (U.S. Geological Survey 2021).

There are 5 past-producing graphite mines in Ontario; all in the Grenville Province (Central Metasedimentary Belt) in the Southern Ontario Resident Geologist Program (RGP) District (Ontario Geological Survey 2021), with the majority hosted in calcic metasedimentary rocks (marble, dolomite, dolostone). Numerous occurrences are also known in that area (MacKinnon and LeBaron 1992). In the Sudbury RGP District, Northern Graphite Corporation's Bisset Creek project is an advanced project with a filed Preliminary Economic Assessment (Leduc 2013). The deposit is located in the Central Gneiss Belt, hosted in felsic paragneisses (metasedimentary rocks) and is flake graphite type. The resource estimate for the deposit, at a cut-off grade of 1.02% graphitic carbon, is 68 690 000 tonnes of Measured and Indicated Resources at 1.72% graphitic carbon, with an additional 24 096 000 tonnes of Inferred Resources at 1.65% graphitic carbon.

In addition to the Bisset Creek deposit, 5 prospects and 13 occurrences of graphite in the Grenville Province of the Sudbury RGP District have been documented in the Mineral Deposit Inventory database (MDI, Ontario Geological Survey 2021; Table 2; Figure 1). The Grenville Province in the Sudbury RGP District lies, for the most part, in the Southern Ontario Mining District and, therefore, affected by surface rights holdings. Although the occurrences in Table 2 are currently on private or mining lands, they are also all hosted in paragneisses or metasedimentary schists (*see* Table 2). In Figure 1, the paragneisses are outlined and the areas unencumbered by withdrawals or surface rights holdings are distinguished by darker shading. There are 23 Discretionary Occurrences in the Grenville Province of the Sudbury RGP District that are also predominantly hosted in paragneisses (shown in Figure 1 as unlabelled black dots, and not listed in Table 2).

Péloquin, A.S. 2022. Graphite in the Grenville Province, Sudbury District; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.14-18.

Many of the occurrences in Table 2 were added to the MDI database based on information in Davidson (1982). Other reports describing the graphite occurrences in Table 2 include Hewitt (1965; Laurier Township) and Garland (1987; Laurier, Ryerson and Maria townships). MacKinnon and LeBaron (1992) concentrate on southern Ontario with mention of the Bisset Creek occurrence. Villard, Keevil and Hogg (1984) reported on the possible association of known graphite deposits with gold (Chaffey, Laurier and McMurrich townships).

Table 1. Natural graphite commodity type characteristics (*from* Robinson, Hammarstrom and Olson 2017, Table J1).

Characteristic	**Commodity type**		
	Amorphous	**Flake**	**Lump or chip**
Deposit type	Amorphous	Disseminated flake	Vein
Crystallinity	Microcrystalline	Crystalline	Crystalline
Properties (crystallinity, form)	Earthy to compact microcrystalline aggregates; grain size is <4 µm	Well-developed crystal platelets, with grain size between 40 µm and 4 cm (but generally ≤1 cm), and 1 to 150 µm thick	Interlocking aggregates of coarse crystals. Available as powders to 10 cm pieces
Origin	Contact metamorphism, often by diabasic or granitic intrusions, and (or) regional metamorphism of carbonaceous sediments, often coal	Regional metamorphism of carbonaceous sediments at or exceeding amphibolite facies conditions	Epigenetic veins and lodes formed from metamorphic fluids in high-grade metamorphic rocks, usually granulites
Orebody	Layers, seams, and lenses in carbonaceous rock, each a few metres thick and hundreds of metres to several kilometres in length; may be folded and faulted	Strata-bound; tabular or lens form, as much as 33 m thick and thousands of metres long. Irregular in hinge areas of folds. The lenses have variable graphite content internally and between lenses	Vein and fracture-filling within or crosscutting metamorphic structures and rock contacts. Individual veins range from 0.05 to 3 m thick, although usually less than 0.3 m, and extend up to hundreds of metres, although rarely more than tens of metres
Ore grade (percent carbon)	50 to 90 (aggregates may contain non-graphitic carbonaceous material)	Generally 5 to 30, locally higher	40 to 90 (may require hand sorting)
Deposit tonnage (million metric tons)	0.1 to 500	0.1 to 100	Small; no reliable data for individual veins
Mine operations	Surface or underground mines	Generally open pit surface mines	Mines are typically small, labour-intensive, and underground.
Product grade (percent graphite)	60 to 90	75 to 97	90 to 99.9
Main uses	Refractories, steel industry, paint, coatings, and batteries	Refractories, brake linings, lubricants, batteries, and expandable graphite applications	Carbon brushes, brake linings, and lubricants
Major producers and resources (in order of production level)	China, Republic of Korea, Mexico, Austria	China, Brazil, India, Madagascar, Germany, Austria, Norway, Canada, Zimbabwe	Sri Lanka

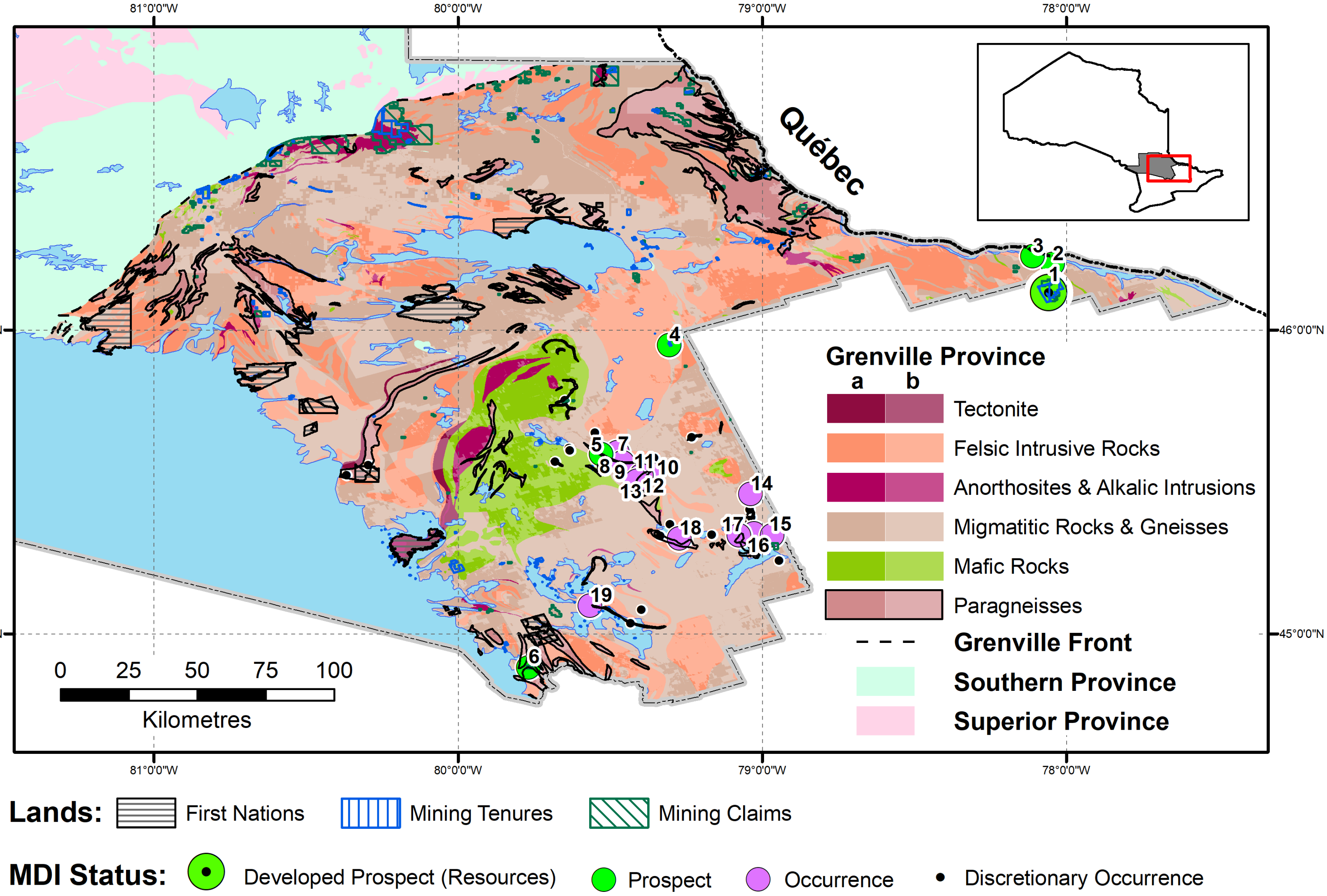

Figure 1. Geological map of the Grenville Province in the Sudbury RGP District, showing the locations of graphite occurrences as documented in the Mineral Deposit Inventory (numbers on map refer to Table 2; Ontario Geological Survey 2021). The presence of paragneisses is highlighted (outlined), as are areas unencumbered by land withdrawals or surface rights holdings (shading in column 'a' of legend) and withdrawals or surface rights holdings (shading in column 'b' of legend); geology *from* Ontario Geological Survey 2011; co-ordinate system: GCS North American 1983 EPSG 4269; Universal Transverse Mercator co-ordinates (UTM) cannot be used as the Sudbury RGP District falls in 2 zones (17 and 18).

Table 2. Summary of graphite occurrences documented in the Ontario Mineral Inventory database in the Grenville Province, Sudbury RGP District, excluding Discretionary Occurrences (Ontario Geological Survey 2021). Map # refers to Figure 1.

MAP #	MDI	NAME	MDI STATUS	TOWNSHIP	HOST ROCK	LAND STATUS
1	31L01SE00002	Bissett Creek Graphite Project	Developed Prospect (Resources)	Maria	Paragneiss	Mining Tenure
2	31L01NE00003	McVittie Group 2	Prospect	Maria	Paragneiss	Surface Rights
3	000000001344	McVittie Group 1	Prospect	Maria	Paragneiss	Surface Rights
4	31E14NW00003	Manella-Maclean Graphite Project	Prospect	Laurier	Metasedimentary schist and veins	Mining Tenure
5	31E12SE00007	Ryerson Graphite Project	Prospect	Ryerson	Paragneiss	Surface Rights
6	31D13NW00002	F.J. Atkinson Property	Prospect	Baxter	Paragneiss	Mining Claim
7	31E11SW00023	North Central Ryerson Graphite	Occurrence	Ryerson	Paragneiss	Surface Rights
8	31E12SE00021	Ryerson Graphite Project	Occurrence	Ryerson	Paragneiss	Surface Rights
9	31E11SW00018	Strarrat Road Graphite	Occurrence	Ryerson	Paragneiss	Surface Rights
10	31E11SW00013	Highway 518 Graphite	Occurrence	Perry	Paragneiss	Surface Rights
11	31E11SW00014	OGS Sample 81-RK-42	Occurrence	Perry	Paragneiss	Surface Rights
12	31E11SW00007	Doe Lake East Graphite	Occurrence	Perry	Paragneiss	Surface Rights
13	31E11SW00006	Doe Lake Graphite	Occurrence	McMurrich	Paragneiss	Surface Rights
14	31E06NE00007	Heck Lake Graphite	Occurrence	Sinclair	Paragneiss	Surface Rights
15	31E07SW00005	Oxtongue River Area	Occurrence	Franklin	Paragneiss	Surface Rights
16	31E06SE00026	Dwight Bay Graphite	Occurrence	Franklin	Paragneiss	Surface Rights
17	31E06SE00021	South Portage	Occurrence	Franklin	Paragneiss	Surface Rights
18	31E06SW00010	Lake Vernon Graphite	Occurrence	Chaffey	Paragneiss	Surface Rights
19	31E04SE00005	Medora Graphite	Occurrence	Medora	Paragneiss	Surface Rights

Recommendations

Recommendations for exploring for graphite, including advice from various sources such as Leduc (2013); Robinson, Hammarstrom and Olson (2017); LeBaron (2017); Scogings (2019a and 2019b) are listed below.

- target paragneisses; examine "undifferentiated gneisses" for metasedimentary origins
- prospecting by outcrop examination, sampling and eventual trenching
- for flake graphite, magnetic and electromagnetic geophysical surveys (grassroots), and induced polarization (property scale) can be effective
- sample analysis
- geochemical, use graphite-specific methods (for example: double loss on ignition; acid leach – IR; consult with commercial labs to determine best methodology)
- petrographic, to estimate *in situ* flake size and distribution and gangue minerals
- sampling residual soils, to examine for graphite flakes
- sampling stream sediments, to examine for graphite flakes, and for sulphides and vanadium-bearing garnet (goldmanite) which are possible indicator minerals
- geochemical surveys, some deposits have positive correlations with vanadium and uranium (also carbon and nickel)
- drilling, diamond drilling is preferred for eventual metallurgical work

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HIGHLIGHTS

- **Critical mineral potential in the Archean suites, Huronian Supergroup and associated intrusions**
- **Lake sediment geochemical anomalies are evaluated for prospective critical mineral target areas using information from the MDI database and bedrock geology**

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Critical Mineral Potential in the Elliot Lake–Sault Ste. Marie Area

The Elliot Lake–Sault Ste. Marie area has historically been known for uranium (U) and nickel-copper-platinum group element (Ni-Cu-PGE) potential, and several producing uranium mines. Recent attention to critical minerals in Ontario (https://www.ontario.ca/page/critical-minerals#section-0) [accessed December 8, 2021], coupled with geological and geochemical data from the Ontario Geological Survey (OGS), provide an opportunity in targeting this part of the Sault Ste. Marie District (Resident Geologist Program, OGS) for exploration of critical minerals.

The general bedrock geology of the area (Figure 1; Ontario Geological Survey 2011) consists of the Proterozoic metasediments of Huronian Supergroup (Southern Province) that unconformably overlie the Archean granitoids and minor supracrustal rocks (Easton 2009). The Huronian Supergroup consists of the Elliot Lake Group, Hough Lake Group, Quirke Lake Group and Cobalt Group. Mafic intrusions in the area include the Late Archean to Early Paleoproterozoic Stone Ridge intrusion; the Early Paleoproterozoic Matachewan dike swarm and East Bull Lake intrusion; and the Paleoproterozoic Nipissing gabbro (diabase) sills and dikes (Easton 2009). The Matinenda Formation overlying the basal unconformity within the Elliot Lake Group has been historically explored for uranium mineralization whereas the margins of East Bull Lake intrusion locally host Ni-Cu-PGE mineralization (James et al. 2002).

A historical OGS lake sediment geochemical survey in the Elliot Lake–Sault Ste. Marie region identified exploration target areas that were anomalous in multiple elements (OFR 6251; Dyer 2010a). For this article, a refined subset of this survey data set (MRD 267; Dyer 2010b) was used to identify sites with elevated and anomalous concentrations of a set of selected critical minerals (Table 1) that are currently available for mineral exploration. These sites have been further evaluated using the bedrock geology combined with information from critical mineral occurrences in the area (as documented in the Mineral Deposit Inventory (MDI) database, Ontario Geological Survey 2021; *see* https://www.geologyontario.mndm.gov.on.ca/MDI_Description.html) to define prospective target areas for exploration. The presence of multiple anomalies for several critical minerals could have resulted from local variations in geology causing background levels of certain elements to be elevated, resulting in what appear to be large-scale anomalies.

Maity, B.K. 2022. Critical mineral potential in the Elliot Lake–Sault Ste. Marie area; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.19-23.

The analytical data were screened for loss on ignition (LOI) values greater than 15% to include samples rich in organic matter that provide a better medium for hosting metals compared to inorganic-rich sediment (LOI <15%) that adds foreign material in the sediment and dilutes their geochemical signals (Stew Hamilton, NDMNRF, personal communication, 2021). Elemental concentrations exceeding the 90th (defined as “elevated”) and 98th (defined as “anomalous”) percentiles were determined for selected critical minerals, measured by inductively coupled plasma mass spectrometry (ICP–MS) for beryllium (Be), bismuth (Bi), cesium (Cs), lithium (Li), selenium (Se), tin (Sn), copper (Cu), molybdenum (Mo), and tungsten (W) and inductively coupled plasma optical emission spectrometry (ICP–OES) for zinc (Zn) (Dyer 2010b). A subset of the data for these survey sites that are currently available for claims are plotted in Figures 2 and 3. Selected sites of anomalous concentrations are grouped together into exploration target areas where the lands are open for claim registration as of November 1, 2021 (Figures 2 and 3, Table 1).

Cesium and lithium are mainly anomalous within the Archean gneissic tonalite suite to the southeast of the survey area. In comparison, anomalous concentrations of Bi, Be, Sn and Se are more abundant in the Archean granite and tonalite suite to the north (*see* Figure 2). Anomalous occurrences of some of the large ion lithophile elements in lakes over the Huronian Supergroup and Nipissing diabase intrusions may have resulted from effluent discharge of uranium mine tailings in the Elliot Lake area (Dyer 2010a) and/or from regional sodium-metasomatism (Fyon et al. 1991).

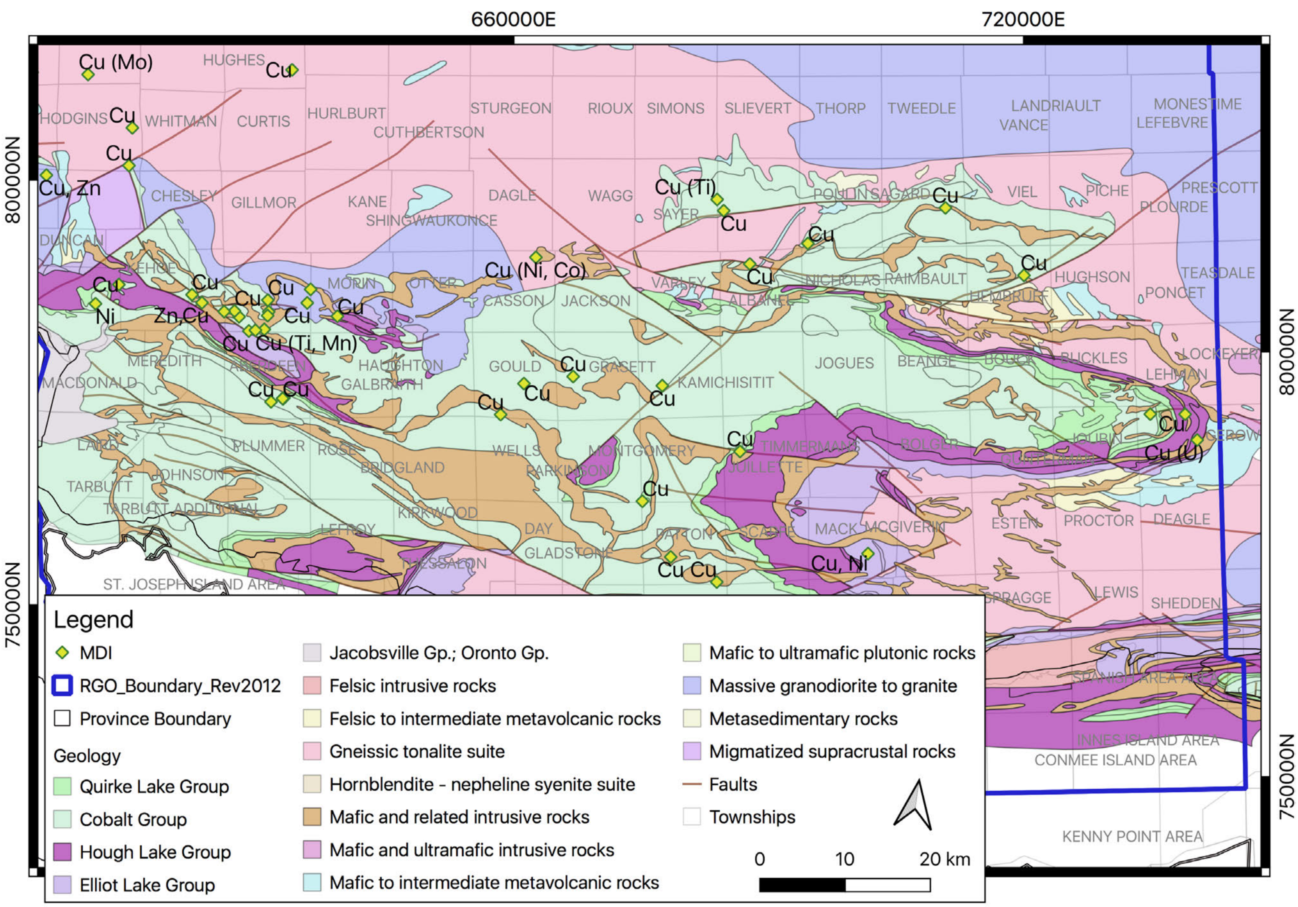

Figure 1. Simplified geological map (*modified from* Ontario Geological Survey 2011) of Elliot Lake–Sault Ste. Marie showing occurrences with documented critical minerals as primary and secondary (in parentheses) commodities (MDI, Ontario Geological Survey 2021). Universal Transverse Mercator (UTM) co-ordinates are provided using North American Datum 1983 (NAD83) in Zone 17. Abbreviations: Co, cobalt; Cu, copper; Ni, nickel; Ti, titanium; U, uranium; Zn, zinc; Gp., Group; MDI, Mineral Deposit Inventory; RGP, Resident Geologist Program.

Currently, there are no occurrences of these elements documented in the MDI database that are available for claiming (Ontario Geological Survey 2021). However, there are records of existing claims containing Bi (occurrence： MDI41J13SE00017; prospect: MDI41J13SE00014, MDI41J11SW00055, MDI41J10SW00059; discretionary: MDI41J11SW00022) as primary or secondary commodity associated with Zn, Pb (lead), Cu, Co (cobalt) and Au (gold), mainly restricted in the Archean suites, and one each in Gowganda Formation and Nipissing sill (Ontario Geological Survey 2021).

Anomalous presence of Zn-Mo-Cu-W is also observed within the survey area. Several of these multi-anomaly sites are spatially associated or in proximity with the known occurrences of Cu, Zn, Mo, Ni and Co as documented in the MDI database, e.g., the Aberdeen-McMahon-Chelsey-Hoggins-Jarvis townships to the northwest part of the survey area (Figure 3, Table 1). The anomalous occurrences of Mo in Lehman Township can be correlated with the Archean gneissic bedrock, whereas Cu-Zn anomalies and 3 occurrences of Cu in Gaiashk Township (Figures 1 and 3, Table 1; Ontario Geological Survey 2021) are related to highly anomalous VMS-type mineralization in the Elliot Lake Group and East Bull Lake intrusive suite from this area (Easton 2009; Dyer 2010a).

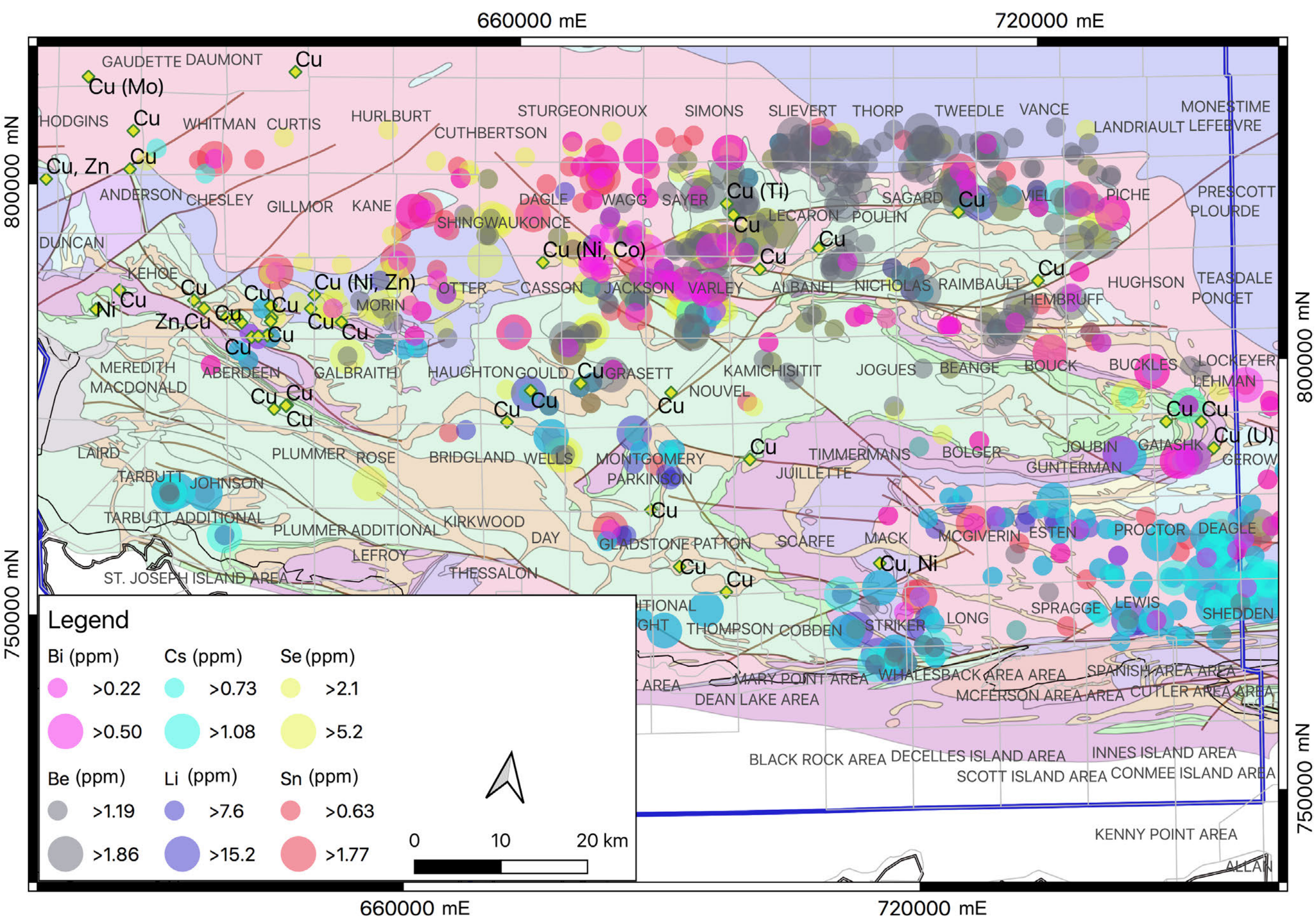

Figure 2. The proportional dot map of Be, Bi, Cs, Li, Se and Sn showing sites of elevated and anomalous concentrations (indicated in the legend) in lake sediment data, that are the potential exploration targets (listed in Table 1) for these elements. See Figure 1 for geological legend; data *from* Dyer 2010b, Universal Transverse Mercator (UTM) co-ordinates are provided using North American Datum 1983 (NAD83) in Zone 17.

The geology of Elliot Lake–Sault Ste. Marie includes several Archean to Proterozoic mafic-ultramafic intrusive rocks, Archean basement, and the unconformably overlying Proterozoic metasediments. Available lithogeochemical and lake sediment geochemistry data coupled with available information in the MDI database suggest potential for critical minerals in several prospective areas (*see* Figures 1 to 3, Table 1) that are recommended for further exploration.

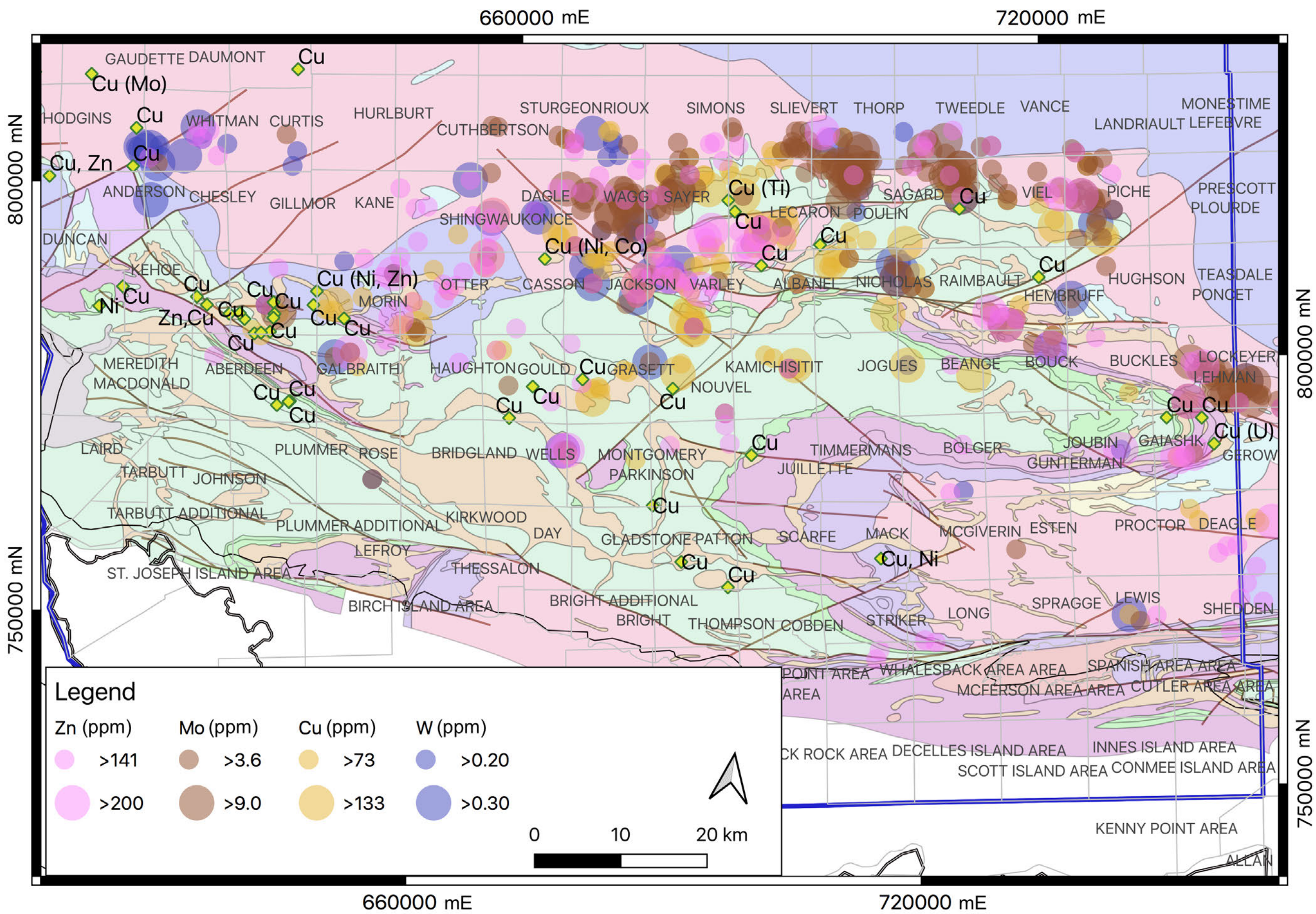

Figure 3. The proportional dot map of Zn, Mo, Cu and W showing areas of elevated and anomalous concentrations (indicated in the legend) that are the potential exploration targets (Table 1) for these elements. See Figure 1 for geological legend; data *from* Dyer 2010b, Universal Transverse Mercator (UTM) co-ordinates are provided using North American Datum 1983 (NAD83) in Zone 17.

Table 1. Target commodities (critical minerals) listed with available MDI records and townships for selected areas where multi-anomaly sites are closely associated with documented mineral occurrences (*from* Ontario Geological Survey 2021).

Townships	MDI	Commodities Recommended
Hoggins, Jarvis	MDI41J12NW00019, MDI41J12NW00022, MDI41K09NE00087	Zn, Mo, W, Cu, Cs
McMahon, Chelsey Additional	MDI41J12SE00038, MDI41J12SW00054, MDI41J12SW00049 MDI41J12SW00055, MDI41J12SW00050, MDI41J12SW00053 MDI41J12SW00060, MDI41J12SW00048, MDI41J12SW00059 MDI41J12SE00043, MDI41J12SW00056, MDI41J12SW00044	Cu, Ni, Zn, Mo, W

Table 1. *continued*

Townships	MDI	Commodities Recommended
Gould, Grasset	MDI41J06NW00026, MDI41J06NW00031 MDI41J06NW00003, MDI41J06NE00054	Cu, Mo, Zn, W
Gaiashk, Lehman	MDI41J08NW00058, MDI41J08NW00062, MDI41J08NW00082	Cu, Zn, Mo, Bi, Li
Poulin, Sagard Lecaron, Sayer, Wagg, Casson	MDI41J10NE00009, MDI41J10SW00061, MDI41J10NE00009 MDI41J10SW00061, MDI41J11SW00050	Cu, Zn, Mo, W, Bi, Sn, Be
Aberdeen, Morin	MDI41J11SW00050, MDI41J05NW00042, MDI41J05NE00045 MDI41J12SE00042	Cu
Montgomery, Patton	MDI41J06SE00060, MDI41J06SE00059, MDI41J06SE00057	Cu
Maek	MDI41J07SW00016	Cu, Ni
Slievert, Thorp, Tweedle	Not available	Mo, Zn, Be
Jackson, Varley	Not available	Cu, Zn, Bi, Be, Se
Lewis, Proctor, Deagle, Shedden	Not available	Ce, Li, Bi, W, Zn

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——— 2021. Mineral Deposit Inventory; Ontario Geological Survey, Mineral Deposit Inventory (July 2021 update), online database.

HIGHLIGHTS

- **Known cesium occurrences present potential for further discovery**
- **Proximal to the fifth largest lithium-pegmatite in Superior Province**
- **An under-explored area specific for critical minerals**

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Looking for Cesium in the Northern Parts of the Kirkland Lake District

In keeping with the theme of critical minerals, and as a follow-up to an article describing the lithium-cesium-tantalum (LCT) pegmatite potential in the Temagami area of the Kirkland Lake District (Suma-Momoh 2021), the following recommendation proposes exploration in the northern parts of the District as potential areas for further cesium and associated rare element mineralization.

Cesium (Cs) is an alkali metal, along with lithium (Li), sodium (Na), potassium (K), rubidium (Rb) and francium (Fr), and is one of the few metals that are liquid at or near room temperature. Cesium is rare globally, and the U.S. Department of the Interior included lithium, cesium and tantalum on its final list of critical minerals, deemed critical to U.S. National Security and the Economy (U.S. Geological Survey, www.usgs.gov/news/interior-releases-2018-s-final-list-35-minerals-deemed-critical-us-national-security. [accessed November 10, 2021]). According to the Minerals Education Coalition (Minerals Education Coalition, www.mineralseducationcoalition.org/minerals-database/cesium/ [accessed November 10, 2021]), cesium has the following uses.

- As a catalyst in chemical reactions.
- Used in photo-electric cells and infrared detectors (as Cs is easily ionized by light).
- Cesium compounds are used in specialized alkaline batteries that are designed for sub-zero climates.
- Production of specialized glass and glass products.
- Cesium-137 is radioactive and may be used for radiation therapy to treat certain cancers.
- Space travel engineers have discovered that burning cesium in space is a very efficient form of fuel (140 times more efficient than other fuels).

Deposit Type: Rare-element pegmatites of the Superior Province

Rare-element pegmatites may host several economic commodities, such as tantalum (tantalum-oxide minerals), tin (cassiterite), lithium (ceramic-grade spodumene and petalite), rubidium (lepidolite and potassium-feldspar), and cesium (pollucite) collectively known as rare elements, in addition to ceramic-grade feldspar and quartz (Selway, Breaks and Tindle 2005).

Rare-element pegmatites derived from a fertile granite intrusion are typically distributed over a 10 to 20 km^2 area within 10 km of the fertile

Chadwick, P.J. 2022. Looking for cesium in the northern parts of the Kirkland Lake District; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.24-29.

granite. A fertile granite is the parental granite to rare-element pegmatite dikes. The granitic melt first crystallizes several different granitic units (e.g., biotite granite to two-mica granite to muscovite granite), due to an evolving melt composition, within a single parental fertile granite pluton. The residual melt enriched in incompatible elements (e.g., rubidium (Rb), cesium (Cs), niobium (Nb), tantalum (Ta), tin (Sn)) and volatiles (e.g., H_2O, Li, F, BO_3 and PO_4) from such a pluton can then migrate into the host rock and crystallize pegmatite dikes (Figure 1). Volatiles promote the crystallization of a few large crystals from a melt and increase the ability of the melt to travel greater distances. This results in pegmatite dikes with coarse-grained crystals occurring in country rocks considerable distances from their parent granite intrusions.

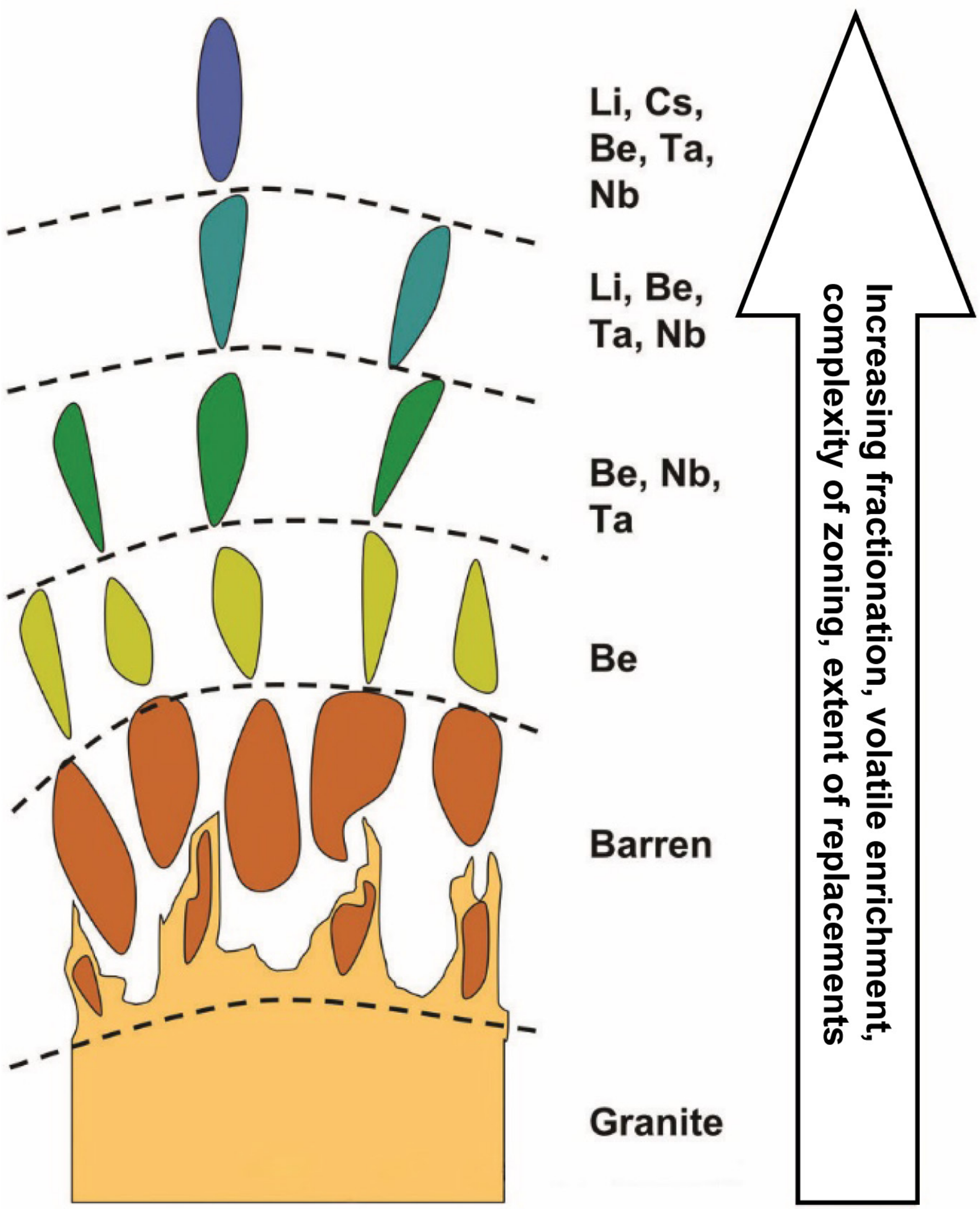

Figure 1. Geological chemical evolution of lithium-rich pegmatites with distance from the granitic source (*modified from* London 2008).

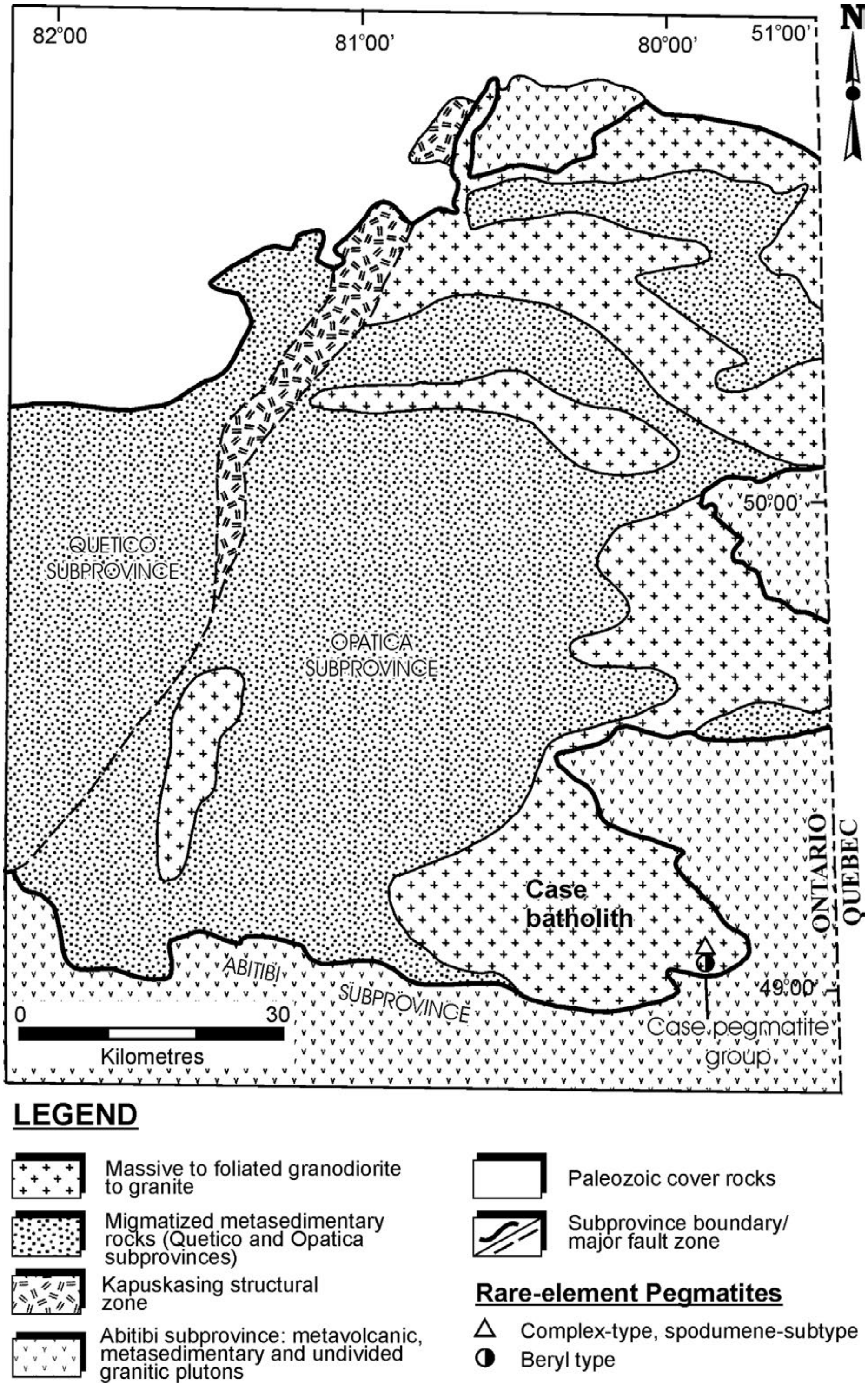

Figure 2. A geological map showing the location of the Case batholith in relation to the Quetico, Opatica and Abitibi subprovinces. The approximate locality of the Case rare-element pegmatite group is indicated (*from* Breaks, Selway and Tindle 2006).

There are several geological features that are common in rare-element pegmatites of the Superior Province of Ontario (Breaks, Selway and Tindle 2003) and those found in neighbouring Manitoba (Černý et al. 1981; Selway, Breaks and Tindle 2005). These will form the basis of formulating areas of interest that may host potential rare-element mineralization, in the northern parts of the Kirkland Lake District. These common features are highlighted as follows.

Metasedimentary-Dominant Subprovince Boundaries:
Most pegmatites in the Superior Province occur along subprovince boundaries, except for those that occur within the metasedimentary Quetico Subprovince.

Greenschist to Amphibolite Metamorphic Grade:
Pegmatites are absent in the granulite terranes.

Fertile Parent Granite:
Most pegmatites in the Superior Province are genetically derived from a fertile parent granite.

Host Rocks:
Highly fractionated spodumene- and petalite-subtype pegmatites are commonly hosted by mafic metavolcanic rocks (amphibolite) in contact with a fertile granite intrusion along geologic subprovince boundaries. Pegmatites within the Quetico Subprovince are hosted by metasedimentary rocks or their fertile granitic parents.

Metasomatized Host Rocks:
Biotite and tourmaline are common minerals, and holmquistite is a minor phase in metasomatic aureoles in mafic metavolcanic host rocks to spodumene- and petalite-subtype pegmatites. Tourmaline, muscovite and biotite are common, and holmquistite is rare in metasomatic aureoles in metasedimentary rocks.

Li Minerals:
Most of the complex-type pegmatites of the Superior Province contain spodumene and/or petalite as the dominant lithium mineral, except for a few pegmatites which have lepidolite as the dominant lithium mineral.

Cs Minerals:
Cesium-rich minerals only occur in the most extremely fractionated pegmatites.

Ta-Sn Minerals:
Most pegmatites in the Superior Province contain ferrocolumbite and manganocolumbite as the dominant niobium–tantalum-bearing minerals. Some pegmatites contain manganotantalite or wodginite as the dominant tantalum-oxide mineral. Tantalum-bearing cassiterite is relatively rare in pegmatites of the Superior Province.

Pegmatite Zone Hosting Ta Mineralization:
Fine-grained tantalum-oxides (manganotantalite, wodginite and microlite) commonly occur in the aplite, albitized K-feldspar, mica-rich and spodumene core zones in pegmatites in the Superior Province.

The Opatica Subprovince – the Case Batholith

The geological features in support of rare-element pegmatites within the Superior Province, as described in the previous section, are based mostly on observations made further to the west within the Quetico Subprovince. Rare-element mineralization in the adjacent Opatica Subprovince, which can be found in the northwestern parts of the Kirkland Lake District, is currently known only at the Case pegmatite in the Lake Abitibi area, but this spodumene-subtype pegmatite comprises the fifth largest lithium-rich pegmatite in the Superior Province of Ontario (Breaks, Selway and Tindle 2006).

The well-documented existence of the Case pegmatite group, currently being explored by Power Metals Corp. (Power Metals Corp., https://www.powermetalscorp.com/projects/cesium-lithium-tantalum/hard-rock-mining/canada/case-lake/ [accessed November 10, 2021]), is situated within the Case batholith, which forms a boundary with the Opatica Subprovince, as illustrated in Figure 2.

The Case pegmatite system is hosted in the southeastern part of the Case batholith, an extensive 50 by 85 km, ovoid granitic complex that is apparently part of the Opatica Subprovince (Jackson and Fyon 1991). The immediate host rocks of the pegmatite dikes consist of massive to subtly foliated, biotite tonalite that is characterized by biotite-rich orbicules that range in diameter from 1 to 7 cm. The foliation of the biotite in the tonalite is perpendicular to the contact with the pegmatite.

Areas of Interest for Future Exploration

Figure 3 represents a geological map of the northern part of the Kirkland Lake District, superimposed over a more simplified base representing the spatial relationship of the migmatized sedimentary rocks of the Opatica Subprovince, the metavolcanic, metasedimentary and undivided granite plutons of the Abitibi Subprovince, and foliated granodiorite of the Case batholith. The location of the Case pegmatite group is represented by a solid triangle.

Areas of interest or potential target areas for future rare-element pegmatite exploration are shown as red rectangles, primarily situated in areas proximal to the contact between greenschist to amphibolite grade metavolcanic rocks of the Abitibi Subprovince and a fertile granite intrusion along a geological subprovince boundary, represented by the Case batholith.

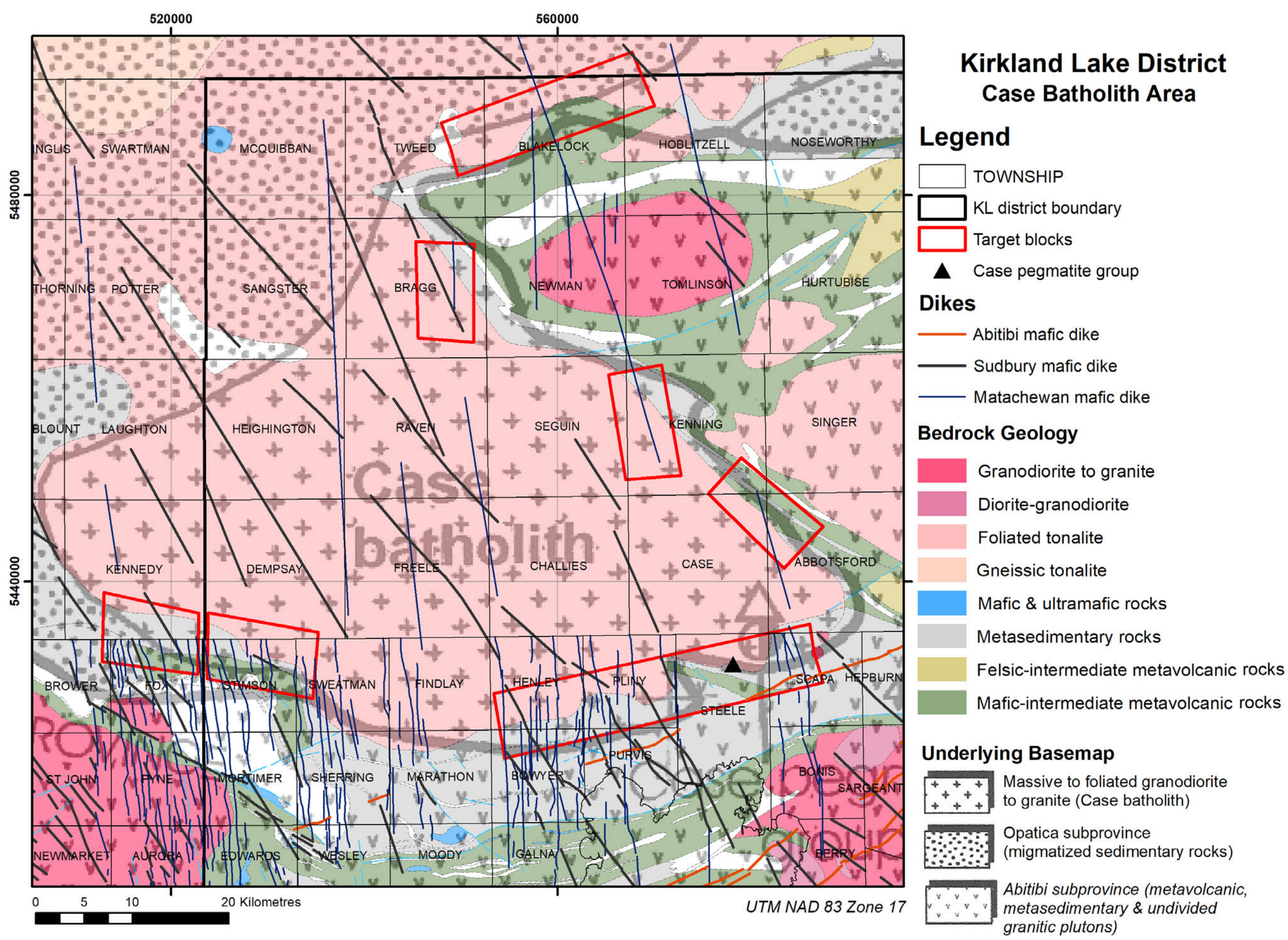

Figure 3. Bedrock geology map of the northern part of the Kirkland Lake District (Ontario Geological Survey 2011), superimposed over the regional geology of the Case batholith area (*modified from* Breaks, Selway and Tindle 2006; *see also* Figure 2).

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HIGHLIGHTS

- **More than 600 critical mineral occurrences recorded in the Timmins camp**
- **Prospects mostly contain base metals including copper, nickel, and zinc**
- **Timmins camp has the potential for lithium, molybdenum, tin, tungsten and beryllium exploration**

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Critical Mineral Potential in the Timmins Mining Camp

Introduction

The term "critical mineral" was first used in a 2008 National Research Council (NRC) report (Verplanck and Hitzman 2016). The report used 2 factors to indicate the degree of criticality for individual chemical elements. The 2 factors used were 1) the degree to which a commodity is essential and 2) the risk of supply disruption for the commodity. The idea of mineral criticality is helpful to predict the vulnerability of the commodity market; however, it is a conceptual framework meaning that the criticality of a given element or mineral can change through time. On the other hand, the risk of supply disruption can be affected by many factors, including political, economic, geologic, geographic, and environmental variables (Verplanck and Hitzman 2016). Following the NRC report, other jurisdictions worldwide began to evaluate the criticality of elements concerning their interests. The governments of Canada and Ontario released their lists of critical minerals in March 2021.

There is no universal definition for critical minerals. The term generally applies to elements or minerals with specific industrial, technological, and strategic applications for which there are few viable substitutions, e.g., antimony, bismuth, cesium, and lithium. These minerals are also at a higher supply risk due to geopolitical considerations and market demand (*see* Ontario Critical Minerals Framework Discussion Paper | Environmental Registry of Ontario (EBR) | Ministry of Energy, Northern Development and Mines| Posted March 10, 2021, https://prod-environmental-registry.s3.amazonaws.com/2021-03/CM_StrategyFramework_DiscussionPaper_02032021_Accessible_EN%20FINAL.pdf [accessed December 7, 2021]). Critical minerals can be recovered either as primary commodities or as a by-product from mining other commodities. For example, 91% of the world niobium (Nb) production comes from the Araxa Mine in Brazil, while gallium (Ga) is recovered primarily as a by-product of bauxite mining or zinc processing worldwide. It is important to note that critical elements solely produced as by-products could pose a supply risk as their production is tied to other markets. Therefore fluctuation in their supply can be independent of their demand (Verplanck and Hitzman 2016).

Ontario's proposed critical mineral list

The proposed critical mineral list from Ontario includes 30 elements and minerals and has an 80% overlap with the proposed list from Canada (Table 1). However, Ontario has 5 elements and/or minerals, namely barite, beryllium, phosphate, selenium, and zirconium, that are specific to the province.

Azadbakht, Z. 2022. Critical mineral potential in the Timmins mining camp; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.30-35.

Table 1. Proposed critical mineral lists from Canada and Ontario in regular font, Canada only in **bold**, and Ontario only in *underlined italics*.

Aluminum	Fluorspar	Molybdenum	Tantalum
Antimony	**Gallium**	Nickel	Tellurium
Barite	Germanium	Niobium	Tin
Beryllium	Graphite	*Phosphate*	Titanium
Bismuth	**Helium**	Platinum group metals	Tungsten
Cesium	Indium	**Potash**	Uranium
Chromium	Lithium	Rare earth elements	Vanadium
Cobalt	Magnesium	**Scandium**	Zinc
Copper	Manganese	*Selenium*	*Zirconium*

Critical mineral potential of Timmins District

In the Timmins District, there are 933 primary and 474 secondary commodities documented as critical mineral occurrences in the Mineral Deposit Inventory (MDI), Ontario Geological Survey 2021. Discretionary occurrences are not considered in this report. Eighty-eight percent of the primary commodities belong to the mineral occurrence category, followed by only 5% as prospects (Figure 1).

Figure 2 shows the location and variety of the critical mineral occurrences in the Timmins District, where most of the primary commodities belong to base metals, including copper (Cu), nickel (Ni), and zinc (Zn), Ontario Geological Survey 2021. Cunningham, Huffman, Mann, Mcarthur, Keith, and Langmuir townships have the highest numbers of registered critical mineral occurrences in the Mineral Deposit Inventory (Ontario Geological Survey 2021) with a few available for claim registration. More than 92% of the 596 occurrences are staked, and only 47 are open for claim registration (Figure 3; Table 2).

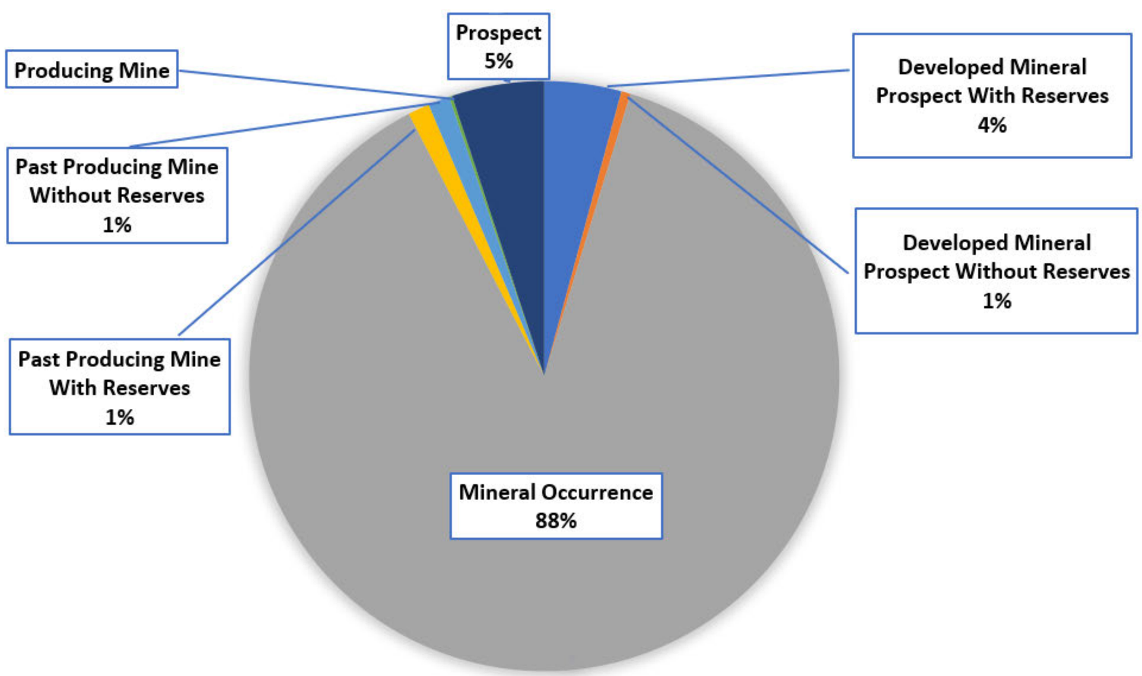

Figure 1. Pie chart showing the distribution of critical minerals as the registered primary commodity documented in the MDI database in the Timmins District (Ontario Geological Survey 2021).

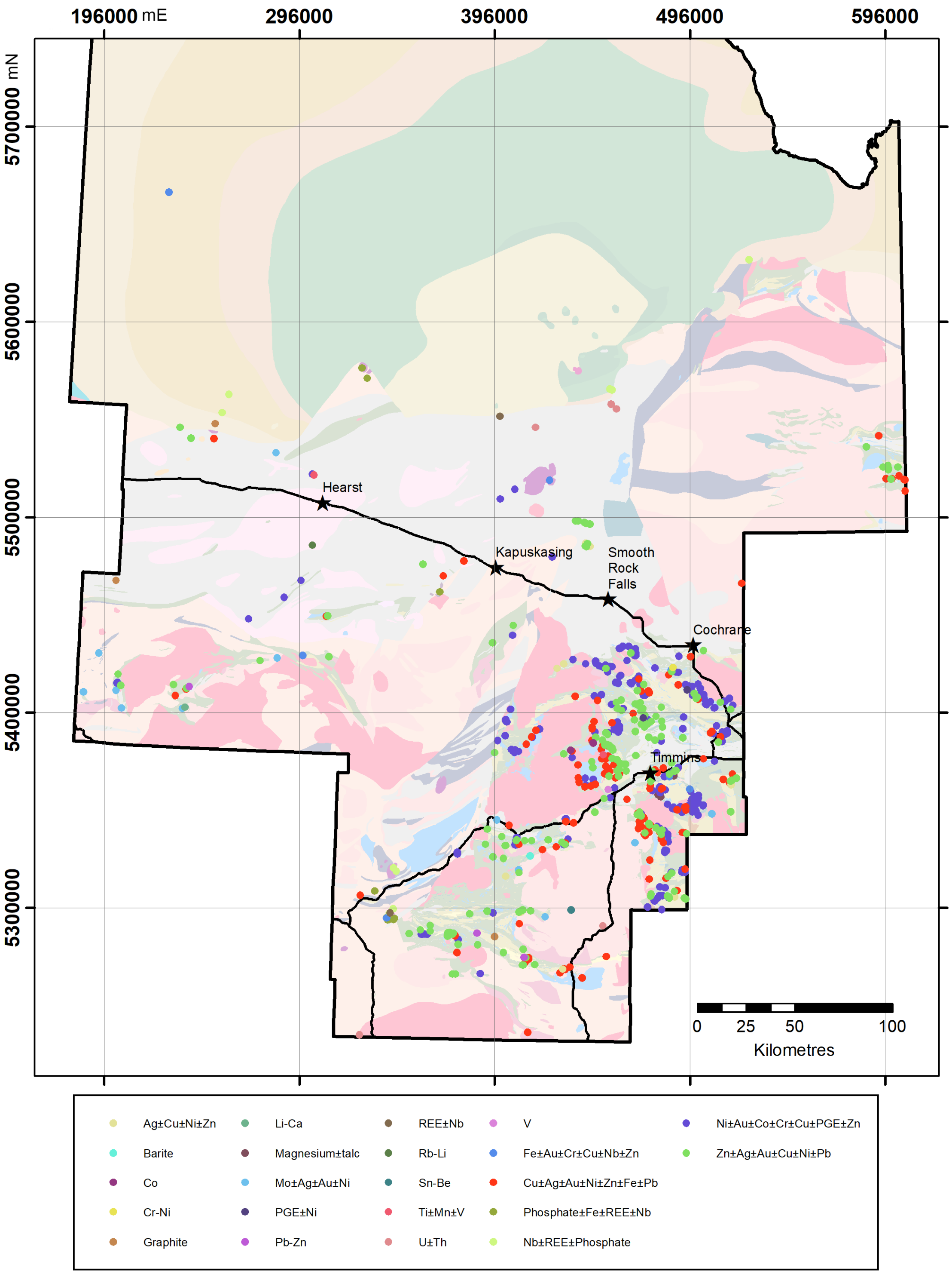

Figure 2. A geological map showing the location and distribution of critical minerals (as the primary commodity) in the Timmins District (documented in the MDI, Ontario Geological Survey 2021).

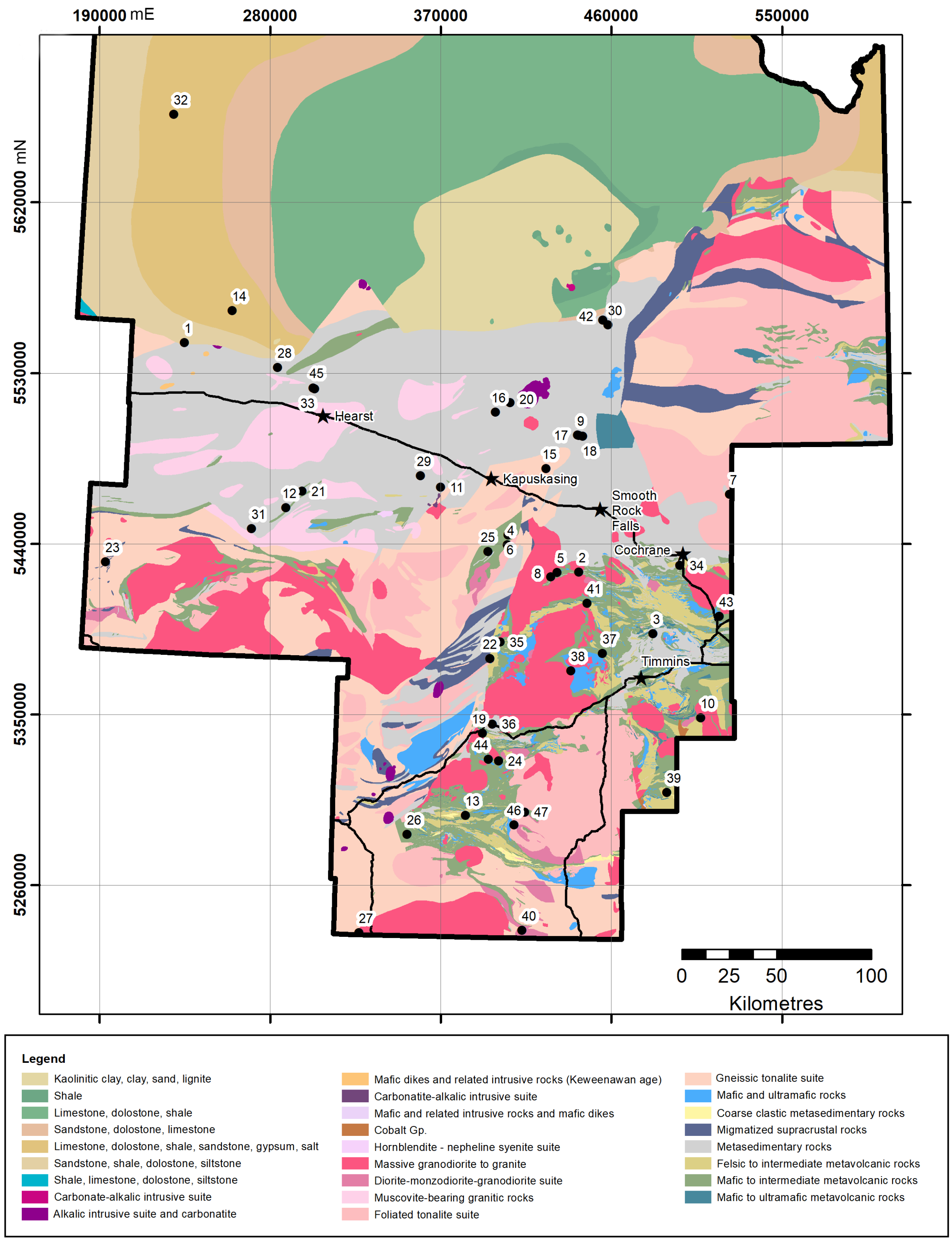

Figure 3. Geological map of the Timmins District showing the locations of critical mineral occurrences available for staking at the time of writing (Ontario Geological Survey 2021). Refer to Table 2 for numbered occurrences on map.

Table 2. Critical mineral occurrences as documented in the MDI, available for staking in the Timmins District, Ontario Geological Survey 2021. Map # refers to numbered locations on Figure 3.

Map #	MDI Number	Primary Commodity	Secondary Commodity	Occurrence Status	Township
1	MDI42K02SE00001	Zn	Cu	Occurrence	Rowlandson
2	MDI42A13NW00012	Ni	Cu, Ag	Occurrence	Laidlaw
3	MDI42A11NE00059	Zn		Occurrence	Wark
4	MDI42G01SW00015	Ni, Cu	Zn	Occurrence	Casselman
5	MDI42A13NW00011	Ag, Ni	Cu	Occurrence	Ford
6	MDI42G01NW00011	Zn	Cu	Occurrence	Casselman
7	MDI42H07SE00010	Co	Au	Occurrence	Potter
8	MDI42A13NW00014	Ag, Ni		Occurrence	Oke
9	MDI42H12SW00018	Zn		Occurrence	Agate
10	MDI42A07SW00015	Mo		Occurrence	Blackstock
11	MDI42G07NW00003	Cu	Ni	Occurrence	Cumming
12	MDI42G04NW00003	Ni, Zn	Cu	Occurrence	Talbott
13	MDI000000000674	Zn, Cu		Occurrence	Dore
14	MDI42K01NW00004	Nb		Occurrence	Nagagami River Area
15	MDI42G08NE00004	Ni, Cu	Pt, Pd, Fe	Occurrence	Beardmore
16	MDI42G09NW00002	Ni		Occurrence	Guilfoyle
17	MDI42H12SW00017	Zn		Occurrence	Agate
18	MDI42H12SW00019	Zn		Occurrence	Agate
19	MDI42B01NW00047	Zn		Occurrence	Foleyet
20	MDI000000001697	Ni	Ag, Zn	Occurrence	Guilfoyle
21	MDI42G05SW00008	Ni	Cu, Fe	Occurrence	Ebbs
22	MDI42B09SW00006	Zn	Ag	Occurrence	Nova
23	MDI42C14NE00001	Mo		Occurrence	Matthews
24	MDI42B01SW00020	Zn, Cu		Occurrence	Keith
25	MDI42G01SW00019	Zn	Cu	Occurrence	Casselman
26	MDI000000001606	Zn	Ag	Occurrence	Tooms
27	MDI41O03NW00003	U		Occurrence	Cassidy
28	MDI42F16NE00005	Mo	Cu, Pb, Zn	Occurrence	Fushimi
29	MDI42G07NW00001	Zn, Ni	Cu	Occurrence	Parnell
30	MDI42I04NE00013	U, Th		Occurrence	Pitt
31	MDI42F01NE00001	Ni	Graphite	Occurrence	Franz
32	MDI42N02SW00001	Fe, Nb	Phosphate	Occurrence	South of Lone Lake Area
33	MDI42G13SW00005	Ti, Mn	Ni, Cu, Co	Occurrence	Hanlan
34	MDI42H03SE00020	Cu	Ag	Occurrence	Lamarche
35	MDI000000001741	Ni		Occurrence	Belford
36	MDI42B01NW00055	Mo	Cu	Occurrence	Muskego
37	MDI42A12SE00005	Zn, Cu	Ag, Au	Developed Prospect with Reserves	Robb
38	MDI000000000650	Cu	Zn, Au, Ag	Occurrence	Massey
39	MDI41P14NE00053	Cu	Zn, Pb, Ag	Occurrence	Hutt
40	MDI41O08SE00004	Cu, Au		Occurrence	Margaret

Table 2. *continued*

Map #	MDI Number	Primary Commodity	Secondary Commodity	Occurrence Status	Township
41	MDI000000001007	Ni		Occurrence	Geary
42	MDI42I04NE00010	U, Th		Occurrence	Pitt
43	MDI42A15SW00034	Zn		Occurrence	Calvert
44	MDI42B01SW00021	Zn	Pb	Occurrence	Ivanhoe
45	MDI42G13SW00004	Ni, Cu, Co		Occurrence	Hanlan
46	MDI41O16SE00011	Cu	Ni	Occurrence	Marion
47	MDI41O16SE00008	Zn	Pb, Cu	Occurrence	Genoa

Figure 2 also displays that most of the exploration has been focused on mafic rocks in the southern and eastern parts of the District. Seven of the named critical minerals in Ontario's list (23%) are exclusively associated with felsic rocks (i.e., granites and their associated pegmatites) with very limited number of occurrences documented in the MDI (Ontario Geological Survey 2021). Four other elements, including antimony (Sb), niobium (Nb), rare earth elements (REE) and uranium (U) can also be found in granitic rocks. Table 3 shows a list of these critical minerals and the number of occurrences documented in the Timmins District in the MDI (Ontario Geological Survey 2021). A few of the townships with lands currently open for claim registration and underlain by felsic rocks are Kirkwall, Lerwick, Bonar, Kapuskasing, Stefansson, and Conking in the east and Burr, Faust, Bull brook, Braithwaite, and Hall in the southern part of the District.

Table 3. Critical minerals associated with felsic rocks and the number of occurrences available in the Timmins District (*from* MDI, Ontario Geological Survey 2021).

	Beryllium (Be)	Cesium (Cs)	Molybdenum (Mo)	Tantalum (Ta)	Tin (Sn)	Tungsten (W)	lithium (Li)
# occurrences in Timmins	2	N/A	10	1	1	N/A	2

Recommendations

1. Registering claims over any of the 47 available critical mineral occurrences, in the Timmins mining camp to explore and evaluate the locations for economic mineralization potential using detailed mapping, sampling, and whole rock geochemistry.
2. Exploring the felsic rocks and their associated pegmatites (using geological mapping, hyperspectral remote sensing, whole-rock geochemistry, and soil and stream sediment geochemistry) in the townships (Kirkwall, Lerwick, Bonar, Kapuskasing, Stefansson, and Conking, Burr, Faust, Bull brook, Braithwaite and Hall) in the Timmins District may lead to the discovering tin (Sn), tungsten (W), etc. mineralization. A complete list of tools and workflows for grassroot exploration of Li–Cs–Ta (LCT) pegmatites are described in Steiner (2019).

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HIGHLIGHTS

- **Critical minerals are a hot commodity; future innovations and need will change how and where these minerals are mined**
- **LCT pegmatites are a significant potential source for some of these critical minerals and are recommended as a current target for exploration**
- **LCT pegmatites are found in several townships in the Timmins District with areas open for claim registration**

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A Green Future with Critical Minerals in the Timmins District

The world is slowly recovering from the global pandemic; during pandemic restrictions, there were global decreases in production, manufacturing, and transportation across nearly all industries. Shortages and transportation issues were global news, making many supply and demand issues increasingly apparent. Diversification and discovery are key to increasing supply and availability of critical minerals. This, coupled with the increasing need to decrease emissions causing climate change, turned the focus even more on the alternative energy market. Minerals which will support the development and growth of these technologies are needed—where and how we will source those minerals is the question.

Which particular minerals will be most prominent in this “green” energy future is not yet completely known, but what is known is that there are several minerals that are necessary to support this transition and many other aspects of our society now and in the near future. The World Bank estimates a 500% increase in demand for many of these critical minerals within the next 30 years (https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action, World Bank Group 2021 [accessed December 10, 2021]). Currently, the mining, production, and refinement of many of these minerals are concentrated in very few countries, creating potential issues with the supply chain. The world is calling for diversification of these minerals, and Ontario is a prime region to get in on this demand.

Previous Recommendations for Exploration articles focused on rare earth elements (REE), a set of essential elements for nearly every electronic device. This recommendation focuses on niobium (Nb), tantalum (Ta), cesium (Cs), lithium (Li). These critical elements have similar properties, are often found in the same host rocks as REEs and are all needed to support the “green” energy future. Lithium has many uses in manufacturing certain types of batteries, manufacturing aircraft and can act as a powerful flux in glass and ceramics applications. Cesium is used in high-pressure, high-temperature drilling applications. Tantalum is heavily used in the electronics industry, with approximately 75% of all electronics manufactured containing tantalum; it is essential in the miniaturization of devices. Niobium is heavily used in the steel industry, high-temperature applications, and superconductors (Selway, Breaks and Tindle 2005). One of the most common rock types for locating Nb, Ta, Cs and Li are pegmatites.

In the Timmins District of the Resident Geologist Program (RGP), there are a variety of areas where Nb, Ta, Cs, and Li might be found and sourced from, including extraction from historic tailings and pegmatites.

Bennett, D.J. and Baumann, C.Q. 2022. A green future with critical minerals in the Timmins District; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.36-40.

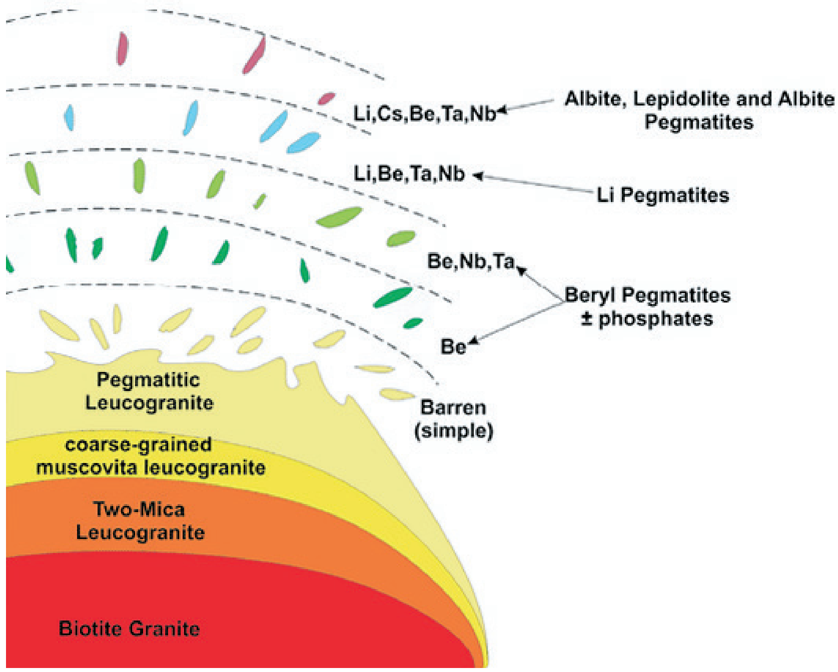

Figure 1. Evolution of LCT pegmatites from parent rock, including index minerals which assist in identifying economically viable pegmatites (*revised from* Queiroz and Botelho 2018).

The remainder of this article will focus on and highlight areas open for staking containing lithium-cesium-tantalum—bearing pegmatites (LCT pegmatites) and exploration methods to find these LCT pegmatites based on their evolution from the parent rock suites.

Figure 1 shows the formation of LCT pegmatites from a granite suite. Pegmatites with economic potential are often associated with S-type granites. S-type granites are granites formed from the melt of sedimentary rocks, which often contain the minerals we now deem as critical (Černý 1991).

How to Explore for LCT Pegmatites

The search for LCT pegmatites begins with a review of a regional geology map. The first clue to potential LCT pegmatites are metasedimentary rocks (Selway, Breaks and Tindle 2005). In Figure 2, you will see a prime area for exploration for LCT pegmatites in the Timmins mining camp—the Quetico subprovince of the Superior Province. Stretching across the lower middle region of the Timmins District, the Quetico Subprovince is a region of low- to mid-grade metamorphosed sedimentary rocks, increasing in metamorphic grade towards the interior (Breaks, Selway and Tindle 2003).

The next step in searching for LCT pegmatites is locating rocks closely associated with them; peraluminous S-type granite plutons. After locating these rock types, a search of some key indicators can help narrow the target; specific ratios of key elements such as $Mg/Li<10$ (where Mg is magnesium), $Nb/Ta<8$ are the main indicators associated with economic LCT pegmatites. Metasomatized host rocks can also be a key indicator of nearby economically viable LCT pegmatites; in these granitic aureoles, elemental compositions of Li, Rb (rubidium), Cs, B (boron) and F (fluorine) tend to be elevated (Selway, Breaks and Tindle 2005). Figure 3 shows some of the known and sampled fertile granites and pegmatites in the Timmins District. As one would expect, granites and pegmatites with key indicators mentioned above tend to be concentrated on the borders of the Quetico subprovince, where low-grade metamorphism has created the conditions of concentrating the critical minerals targeted in this article (Breaks, Selway and Tindle 2003).

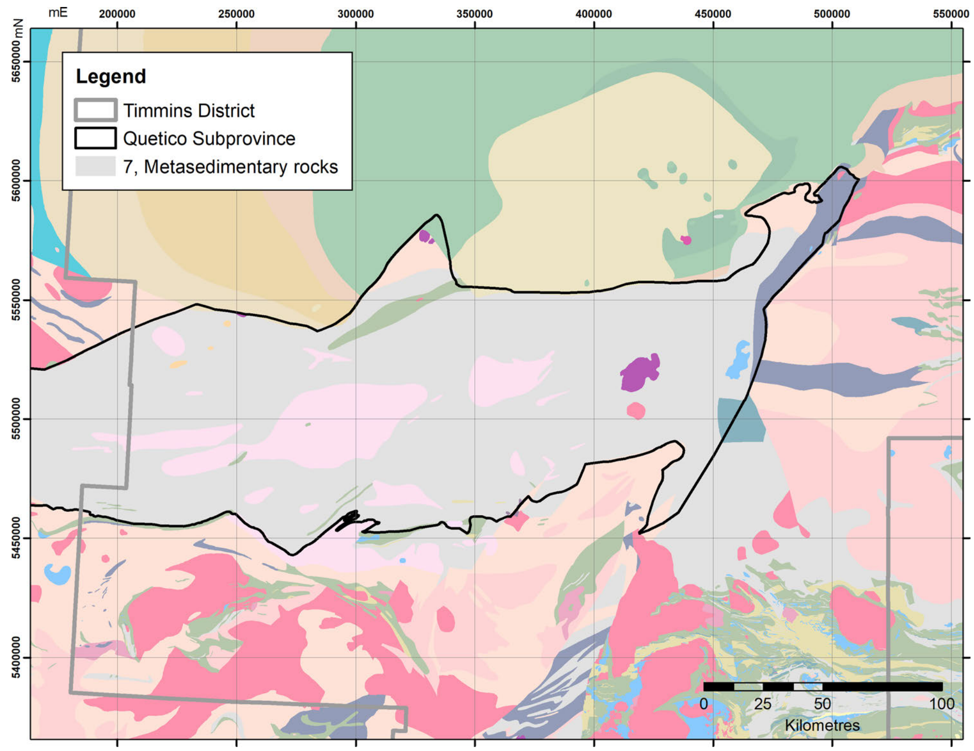

Figure 2. Bedrock geology of the Timmins District showing outline of the Quetico Subprovince, *modified from* Ontario Geological Survey 2011.

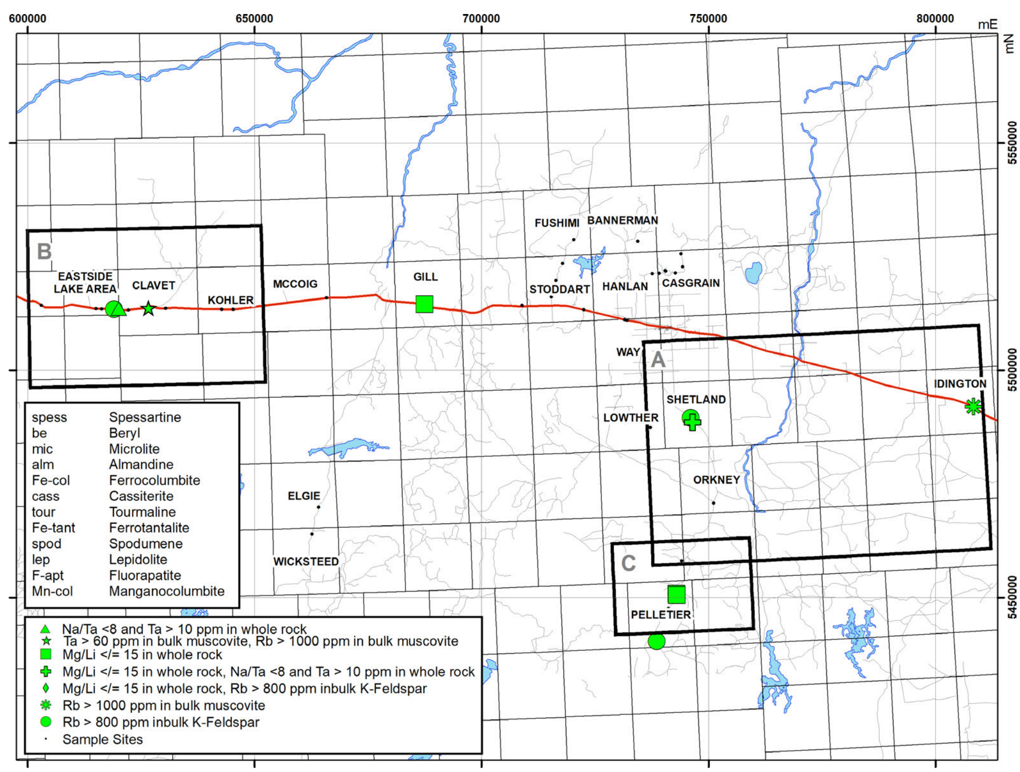

Figure 3. Areas in the Timmins District with mineral indicators of economic pegmatites.

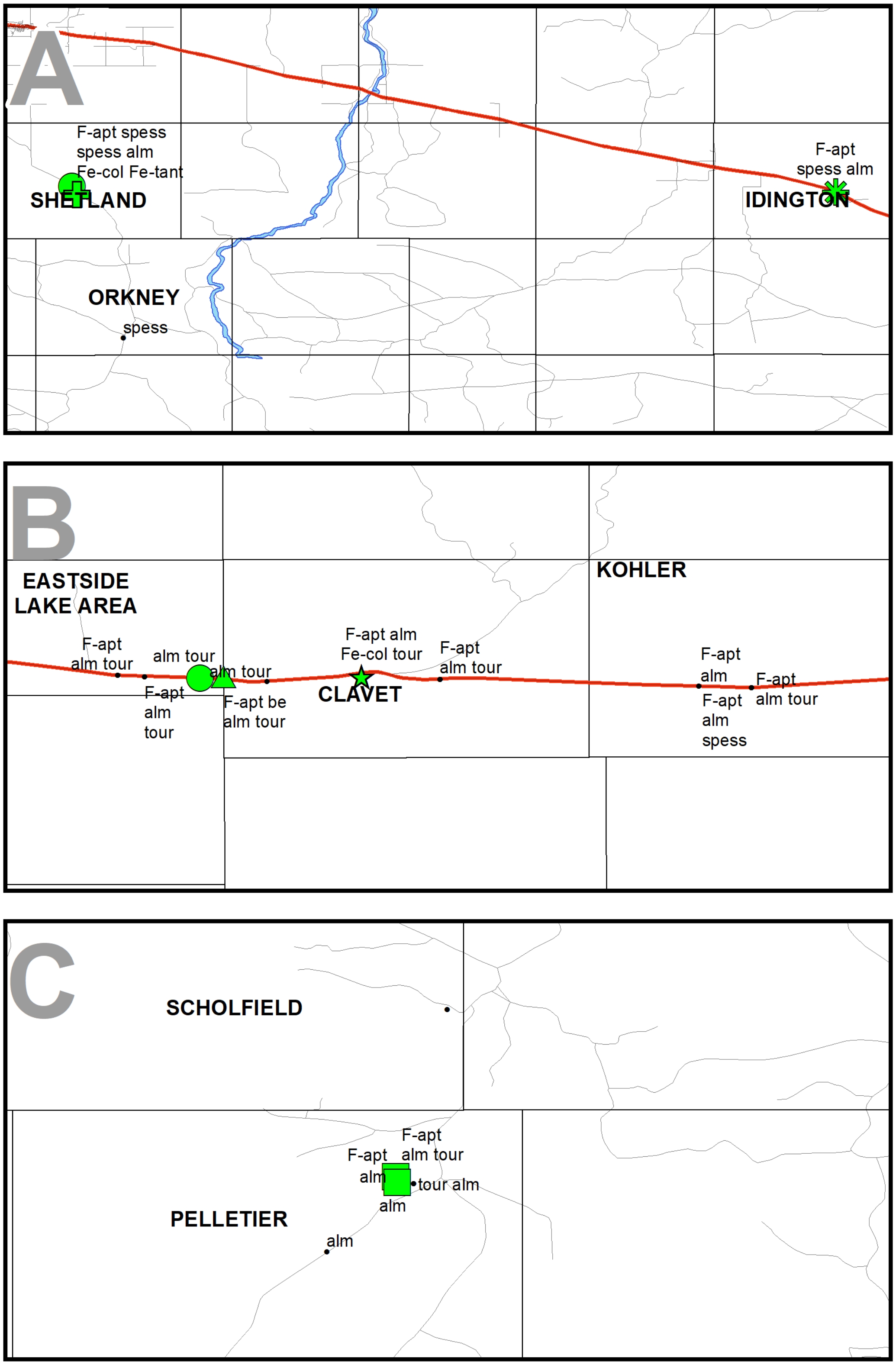

Figure 4. Areas in the Timmins District, showing mineral indicators of key pegmatite area, *see* Figure 3 for location and legend.

Once likely areas are identified for fertile granites and pegmatites through the examination of maps and elemental indicators, the next step is to find the pegmatites. As mentioned, these rocks tend to be found in fractures and on the boundaries of batholiths due to their formation processes. Taking several samples from outcrops at different points along the length and identifying some of the minerals mentioned above can help guide your exploration. After visual inspection for key minerals, the next step would be sample analysis and checking for mineral abundances and ratios. Increasing trends of those key indicators can help guide you to pegmatites that might be nearby. If you have found the pegmatite, the process is similar: observe the rock for visual indicators; if these are present, send in several samples for analysis. The Timmins District office can help find areas open for claim registration that may contain these rocks. We can also assist with the visual identification of the key indicators and provide information on the next steps in the exploration process.

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HIGHLIGHTS

- **Numerous lithium and cesium lake sediment anomalies**
- **8 target areas containing numerous anomalous and strongly elevated lithium and cesium values**
- **All target areas associated with known batholiths and/ or plutons with potential to host fertile granites and pegmatites**

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Armstrong to Longlac Anomalous Lake Sediment Lithium Potential

Historical exploration activity in the Onaman–Tashota and Caribou Lake greenstone belts in northwestern Ontario has primarily focussed on precious and base metals; however, lithium-bearing pegmatites have continued to be discovered since the 1950s. Due to the continued demand for electric cars, mobile devices and long-term energy storage and the sustained need for the raw materials used in the creation of lithium-ion batteries (i.e., lithium, graphite, cobalt and nickel), new sources need to be discovered. This article highlights 8 grassroot areas in the Wabigoon Subprovince that may have the potential for lithium based on lake sediment anomalies. At the time writing, all 8 areas recommended were available for online claim registration.

1. Southern Caribou Lake Target
2. Wagaming Station Area
3. Return Lake Area
4. Kapikotongwa River Area
5. Abamasagi Lake Target
6. Gzowski Target
7. Dome Lake Target
8. Relief Lake Target

The data presented is based on lake sediment data from the Armstrong–Lake Nipigon area (Ontario Geological Survey 2000a, 2000b), Nakina–Longlac area (Ontario Geological Survey 2000c, 2000d) and the Nakina–Marshall Lake area (Handley and Dyer 2018) surveys collected by the Ontario Geological Survey (OGS) and information from the OGS Resident Geologist's Program (RGP) Mineral Deposit Inventory (MDI, Ontario Geological Survey 2021) online database. The raw data and the interpreted anomalies are not proximal to any known rare earth element or rare metal occurrences documented in the MDI.

Only lithium (Li) and cesium (Cs) data were considered in this article as lithium-cesium-tantalum (LCT) pegmatites are the intended target rock unit. Both deep and shallow lake sediment geochemical results show similar anomaly distribution patterns, though only deep (Figure 1) sediment anomalies will be discussed here, as justified below. Shallow sampling is defined as material collected from 0 to 15 cm into the lake bottom, whereas deep sampling is material collected from a depth greater than 20 cm into the lake bottom. In the Armstrong–Lake Nipigon and Nakina–Longlac area surveys, only the deep sediment was collected, whereas the Nakina–Marshall Lake survey had both shallow and deep sediment collected.

Paju, G.F. 2022. Armstrong to Longlac anomalous lake sediment lithium potential; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.41-48.

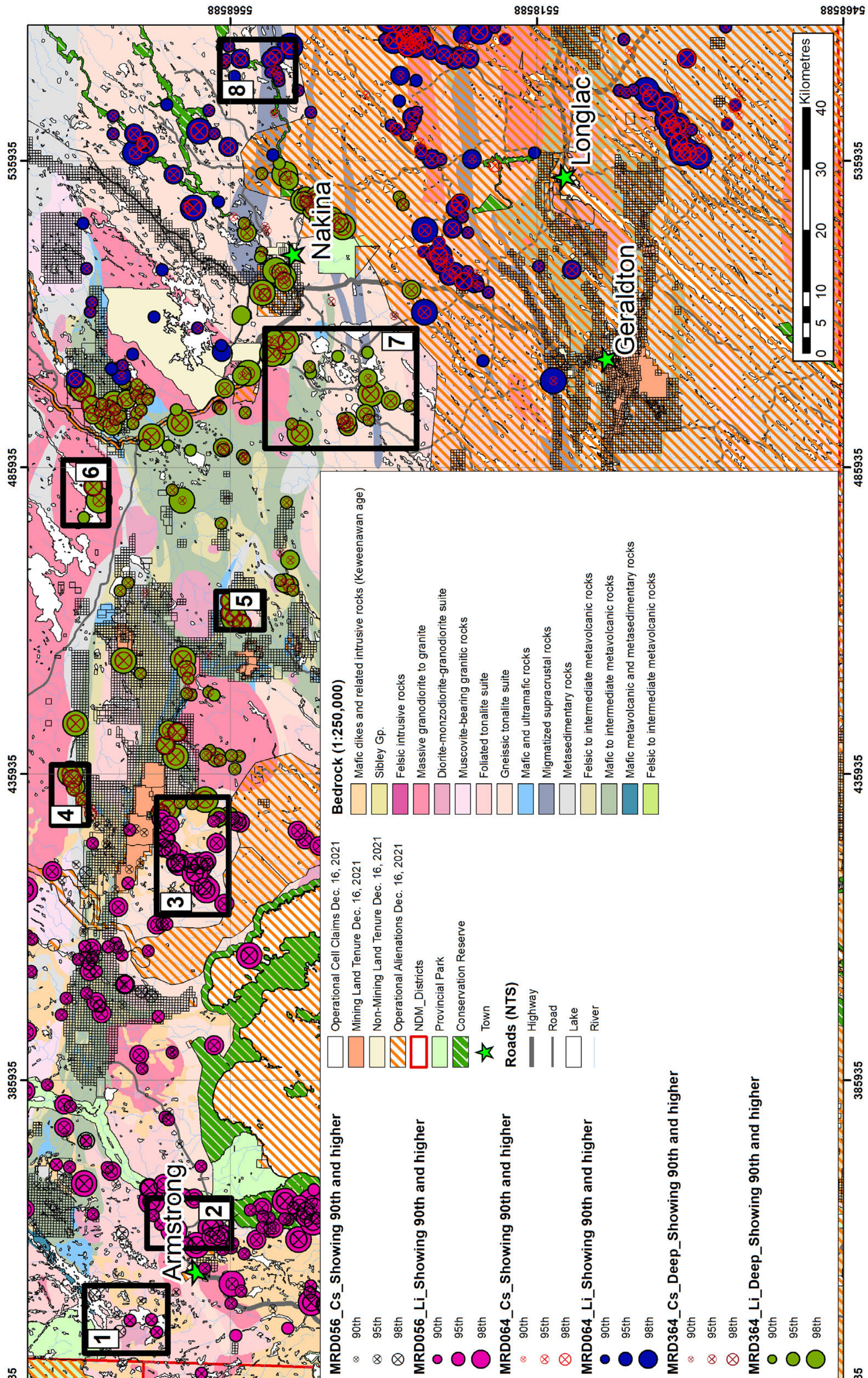

Figure 1. Location of target areas (1 to 8) overlain on bedrock geology map with deep sediment sampling lithium and cesium anomalies. Geology data *from* Ontario Geological Survey (2011); lake sediment data *from* Ontario Geological Survey 2000b; 2000d; Handley and Dyer 2018; Universal Transverse Mercator (UTM) co-ordinates in North American Datum (NAD83), Zone 16. Claim units current to December 16, 2021.

Based on the work of Hunt (2003) and Dickman and Fortescue (1991), the average sediment deposition rate is approximately 1.5 cm per decade within lakes on shield landscapes Therefore, the shallow sampling is considered to approximately represent sedimentation occurring during the past 100 years and may be subject to anthropogenic contamination. The deep sediment sample represents sedimentation older than 100 years and as such, is a better reflection on the effects of natural geochemical inputs that may be traced to local geology and/or mineralization. In the case of lithium and cesium, there should be no anthropogenic input into the study area, so the geochemistry of the shallow samples should be representative.

Proportional dot maps for lithium and cesium are plotted on a general bedrock geology map. “Anomalous” is defined for concentration values exceeding the 95th percentile of the data set for that element, while “strongly elevated” is defined for values exceeding the 90th percentile. The concentrations of all elements have been normalized to loss on ignition (LOI) during the assay process, to remove any artificial anomalies generated by the effect of the organic content on the trace element concentrations.

Regional ice movement indicates a southwest movement, fanning out to the west and south, based on glacial striae and features such as drumlins and eskers (Zoltai 1965, 1967). The ice movement direction suggests that the observed anomalies are most likely not derived from the known pegmatite fields located north of Lake Nipigon. All 8 target areas display varying degrees of outcrop and possible outcrop based on satellite imagery (due to the scale necessary to observe these features, the imagery has not been included in this publication).

Target area 1 consists of the southern portion Caribou Lake, with Beaver Island and Alphonse Bay near the northern boundary (Figure 2). The centre of the target area is underlain by the southern Caribou Lake pluton; a 6 km by 3.5 km alkaline pluton (Sutcliffe 1983, 1986) which intrudes the weakly to strongly foliated, locally gneissic biotite and hornblende-biotite tonalite and quartz diorite (Percival et al. 2002). The southeastern shore of Caribou Lake is dominated by the Proterozoic Nipigon diabase sills (Hollings et al. 2007). Nipigon diabase sills and the southern Caribou Lake pluton intrude the south Caribou batholith (McCrank, Misiura and Brown 1981). To the northwest of target area 1 within Wabikimi Provincial Park, the Smoothrock Lake pluton, a medium-grained massive garnet-muscovite-biotite granite, has numerous sills and dikes of garnet ± biotite-muscovite–bearing granite pegmatite which intrudes the surrounding Archean rocks (Sutcliffe 1983, 1986). The Smoothrock Lake pluton may represent a fertile parent granite source for potential LCT pegmatites.

Target area 2 is located east of the town of Armstrong Station and southeast of Big Lake within Wagaming Station Area (*see* Figure 2). This area is located within the south Caribou batholith (McCrank, Misiura and Brown 1981), which was mapped as weakly to strongly foliated, locally gneissic biotite and hornblende-biotite tonalite and quartz diorite (Percival et al. 2002).

Target area 3 (Figure 3) is located within the Laumone batholith (McCrank, Misiura and Brown 1981). MacDonald et al. (2009), stated that the granitic rocks south of the Caribou Lake greenstone belt generally consist of moderately foliated to gneissic biotite tonalite to granodiorite, which generally range from white to light pink on weathered surfaces and light grey to grey-pink when fresh, with prominent millimetre-to metre-scale gneissic banding. All gneissic phases contain or are crosscut by fine-to coarse-grained and locally pegmatitic, 2 cm to 5 m wide granodiorite pods, lenses and dikes; less than 1 to 10 m wide fine- to coarse-grained mafic dikes and 1 to 10 cm wide pink aplite dikes.

Readers are advised that despite the observed 95th percentile and greater lake sediment anomalies, caution should be used when evaluating target area 3 as it down ice from the Swole Lake pegmatite boulder field (Breaks, Selway and Tindle 2006) located to the northeast (Zoltai 1965, 1967).

Target area 4 is north of Tape Lake (*see* Figure 3) and straddles the boundary of the Caribou Lake greenstone belt and the English River Subprovince (MacDonald et al. 2009). Target area 4 is adjacent to Landore Resources Canada Inc.’s Junior Lake property. This area hosts known rare-element mineralization distributed over a 130 km strike length between Linklater Lake to Superb Lake near Nakina (Breaks et al. 2003).

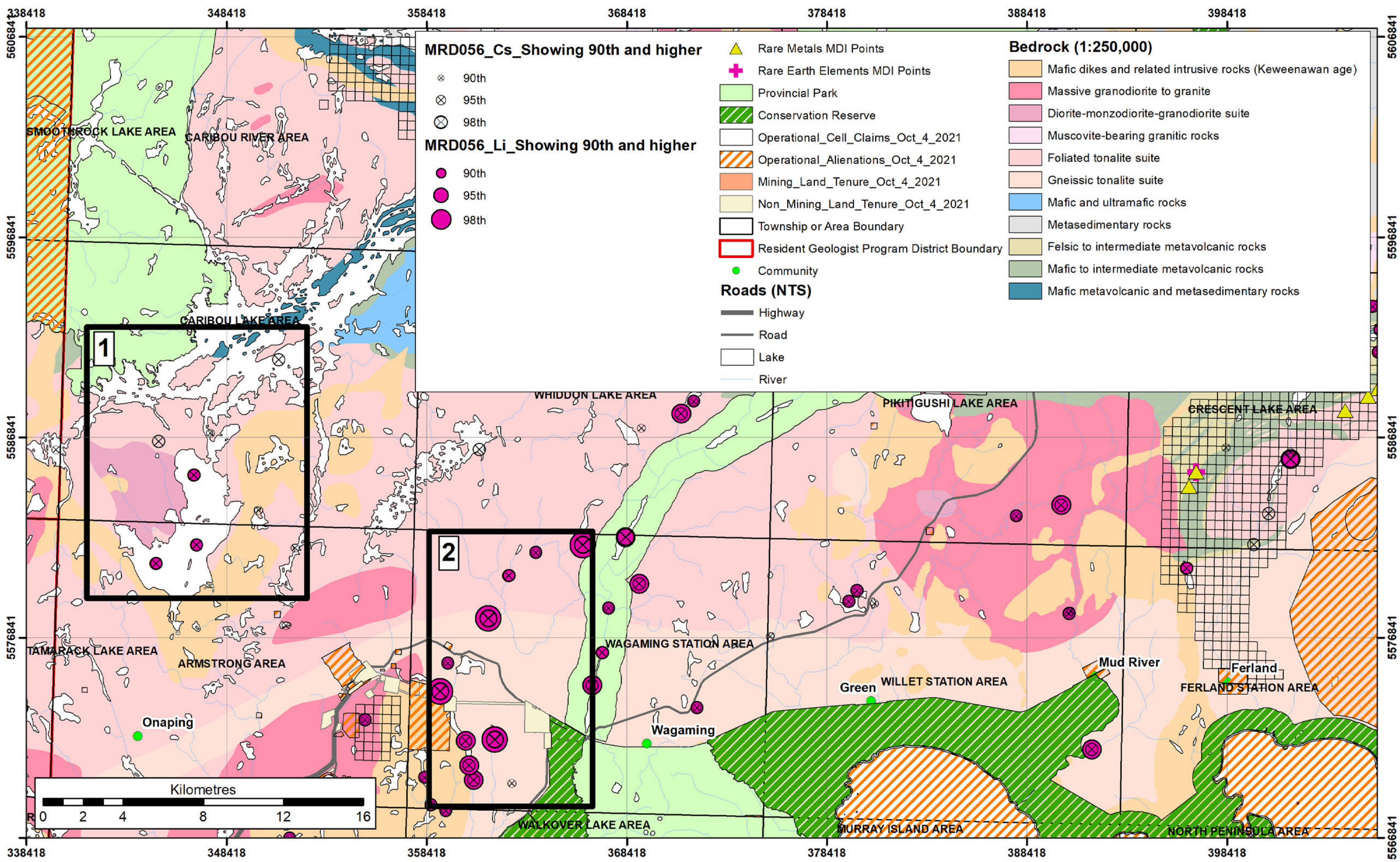

Figure 2. Target areas 1 and 2 overlain on bedrock geology map. Deep sediment sampling lithium and cesium anomalies. Geology data *from* Ontario Geological Survey (2011); lake sediment data *from* Ontario Geological Survey 2000b; 2000d; Handley and Dyer 2018; Universal Transverse Mercator (UTM) co-ordinates in North American Datum (NAD83), Zone 16. Claim units current to December 16, 2021.

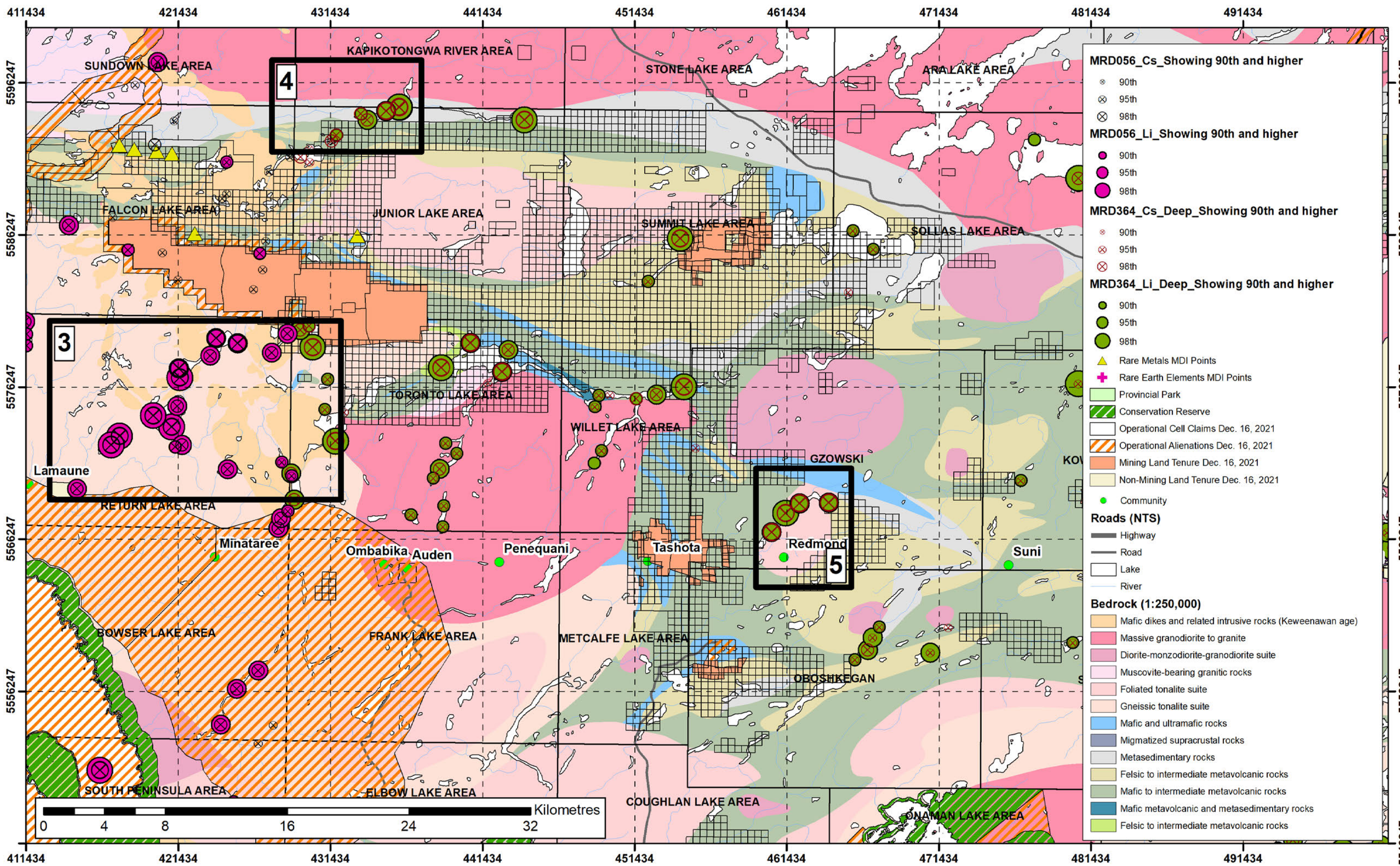

Figure 3. Target areas 3, 4 and 5 overlain on bedrock geology map. Deep sediment sampling lithium and cesium anomalies. Geology data *from* Ontario Geological Survey (2011); lake sediment data *from* Ontario Geological Survey 2000b; 2000d; Handley and Dyer 2018; Universal Transverse Mercator (UTM) co-ordinates in North American Datum (NAD83), Zone 16. Claim units current to December 16, 2021.

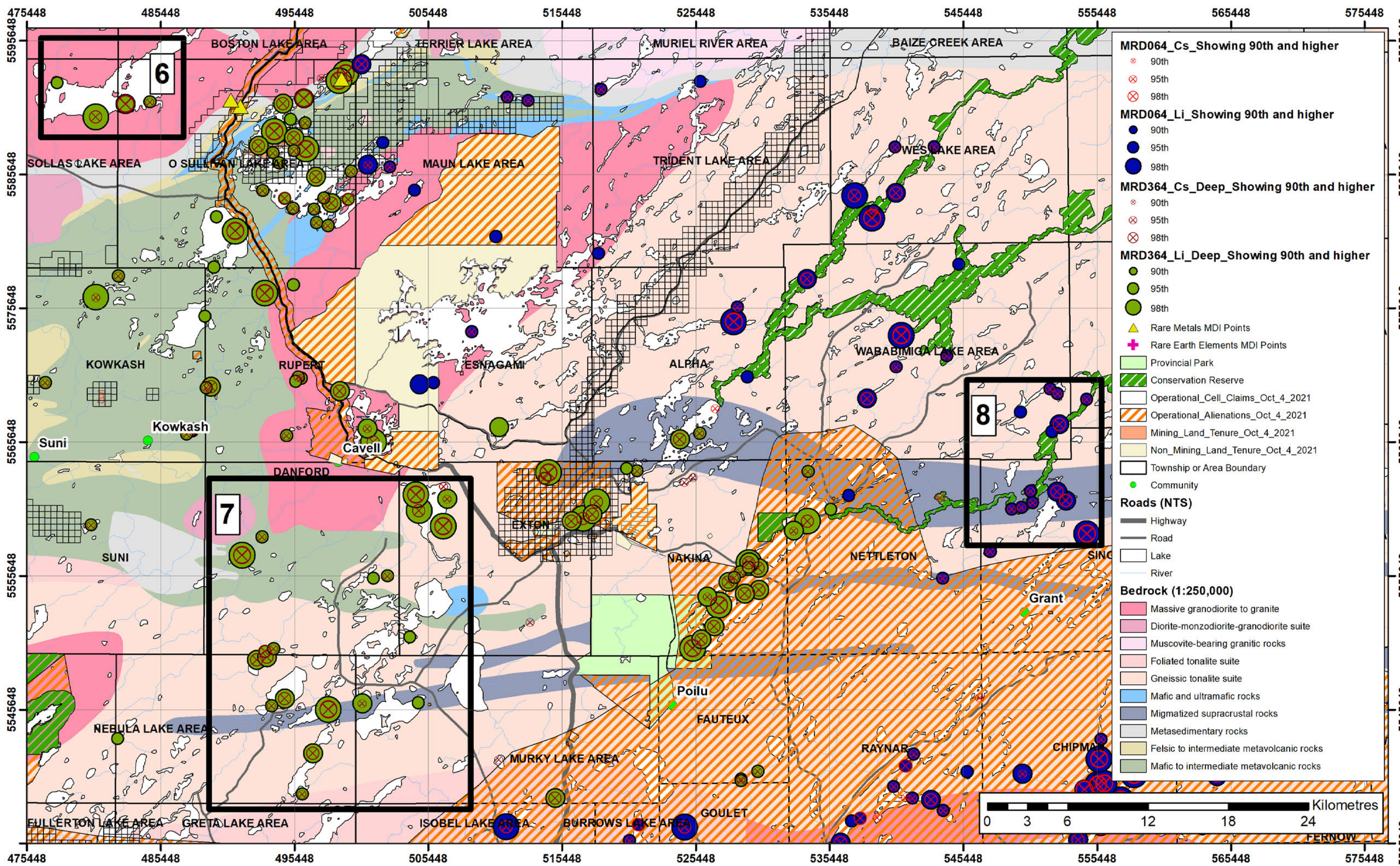

Figure 4. Target areas 6, 7 and 8 overlain on bedrock geology map. Deep sediment sampling lithium and cesium anomalies. Geology data *from* Ontario Geological Survey (2011); lake sediment data *from* Ontario Geological Survey 2000b; 2000d; Handley and Dyer 2018; Universal Transverse Mercator (UTM) co-ordinates in North American Datum (NAD83), Zone 16. Claim units current to December 16, 2021.

Target area 5 is within the Neoarchean Onaman–Tashota greenstone belt (Stott et al. 2002) and is hosted within the 2698.3±1.3 Ma (Davis et al. 2000) Gzowski pluton (*see* Figure 3). This late stage body has been mapped as massive granodiorite to monzogranite with potassium feldspar porphyritic, amphibole-bearing with hornblende clots and co-magmatic gabbro dikes with a hornblende porphyritic hornblendite-melanogabbro co-magmatic marginal phase (Stott et al. 2002).

Target area 6 lies within the English River Subprovince (Figure 4), north of the contact with the Caribou Lake greenstone belt and is centred on Abamasagi Lake (Stott et al. 2002). Breaks et al. (2006), noted that near the Abamasagi Lake Road in the vicinity of its junction with the Anaconda Road, a well-exposed, clean, glacially polished outcrop of garnet-biotite-muscovite pegmatitic leucogranite was observed at 02-FWB-54 (UTM 490691E 5591192N, NAD83, Zone 16). Fertile peraluminous granite units are well exposed on glacially polished surfaces at this locality:

- pegmatitic leucogranite
- sodic aplite layers
- quartz-rich patches with blocky potassium feldspar and sparse green beryl
- potassic pegmatite segregations

Breaks et al. (2006), noted that the bulk composition of a green muscovite (02-FWB-54-02) revealed levels of elements indicative of a fertile pegmatitic granite system and, particularly the elevated tantalum (63 ppm Ta), infers the presence of beryl-type pegmatites.

Target area 7 is located in the eastern margin of the Onaman–Tashota greenstone belt (*see* Figure 4) within the Willet assemblage and the Esnagami batholith to the north and the Onaman pluton to the south (Stott et al. 2002). The Esnagami batholith is biotite bearing with quartz phenocryst granodiorite to tonalite containing multiple-age phases that range from unmetamorphosed to weakly deformed with chlorite and epidote factures (Stott et al. 2002). The Onaman pluton is a medium- to fine-grained, locally biotitic and quartz porphyritic granodiorite to tonalite unit with late granite dikes and amphibolite inclusions which may be related to a part of the Nakina tonalite gneiss (Stott et al. 2002).

Target area 8 is located within the eastern portion of the Wabigoon Subprovince (*see* Figure 4) and is underlain by foliated to gneissic tonalite to granodiorite with minor supracrustal inclusions. Rocks in the area are also cut by diabase dikes of the northwest trending 2454 Ma Matachewan swarm and northeast trending 2101-2126 Ma Marathon swarm (Ontario Geological Survey 2011). The area has not undergone detailed geologic mapping since 1971 by Innes and Ayres of the Ontario Department of Mines (Innes and Ayres 1971).

Grassroots exploration of all 8 target areas should include both the determination and examination of any regional zoning of fertile granites and pegmatite dikes. Field work should include sampling and analysis of bulk whole-rock compositions and bulk potassium feldspar and muscovite compositions to determine the degree of fractionation of the granite and pegmatite. Identification of tantalum minerals, as well as sampling of metasomatized host rocks will aid in vectoring towards LCT pegmatite unit (Selway, Breaks and Tindle 2005). Following up on the recommendation by Breaks, Selway and Tindle (2006) in the Superb–Odman–Abamasagi lakes area in the vicinity of the Wabigoon–English River subprovinces boundary, is recommended as an area that should be prospected for further rare element mineralization.

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HIGHLIGHTS

- **Carbonatite intrusions in NTS map areas 53 A/12 and 53 A/13**
- **Underexplored area with known niobium and phosphate mineralization**
- **Rare earth element (REE) mineralization potential**

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Niobium and Phosphate Potential in the Schryburt Lake Carbonatite Complex

Carbonatites are a relatively rare type of intrusive rock, comprising more than 50% carbonate minerals and contain the highest concentrations of rare earth elements of any igneous rock. Globally, carbonatites are the primary source of niobium and rare earth elements. Other commodities produced from carbonatite-related deposits include phosphate, iron, fluorite, copper, vanadium, titanium, uranium, and calcite (Verplanck, Mariano and Mariano 2016).

The Schryburt Lake carbonatite complex (the complex) lies within the Island Lake domain of the North Caribou terrane of the Superior Province and has been dated by K-Ar techniques at 1145±74 Ma (Sage 1988). The complex has a prominent circular aeromagnetic expression (Figure 1) which combined with the very limited outcrop available, suggests that the complex has a surface area of approximately 4.4 km^2 (Sage 1976).

The complex was discovered in 1960 when Many Lakes Exploration Company flew an aeromagnetic survey. Many Lakes staked 34 claims and prospected for niobium in 1961, carrying out line cutting, geological mapping, trenching, sampling, and a ground magnetic survey. The carbonatite was described by Parsons (1961) as follows.

> The carbonatite consists of varying proportions of calcite, magnetite, perovskite, fluorite, pyrochlore and sulphides. It varies from nearly pure calcite to almost pure apatite. Bands of nearly massive magnetite several feet across are also present, and in some cases carrying up to 10% perovskite. Green, streaky fragments and bands consisting mostly of apatite and mica are common features in the carbonatite.
>
> Except for the outcrop and boulder area, in the river running out of Schryburt Lake on the east boundary of the property, all carbonatite found is a granular type, in the river, it occurs as slabs and as a solid outcrop in its floor. Where the granular carbonatite is near surface, it is covered with residual soils, generally brown, micaceous and radioactive.

Mapping of the complex was carried out by Ontario Geological Survey (OGS) geologists in the 1970s (Sage and Wright 1979). Samples collected from the pits and trenches indicate the complex is composed predominantly of sovite (calcitic carbonatite) with subvertical bands of nearly pure sovite alternating with bands of silicocarbonatite. One pit exposed a coarse-grained dolomite dike. In the carbonatite, very pronounced bands of nearly pure actinolite, apatite, magnetite, biotite-phlogopite, or pyrrhotite alternate with pink to pink-white carbonate are also present. The outcrops are banded on a scale of 1 to 5 cm, weather grey, and are grey-pink on fresh surface. The Schryburt carbonatite complex intrudes granitoid country rocks which are rare near the

Pettigrew, T.K. 2022. Niobium and phosphate potential in the Schryburt Lake carbonatite complex; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.49-53.

complex as noted by the presence of only 2 outcrops of granitic rock mapped on Schryburt Lake (Sage 1983). The granitic country rock in the immediate area of the Schryburt Lake complex is generally classified as a granodiorite (Sage 1983) similar to that mapped by Thurston, Sage and Siragusa (1973) who mapped similar granitic rocks throughout the area.

The intrusion is known to contain niobium, uranium and apatite mineralization. Samples from Many Lakes Exploration's trenches returned assays of up to 1.82% Nb_2O_5 from a grab sample and 0.40% Nb_2O_5 over 2.4 m from a channel sample. Perovskite is the primary source of the lower niobium values, the higher values occurring in pyrochlore associated with apatite-rich samples (Parsons 1961). International Minerals and Chemical Corp. carried out geologic and soil surveys during July 1976, followed by vertical reverse circulation drilling of 6 widely spaced holes in January 1977. This drilling encountered residual apatite accumulations in hole SC-1 returning 9.0 m of apatite-rich residual soil with an average assay of 17.5% P_2O_5, and values up to 19.6% P_2O_5 over 1.5 m (Erdosh 1977a). A soil sample collected by Sage returned 0.039% U_3O_8 and 0.08% niobium (1988).

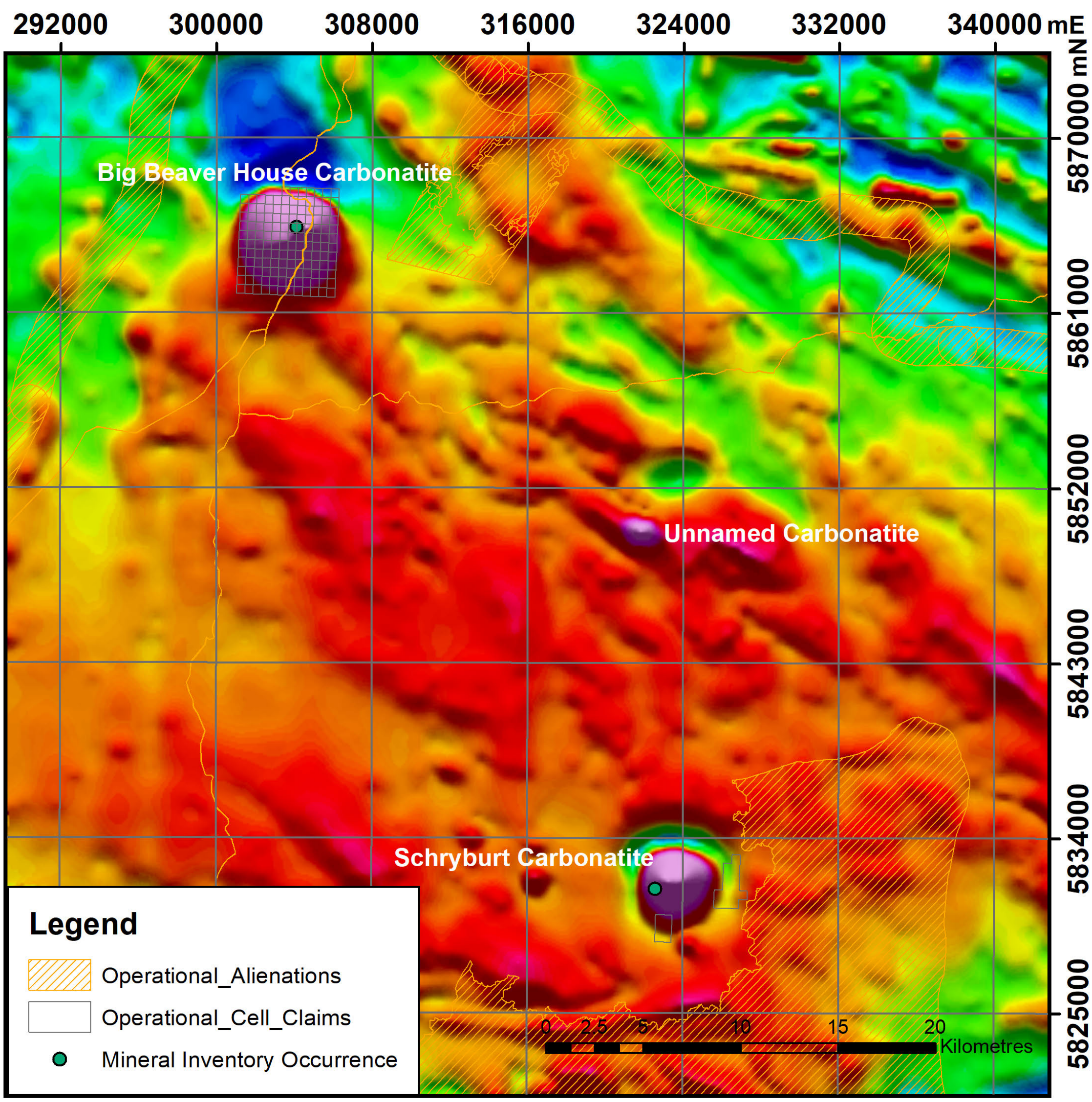

Figure 1. Image of the total magnetic field in the Schryburt Lake and Misamikwash Lake area showing the location of the Schryburt and Big Beaver House carbonatite complexes, Thunder Bay North District. Geophysical data from Ontario Geological Survey (2003). Universal Transverse Mercator (UTM) co-ordinates in NAD83, Zone 16. Claim units as of November 3, 2021.

The Big Beaver House carbonatite complex is located approximately 39 km to the north- northwest of the Schryburt Lake complex and also hosts niobium and phosphate mineralization. In 1962, Many Lakes Exploration drilled 7 holes, with diamond-drill hole DDH 4 returning up to 1.46% Nb_2O_5 over 0.12 m, 3.05% Nb_2O_5 over 0.3 m and 5.3% Nb_2O_5 over 1.07 m (Parsons 1962). International Minerals and Chemical Corp. drilled 5 holes and reported assays of 2.01 to 8.80 weight percent P_2O_5 (Erdosh 1977b). The Big Beaver House carbonatite complex is covered by claims registered to 2609572 Ontario Inc. at the time of publication.

Between the Schryburt and Big Beaver House carbonatites, approximately 1.5 km east of the southern end of Bate Lake, there is a smaller, unnamed geophysical anomaly that has been interpreted as a carbonatite (Figures 1 and 2). This feature has not been explored to date. Thurston, Sage and Siragusa (1973) indicate that there is no outcrop in the area, which is consistent with the lack of outcrop at the Big Beaver House and Schryburt Lake

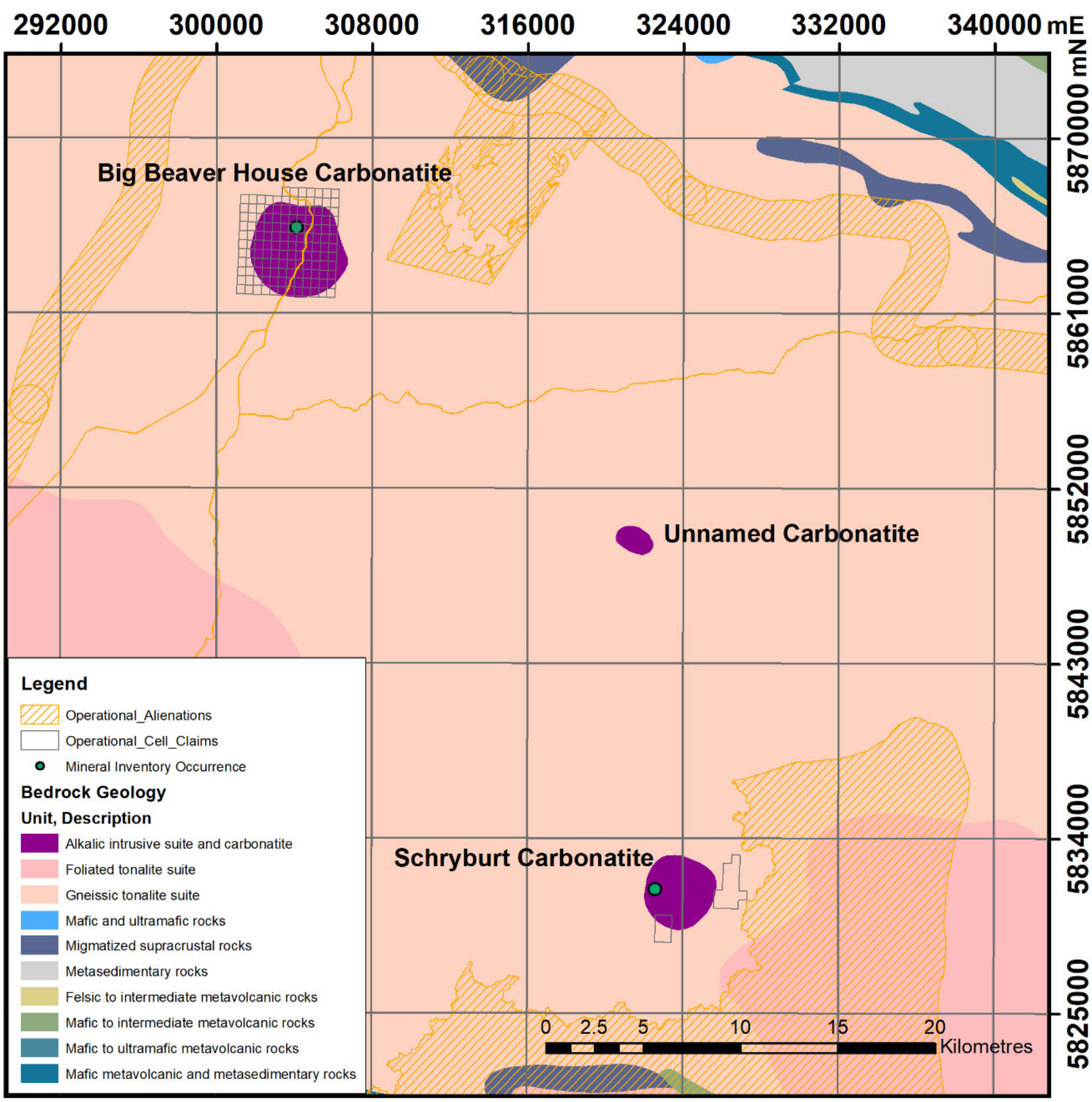

Figure 2. Geological map of the Schryburt Lake to Misamikwash Lake areas showing the locations of the Schryburt and Big Beaver House carbonatite complexes in the Thunder Bay North District. Geology *from* Ontario Geological Survey (2011). Universal Transverse Mercator (UTM) co-ordinates in NAD83, Zone 16. Claim units as of November 3, 2021.

carbonatite complexes (Sage 1987, 1988). A geophysical anomaly has been identified on the Geological Survey of Canada's aeromagnetic map 939 (1960) as well as in the Ontario regional magnetic survey (Figure 1, Ontario Geological Survey 2003). It has been interpreted on the bedrock geology map as a carbonatite (Ontario Geological Survey 2011). This anomaly has the potential to be another niobium- and phosphate-bearing carbonatite, particularly as it lies between 2 known carbonatites containing niobium and phosphate.

Only a very small portion of the Schryburt Lake carbonatite has been explored and tested. Those tests have indicated the occurrence of niobium, phosphate and uranium. There is significant potential for further exploration on this complex, which requires additional testing for its niobium potential and for apatite, which occurs as residual soil infillings on the bedrock surface of the complex. The carbonatite should also be analyzed for rare earth element content, which has not been a focus of exploration to date but is frequently found in carbonatites. In establishing exploration guidelines for carbonatites in Ontario, Easton came to the conclusion that "calcio-carbonatites associated with coeval feldspathoidal-dominated silicate rocks (e.g., ijolite, nepheline syenite) are more likely to host niobium and/or rare earth element mineralization than are calcio-carbonatites found with other igneous rock associations" (2020). The Big Beaver House carbonatite complex is associated with pyroxenite, ijolite, and magnetite-apatite rock and the Schryburt Lake complex is associated with fenite, all alkalic rock types. Easton (2020) suggests that both complexes have favourable compositions with established niobium and phosphate mineralization, and therefore warrant additional study despite not being clearly associated with a tectonic zone.

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HIGHLIGHTS

- **Cluster of lithium anomalies in lake sediment along a northeast-trending regional fault system on the north arm of Bedivere Lake**
- **Biotite granitic pegmatites mapped in the Bedivere and Lac des Mille Lacs lakes area**
- **Lake sediment lithium anomalies at Bedivere Lake located approximately 10 km from a biotite granite intrusion and near the Wabigoon–Quetico subprovince boundary**

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Lithium Potential in the Bedivere–Lac des Mille Lacs Lakes Area

The potential to host economic concentrations of rare metal mineralization, such as lithium (Li), cesium (Cs), beryllium (Be), tantalum (Ta) and niobium (Nb) is closely associated with pegmatites often situated distal to a parental fertile granite, typically within a 10 km radius (Figure 1). These rare metal pegmatites referred as lithium–cesium–tantalum (LCT) type pegmatites, typically occur in rocks associated with S-type granitic intrusions of intermediate metamorphic grade, near subprovince boundaries and/or along fault systems (Trueman and Černý 1982; Černý 1989, 1991; *as cited in* Sinclair 1996).

The Ontario Geological Survey (OGS) completed a lake sediment geochemical survey covering the Atikokan area (Dyer 1999a). A cluster of lake sediment lithium anomalies located on the north arm of Bedivere Lake returned the 6 highest lithium values, and the 9th highest value in the survey. These high lithium values range from 20.806 to 27.728 ppm Li and are represented by the larger black dots in Figures 2 and 3.

In the Atikokan area, historical and recent exploration has been mainly focused on gold mineralization associated with northeast-trending structures and copper–nickel–platinum group elements associated with mafic–ultramafic intrusions. As such, Dyer's OFR 5986 report (1999b) was focused on gold and PGEs and the lithium data was not presented as a proportional dot map in the report. The reader is referred to the MRD 43 for the lithium data.

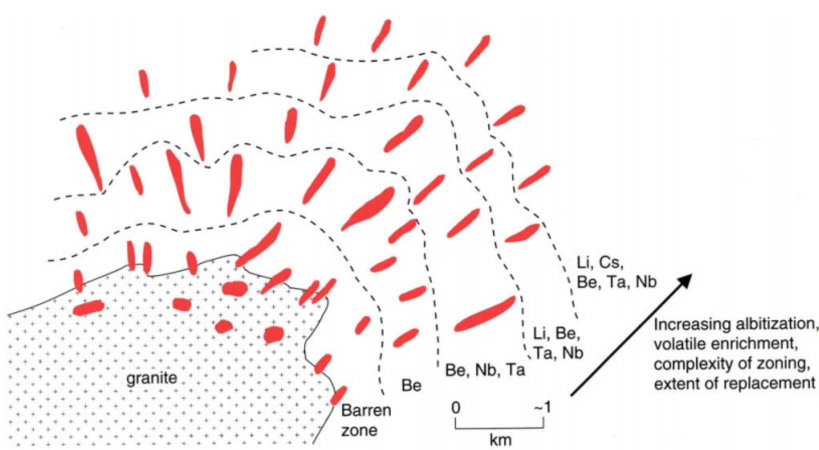

Figure 1. Deposit model of lithium-bearing granitic pegmatites often situated distal to parental fertile granite (*modified from* Trueman and Černý 1982; *as cited in* Sinclair 1996).

Campbell, D.A. 2022. Lithium potential in the Bedivere–Lac des Mille Lacs lakes area; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.54-58.

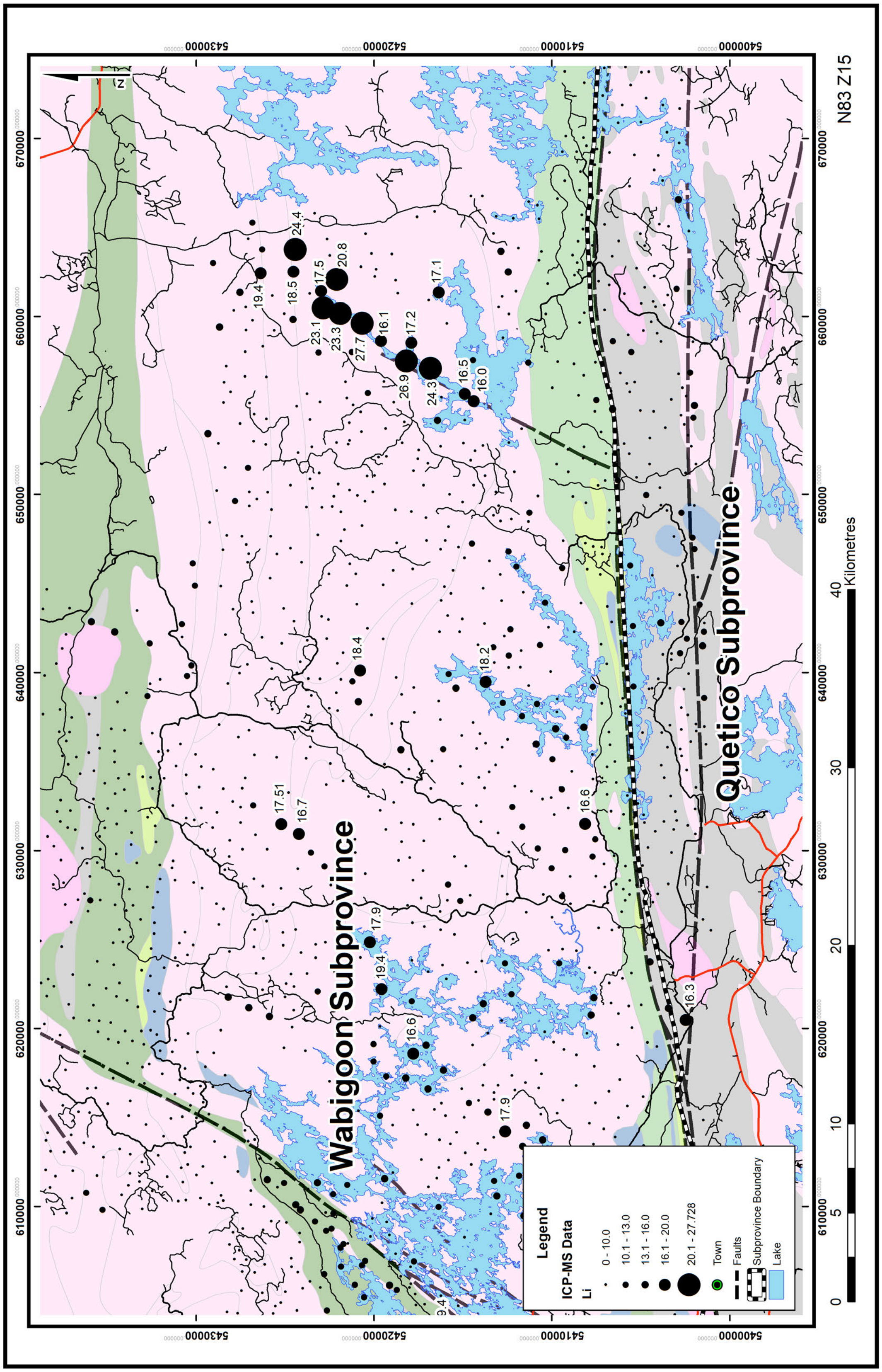

Figure 2. Regional geological map (*modified from* Ontario Geological Survey 2011) showing the location of the OGS lake sediment lithium anomalies (black dots with lithium values in ppm) (*from* Dyer 1999a). Granitoid rocks shown in various shades of pink, metavolcanic rocks in shades of green, metasedimentary rocks in grey, and gabbroic intrusive rocks in blue.

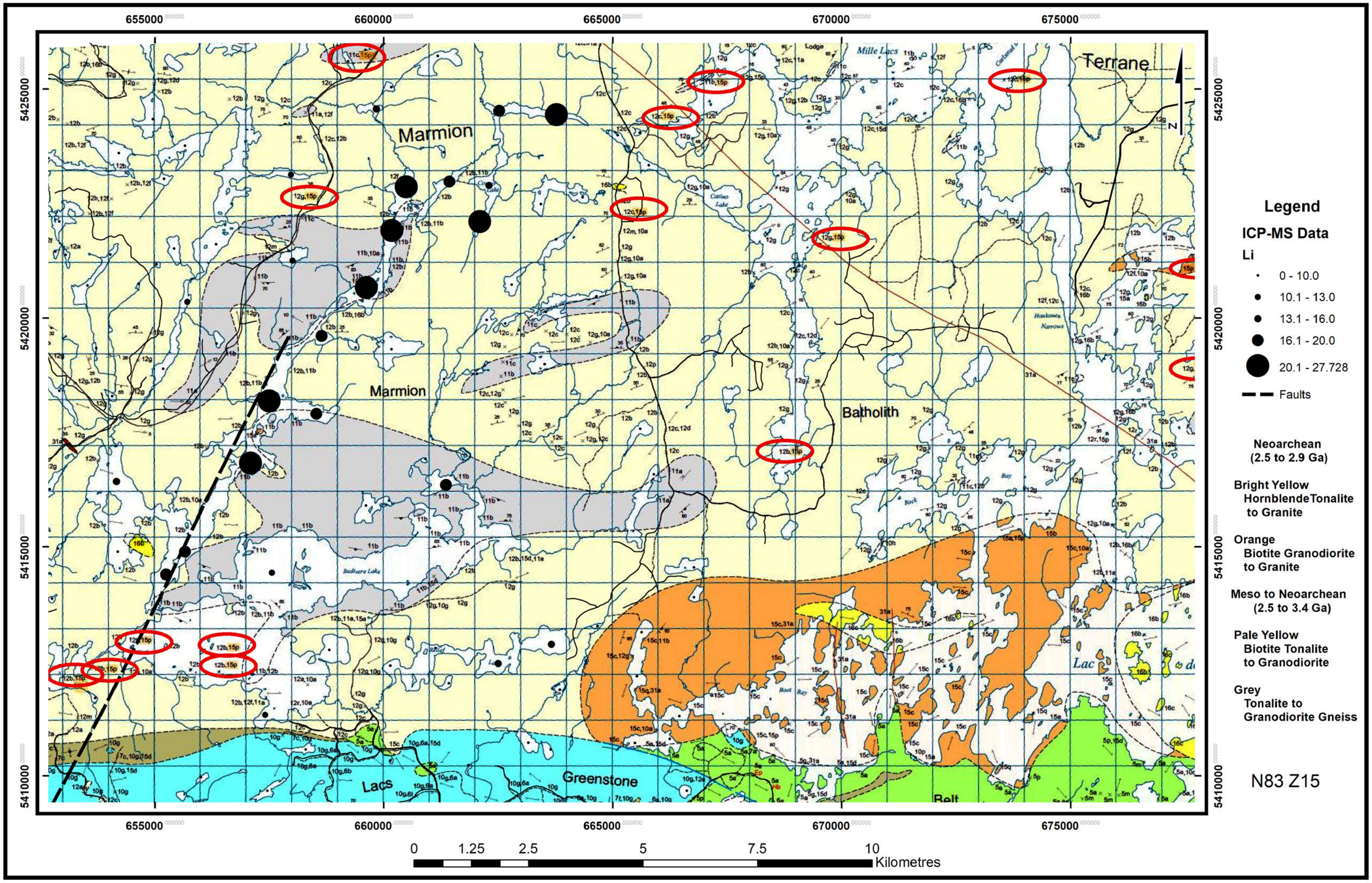

Figure 3. Regional geological map (*modified from* Stone 2005) showing the location of the OGS lake sediment lithium anomalies (black dots) (*from* Dyer 1999b), biotite-granitic intrusive at Boot Bay (orange) and outcrops of biotite granitic pegmatites (outlined by red ovals).

The lake sediment lithium data as provided in MRD 43 (Dyer 1999a), indicated the method of analyses used was ICP–MS, by aqua regia, which is a near-total digestion; therefore, lithium may be under-represented because it will usually be in silicate form and sometimes not fully digested. According to S. Hamilton (personal communication, OGS Senior Science Leader Geochemistry, 2021),

> The response observed in the Bedivere Lake area would if anything, be an under-representation of the actual lithium content in the sediments. Sometimes limnological or lake morphology-related overprints can cause sediment response in some elements (arsenic, for example) but I am not aware of any that affect lithium. Therefore, the response is very likely to originate from local bedrock sources.

The bedrock geology in the Bedivere Lake area is mapped as a mix of metasedimentary and granitic or granitoid rocks (Stone 2005). The 4 main granitic suites within Marmion batholith mapped by Stone (2005) in the Bedivere Lake area (Figure 3) are listed as follows with mapped geological units in brackets, and the OGS Preliminary map consulted.

Neoarchean (2.5 to 2.9 Ga):

- Hornblende Tonalite to Granite (map unit 16) Bright Yellow - P3523
- Biotite Granodiorite to Granite (map unit 15) Orange - P3523

Mesoarchean to Neoarchean (2.5 to 3.4 Ga):

- Biotite Tonalite to Granodiorite (map unit 12) Pale Yellow - P3523
- Tonalite to Granodiorite Gneiss (map unit 11) Grey - P3523

Mesoarchean biotite tonalite (12) and tonalite to granodiorite gneiss (11) suites are the most common rock types within the Marmion batholith, and in the Bedivere Lake area. Younger Neoarchean hornblende tonalite (16) and biotite granodiorite to granite (15) suites occur as irregular to oval and highly elongate forms mostly along the west, north and a portion of the southeast margin of the Marmion batholith (Stone 2010); however smaller bodies/outcrops in the Bedivere Lake area occur in the center of the Marmion batholith.

Readers are referred to the biotite granitic intrusive body in Boot Bay along the southwest arm of Lac des Mille Lacs Lake, outlined in orange on Figure 3. This granitic intrusion may represent a parental fertile granite. Stone (2005) mapped smaller outcrops of pegmatitic biotite-granitic rocks (map unit 15p) within a 10-15 km radius of the Boot Bay biotite-granitic intrusive. These pegmatitic outcrops are highlighted in light orange and outlined with red ovals on Figure 3.

According to Černý and Meintzer 1988 (*as cited in* Breaks, Selway and Tindle 2003), a fine-grained or porphyroblastic biotite granite has been identified as 1 of 5 possible rock types that may be part of a single fertile granite intrusion. Its also important to note, Breaks, Selway and Tindle (2003) point out that a fertile biotite granite cannot be distinguished from barren biotite granite in hand sample.

There is very little to no known exploration for LCT pegmatites in the Bedivere–Lac des Mille Lacs lakes area. Exploration for LCT pegmatites in the Bedivere Lake area is recommended based on the cluster of lake sediment lithium anomalies located along a regional fault system and the occurrences of biotite granitic pegmatites mapped nearby. On a regional scale, the lake sediment lithium anomalies at Bedivere Lake are located approximately 10 km from a biotite granite intrusion and are situated near the Wabigoon–Quetico subprovince boundary.

Reconnaissance sampling and lithogeochemistry is recommended in the Boot Bay area to determine if the biotite granite intrusion is a fertile parental granite. Prospecting, reconnaissance sampling and lithogeochemistry is proposed on the biotite granite pegmatite outcrops mapped by Stone (2005) in the Bedivere and Lac des Mille Lacs lakes area. Reference can also be made to Selway, Breaks and Tindle (2005) for a comprehensive review of exploration techniques for LCT pegmatites in the Superior Province. At the time of writing, the cluster of lake sediment lithium anomalies located on the north arm of Bedivere Lake was open for staking.

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HIGHLIGHTS

- **Year four of seven-year, $104 million mineral exploration research and development program**
- **New all-access data compilations and geologic maps for western Wabigoon subprovince can be utilized for exploration geological research and comparative studies**

Also refer to Open File Report 6381, *Report of Activities 2021, Resident Geologist Program, Red Lake Regional Resident Geologist Report (Kenora District—2021)* (p.15-16), for an emended version of this article.

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New Data from Metal Earth Program for the Western Wabigoon Subprovince

Metal Earth is a seven-year, $104 million applied research and development program that is led by the Mineral Exploration Research Centre (MERC), part of the Harquail School of Earth Sciences based at Laurentian University in Sudbury, Ontario. The program received funding in 2016 with field work commencing in 2017 (Mineral Exploration Research Centre 2018).

In order to reveal the fundamental geological processes that were responsible for the formation of mineral deposits in Superior Province, 49 MSc, PhD students, research associates and field assistants are conducting research for Metal Earth projects across northern Ontario and Quebec.

Metal Earth PhD candidate Rebecca Montsion and co-authors Stéphen Perrouty and Ben Frieman published an article in May 2021 titled "Geological and Geophysical Data Compilation for the Western Wabigoon and Southern Abitibi Subprovinces of the Superior Province, Ontario, Canada". The article describes the compilation of mineral deposit information, structural databases, magnetic susceptibility measurements, reprocessed aeromagnetic grids and new geological interpretations. The data set is comprehensive and provides access to observational, measured and interpreted data that can be used as a "foundation for experimental and exploration geological research" (Montsion, Perrouty and Frieman 2021) in the western Wabigoon and southern Abitibi subprovinces.

New geological maps and interpretations have been produced in hard copy map and GIS formats. Montsion, Perrouty and Frieman (2021) describe the new geological map of the Dryden area in the western Wabigoon subprovince of the Superior Province as "displaying poly-deformed Archean bimodal volcanic stratigraphy with overlying sedimentary packages variably intruded by tonalitic to granitic plutons and smaller porphyritic bodies. Proterozoic diabase dikes crosscut stratigraphy as well as intrusive bodies." (Figure 1). The new map incorporates interpretations from 64 geological maps, geophysical map patterns, field observations, geochronological data, published structural measurements combined with new observations and mineral deposit inventory data.

The compiled data sets and new geologic maps are open access and can be accessed by the link to the data repository on page 2 of the Montsion, Perrouty and Frieman (2021) article. The data repository contains geological layers representing geological observations and interpretations of the western Wabigoon, structural measurements, 2 geophysical data sets, new magnetic susceptibility measurements and an ensemble of reprocessed aeromagnetic grids.

Wiebe, K. 2022. New data from Metal Earth program for the western Wabigoon subprovince; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.59-61.

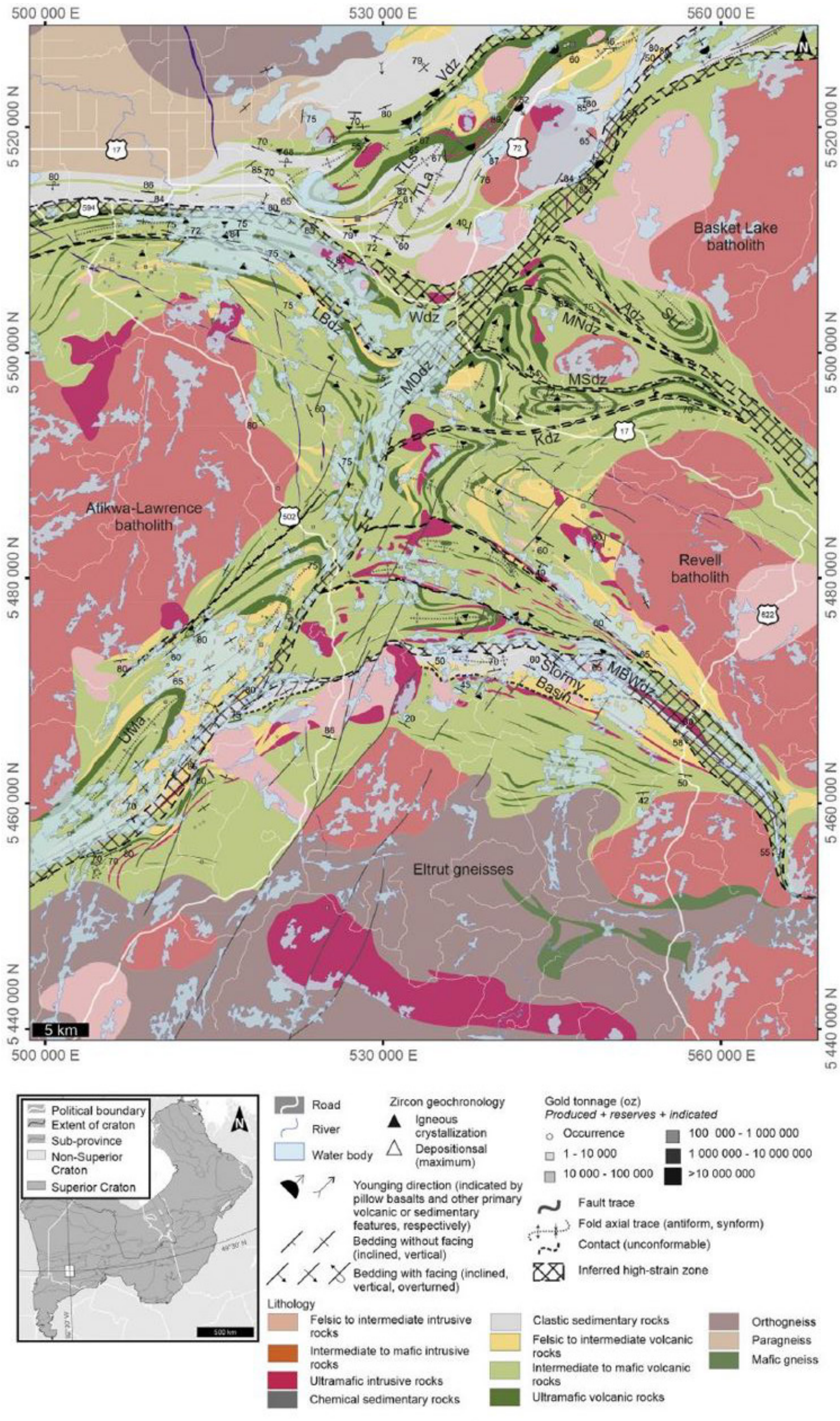

Figure 1. New geological map of the Dryden area, *from* Montsion, Perrouty and Frieman 2021. The map is a compilation of data sets and new field observations obtained in the Metal Earth research program.

The ongoing research by Metal Earth in the Kenora District, Ontario and Quebec provides exceptional geoscientific studies and concepts and a more comprehensive understanding of the formation and mineral deposits in the Superior Province. As stated by Montsion, Perrouty and Frieman (2021), the wealth of geological knowledge captured through the Metal Earth program should be used as a basis for exploration activity in the Western Wabigoon subprovince.

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Re-examining Graphite Potential in the English River Subprovince with Lake Sediment Data

HIGHLIGHTS

- **Underexplored area with significant graphite potential and other critical minerals**
- **Anomalous vanadium and nickel lake sediment anomalies associated with known graphite mineralization**
- **Known occurrence of graphite within English River subprovince**

Also refer to Open File Report 6381, *Report of Activities 2021, Resident Geologist Program, Red Lake Regional Resident Geologist Report (Red Lake District—2021)* (p.71-76), for an emended version of this article.

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Introduction

With the importance of critical minerals to Ontario and Canada, graphite is one commodity on the Ontario critical mineral list with excellent exploration potential in the Red Lake District. The Treelined Lake graphite occurrence is located along the southwest portion of the English River subprovince having seen sporadic exploration work over the past few decades. Highly metamorphosed metasedimentary rocks are abundant throughout the English River subprovince, potentially containing flake graphite deposits (Storey 2013). Most graphite deposits worldwide are discovered in crystalline metamorphic basement rocks, as akin to those found in the English River subprovince (Robinson, Hammarstrom and Olson 2017). This recommendation for exploration utilizes the inverse distance weighting interpolation method to create geochemical maps of lake sediment data collected by the Ontario Geological Survey (OGS) which are then used to highlight anomalous areas for vanadium and nickel in the area. Anomalous values of these metals are potential exploration indicators for flake graphite deposits that could aid in the discovery of new deposits within the region.

Graphite Usage

Graphite is essential to many industries, with approximately 1 million tonnes produced annually worldwide in 2011 (Robinson, Hammarstrom and Olson 2017). The range of applications for graphite include refractories, steel making, batteries, brake linings, electrical motor brushes, and high-temperature lubricants. Graphite ore is categorized into 3 commodity classes that range in price; amorphous (microcrystalline) at US$600–800/tonne; flake (crystalline) at US$1150–2000/tonne; and lump/chip (crystalline) at US$1700–2070/tonne (Robinson, Hammarstrom and Olson 2017). China is currently the primary producer of graphite globally, producing 67% of total production between 2006 and 2010 (Robinson, Hammarstrom and Olson 2017). However, with a limited supply of domestic graphite production in Canada, companies requiring high purity graphite may turn to synthetic graphite that ranges from US$7000 to 20 000/tonne (Robinson, Hammarstrom and Olson 2017). Significant graphite production has come from flake graphite deposits hosted in schists and paragneiss, as in the mines of the Jixie District of China (Robinson, Hammarstrom and Olson 2017).

Malegus, P.M. 2022. Re-examining graphite potential in the English River subprovince with lake sediment data; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.62-68.

Treelined Lake Graphite Occurrence

Mr. Linklater discovered the Treelined Lake graphite occurrence (MDI52L08SW00004) in 1968 with the most recent work completed by P. Heatherington in 2015 (Ontario Geological Survey 2021). The English River subprovince (Figure 1) is composed of metasedimentary rocks formed as part of an accretionary prism (Breaks 1991) and bound to the south by the Winnipeg River subprovince granitoid terrane and specifically the Separation Lake greenstone belt (Beakhouse 1991). Quartz sandstones and arkoses/wacke protoliths were formed from the deposition of organic-rich sediments (Winter 2012). Disseminated flake-type graphite occurs within quartz-rich migmatite (paragneiss) and quartz-feldspar-biotite schist surrounded by granitoid rocks (Blackburn, Young and Breaks 2008). The dominant metamorphic grade throughout the Treelined Lake occurrence is granulite facies (Blackburn and Young 2000). The occurrence trends northeast (60°) over a strike length of 2–3 km (Figure 2), ranging from 0.40% to 9.15% graphitic carbon (Blackburn and Young 2000; Winter 2012). Electromagnetic and magnetic surveys were successful in delineating the strike length of graphite mineralization due to the presence of pyrrhotite and the strong conductivity of graphite (Kuehnbaum and Zebruck 2002).

Graphite formation requires organic-rich sediment deposited on basement rock in an anoxic environment (Robinson, Hammarstrom and Olson 2017). In addition, amphibolite- to granulite-grade metamorphism is necessary to crystallize graphite in aluminum-rich paragneiss (Robinson, Hammarstrom and Olson 2017). The depositional environment of the Treelined Lake occurrence appears to meet the requirements for graphite crystallization; carbon-rich sedimentary rocks deposited on an accretionary prism, bounded by a granitoid terrane of the Winnipeg River subprovince. Lastly, protoliths at the occurrence were metamorphosed to migmatite and schist containing newly crystallized graphite due to granulite-grade metamorphism.

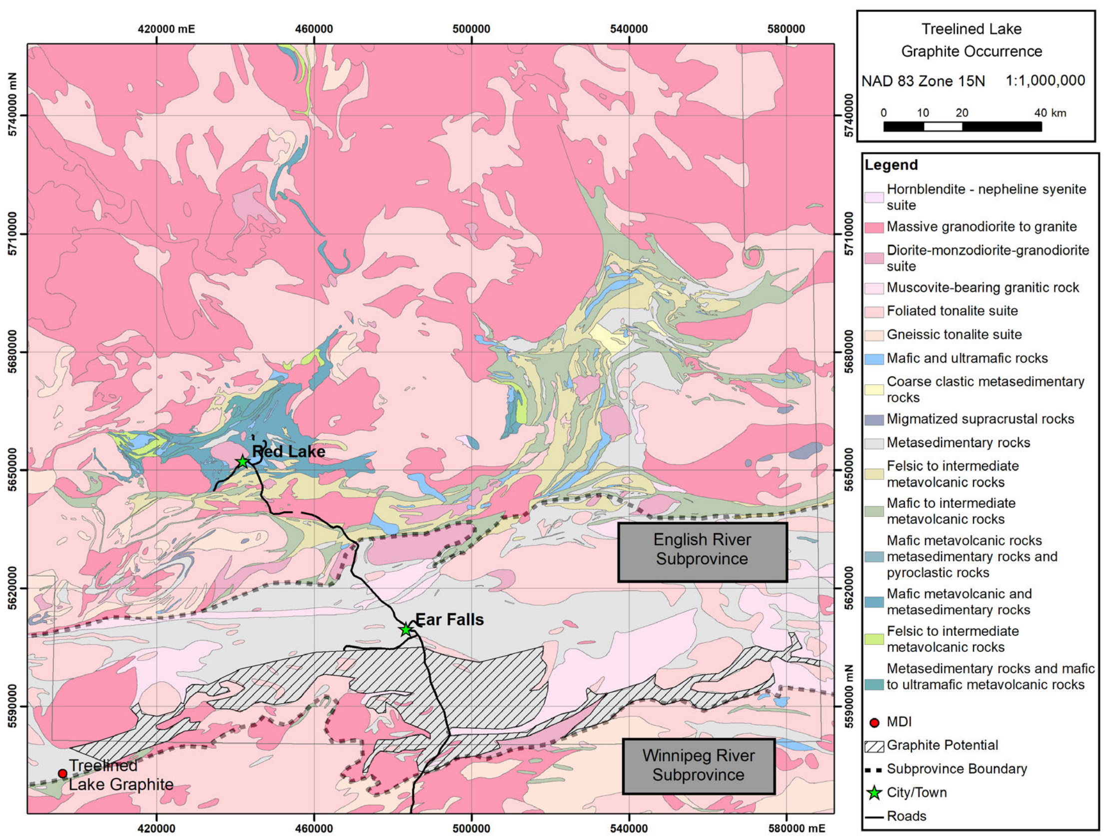

Figure 1. Treelined Lake graphite occurrence and potential graphite location in the English River subprovince (*modified from* Ontario Geological Survey 2011; MDI refers to the occurrence as documented in the Ontario Mineral Inventory, *see* Ontario Geological Survey 2021).

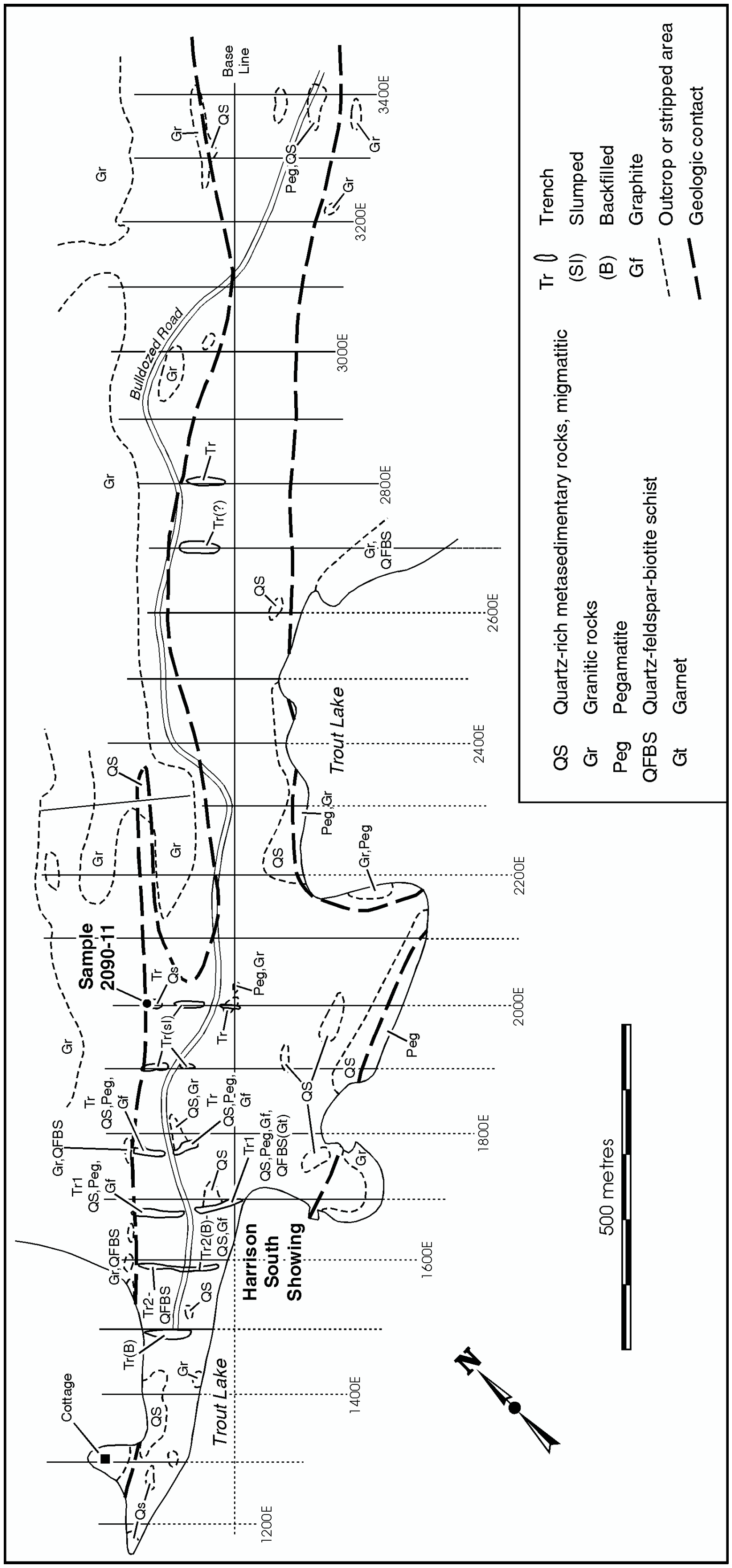

Figure 2. Detailed geology of the Treelined Lake graphite occurrence (*from* Blackburn and Young 2000).

Exploring for Graphite

The presence of flake graphite at the Treelined Lake occurrence in the English River subprovince highlights the potential for other discoveries along the boundary between the English River and Winnipeg River subprovinces. The geological environment along the southern boundary of the English River subprovince is similar to that which hosts other graphite deposits including high-grade metamorphism, paragneiss/schists and organic material deposited during lithification of wacke, siltstone and shale (Breaks 1991).

Elements with a potential affinity for graphite include vanadium, nickel and (or) uranium (Robinson, Hammarstrom and Olson 2017). Vanadium in particular, has a strong relationship with graphite. Both vanadium and graphite are typically deposited in anoxic environments from carbon-rich sediments, with immobile vanadium enriched alongside graphite (Couëslan 2019). An inverse distance weighting (IDW) interpolation method conducted on lake sediment geochemical data in the area was used to create geochemical maps to determine whether vanadium or nickel were present along the subprovince boundary (Ontario Geological Survey 2001, 2002, 2014; Figures 3 and 4). The elemental data used to develop the IDW maps were first normalized by removing LOI (loss-on-ignition) material from the sample data.

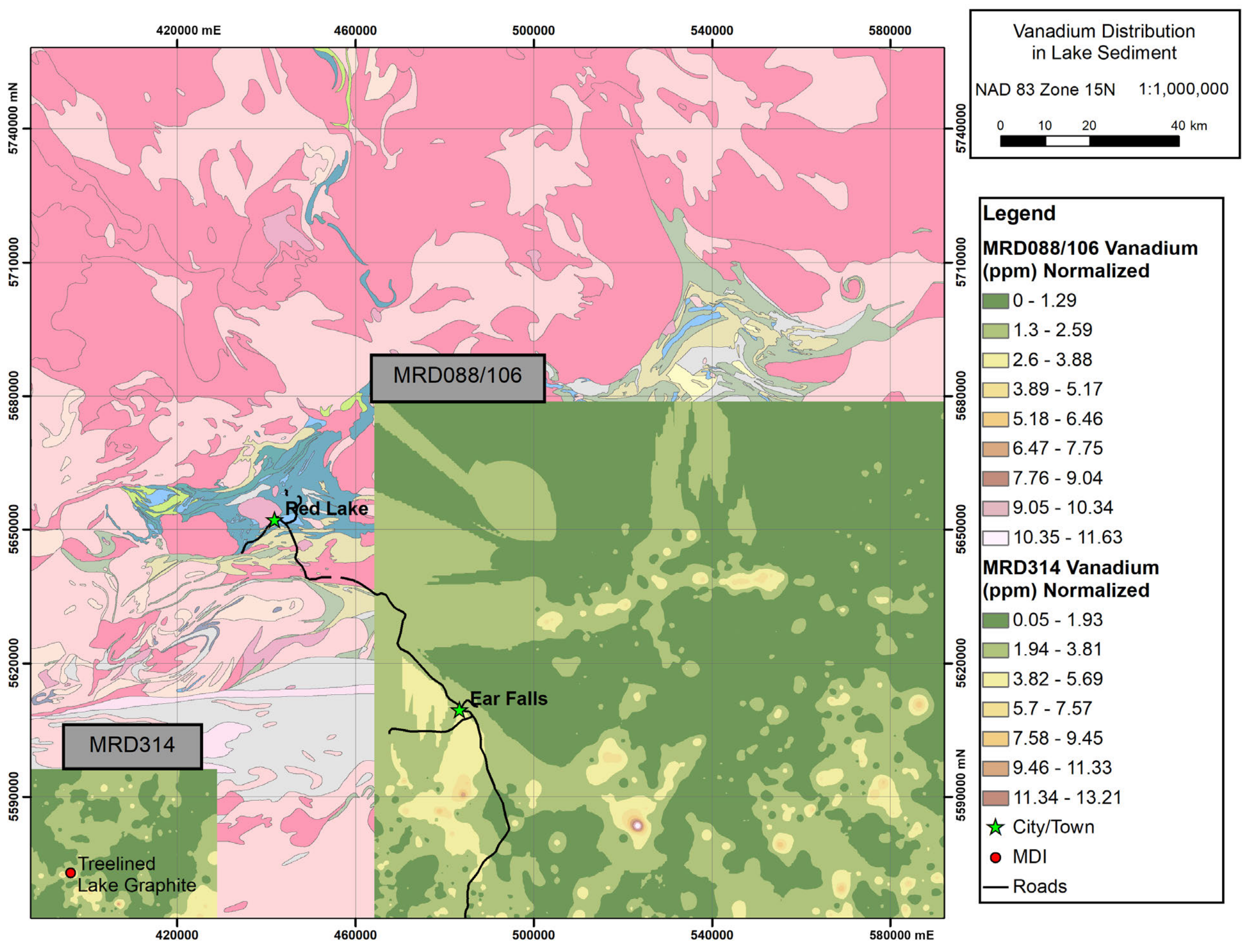

Figure 3. Geochemical map of the distribution of vanadium in lake sediment, using IDW interpolation (data *from* Ontario Geological Survey 2001, 2002, 2014) over bedrock geology (*modified from* Ontario Geological Survey 2011) in the area along the southern boundary of the English River subprovince. The Treelined Lake graphite occurrence is noted in the southwestern corner of the map (MDI refers to the location of the occurrence as documented in the Ontario Mineral Inventory, *see* Ontario Geological Survey 2021).

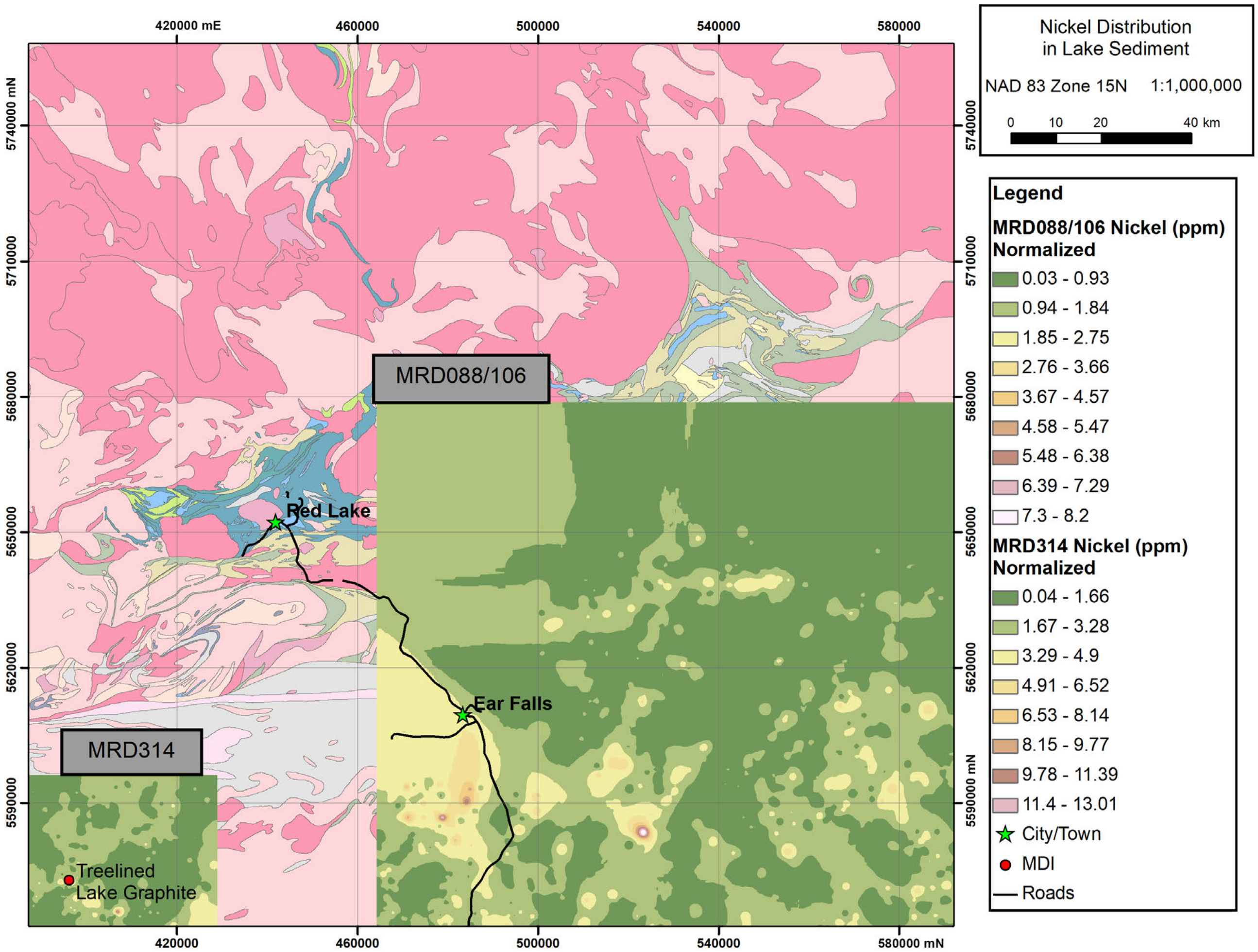

Figure 4. Geochemical map of the distribution of nickel in lake sediment, using IDW interpolation (data *from* Ontario Geological Survey 2001, 2002, 2014) over bedrock geology (*modified from* Ontario Geological Survey 2011) in the area along the southern boundary of the English River subprovince. The Treelined Lake graphite occurrence is noted in the southwestern corner of the map (MDI refers to the location of the occurrence as documented in the Ontario Mineral Inventory, *see* Ontario Geological Survey 2021).

The geochemical maps showing the distribution of vanadium and nickel revealed multiple anomalous locales along the southern boundary with the majority of the anomalies proximal to mapped migmatized paragneisses. Additionally, the association of moderately anomalous values of vanadium and nickel located at and likely associated with the Treelined Lake occurrence confirm the affinity between vanadium, nickel and graphite. With the anomalous vanadium and nickel values present at the Treelined Lake occurrence confirming the association with graphite, it is likely that other lake sediment anomalies along the subprovince boundary may display potential for flake graphite mineralization.

Figure 5 illustrates the high-grade metamorphism prevalent throughout the English River subprovince. Granulite-grade metamorphism is contained to the Umfreville–Conifer Lake and the Eastern Lac Seul zones (*see* Figure 5), with the remainder of the southern boundary displaying lower grade (sub-amphibolite) metamorphism. The primary lithology found along the southern boundary is metatexite. Metatexite is a migmatized metasedimentary rock (paragneiss) formed from high-grade metamorphism (Breaks 1991), one of the primary host rocks of flake graphite.

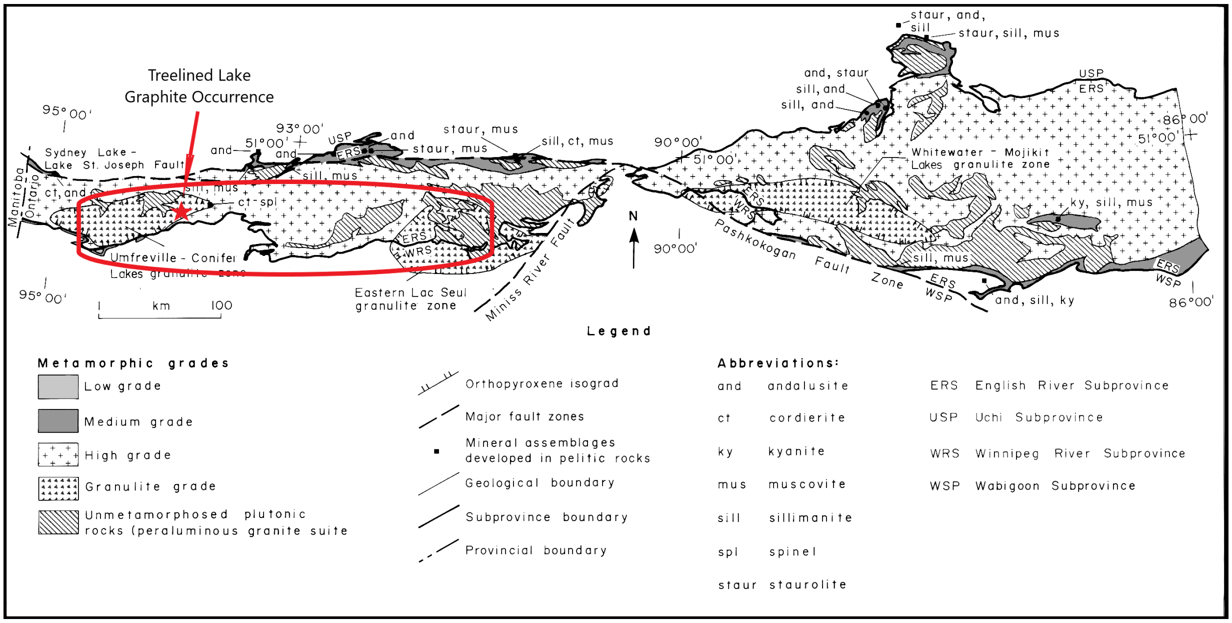

Figure 5. Metamorphic grade of metasedimentary rocks in English River subprovince, including area recommended for exploration highlighted in red (*modified from* Breaks 1991).

Geophysical methods will aid in exploration for graphite mineralization due to the thickness of overburden in the low-lying English River subprovince. With the high conductivity of graphite and the potential for magnetic pyrrhotite as in the Tree Lake graphite occurrence, the use of air and/or ground electromagnetic geophysical tools on the anomalous locations could be of significant exploration value.

Conclusion

Exploration for potential flake graphite deposits along the southern boundary of the English River subprovince should focus on the following areas that have been highlighted in Figure 1;

1. metasedimentary rocks with abundant paragneiss and schists,
2. anomalous vanadium and nickel values, and
3. high-grade metamorphic facies.

For the explorationist, locations with anomalous vanadium and nickel can assist in refining exploration targets. With large portions of the English River subprovince open to acquisition (as of October 2021), there is significant ground available to find the next flake graphite deposit and support Ontario’s critical mineral strategy.

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HIGHLIGHTS

- **Conifer Lake complex shares mafic-ultramafic rock type and major structure with the economically significant deposits along the Werner–Rex lakes fault**
- **Recent geophysical imagery shows anomalies with magnetic signature of mafic-ultramafic rocks**

Also refer to Open File Report 6381, *Report of Activities 2021, Resident Geologist Program, Red Lake Regional Resident Geologist Report (Red Lake District—2021)* (p.77-80), for an emended version of this article.

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Ni-Cu-PGE Potential in the Conifer Lake Complex

Introduction

The Conifer Lake complex hosts mafic-ultramafic rock type and lies along a major regional structure which are characteristic features of the economically significant deposits along the Werner–Rex lakes fault. Two previously unrecognized inverse magnetic anomalies are discussed and these areas are recommended for exploration because they are consistent with the magnetic signature of mafic-ultramafic rocks. The complex is road accessible and is largely open for acquisition at the time of publication.

Geology, Mineralization and Geophysics

Mafic-ultramafic pods and lenses are documented throughout the English River subprovince (Breaks 1991) and tend to occur along major structures or as isolated bodies in the metasedimentary assemblages (Parker 1998). Along the deposits of Werner–Rex lakes fault, sulphide mineralization is disseminated within 0.5–180 m elliptical mafic-ultramafic pods or is remobilized into structural features within the country rock (Table 1; Scoates 1972; Parker 1998). The mafic-ultramafic pods along the Werner–Rex lakes fault are part of a syntectonic intrusion, where the intrusion has been tectonically dismembered into pods that have been structurally aligned (Parker 1998). A structural study by Hrabi and Cruden (2006) places the Werner-Rex lakes fault along regional post D_2 lineation that extends roughly 40 km from the Ontario–Manitoba border to the Conifer Lake complex (Figure 1).

Table 1. Resources in the Werner–Rex lake fault area. Resources are historic unless specified (*modified from* Parker 1998; AGP Mining Consultants Inc. 2018).

	Historic resources				
Deposit	**Tonnage ('000 t)**	**Ni (%)**	**Cu (%)**	**Co (%)**	**Au (gpt)**
Gordon Lake	170	0.85	0.50	-	-
Norpax	1000	1.20	0.50	-	-
Werner Lake (*)	64.2	-	0.24	0.43	0.22

(*) Indicated and Inferred Resources

In the Conifer Lake complex, only the Conifer Lake stock has been subject to historical exploration activity and subsequently has documented assessment work. Diamond drilling of 2 holes into the stock intersected dominantly granitic rocks with secondary pyroxenitic and/or gabbroic intervals ranging from one to several metres thick and returned trace sulphide (Walker and Wilson 1993; Brozdowski et al. 2010). Rock samples

Amyotte, E.G. 2022. Ni-Cu-PGE potential in the Conifer Lake complex; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2021–2022, p.69-72.

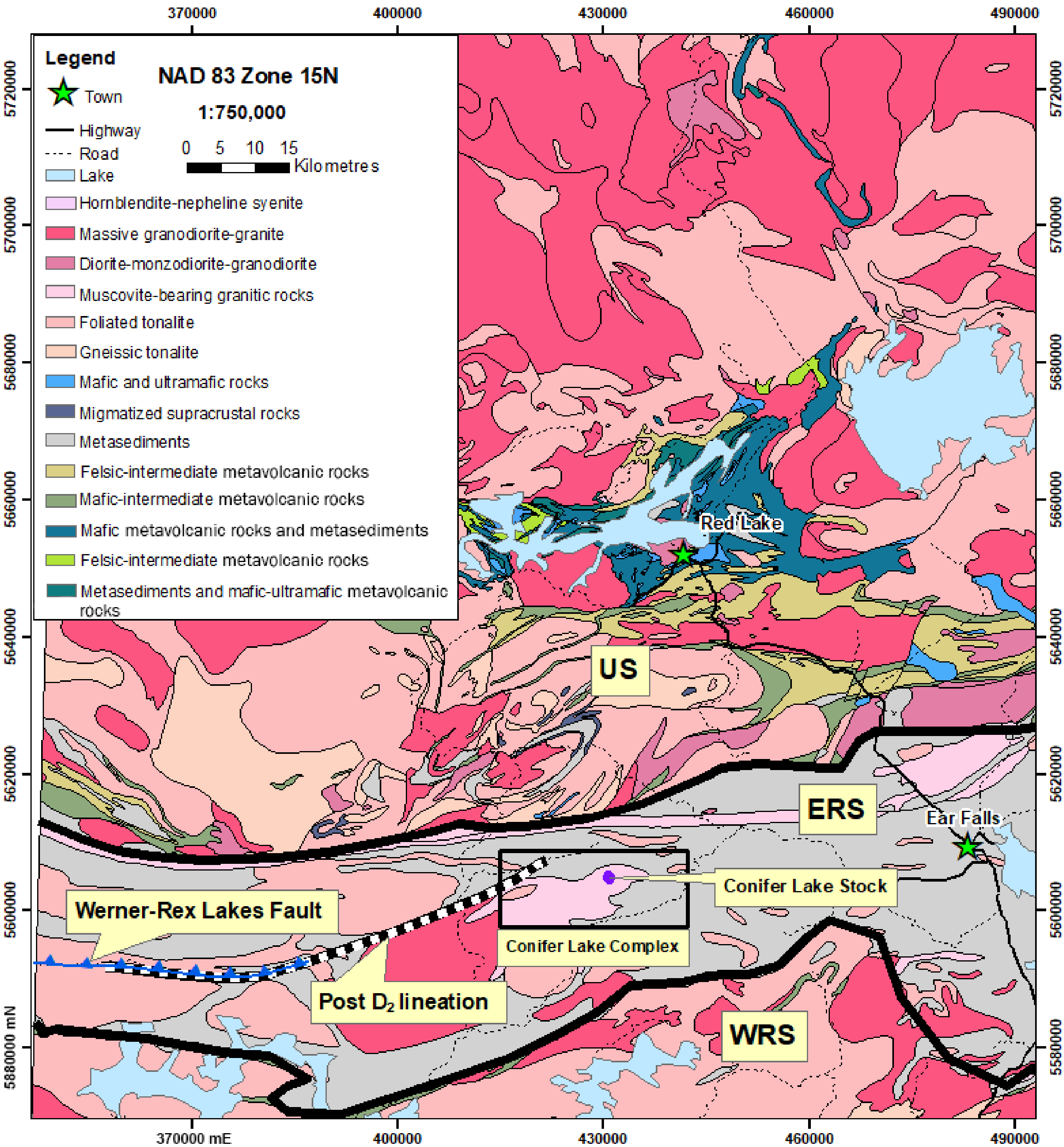

Figure 1. Regional geology map of the Conifer Lake complex and Werner–Rex lakes fault area. Abbreviations: US, Uchi subprovince; ERS, English River subprovince; WRS, Winnipeg River subprovince (*modified from* Hrabi and Cruden 2006, Ontario Geological Survey 2011). Subprovince boundaries are shown in heavy black lines.

collected in the Conifer Lake stock area contained coarse-grained olivine-pyroxenite, pyroxenite, hornblendite and lherzolite, determined petrographically to contain 0.1-1% three-phase pyrrohotite-chalcophyrite-pentlandite immiscible sulphide blebs (Oz Minerals Ltd, unpublished data, Shannon 2009).

The 2017 Ontario Geological Survey's Separation Lake geophysical survey revealed a series of inverse magnetic anomalies in the Conifer Lake complex, including the Conifer Lake stock (Figure 2). The anomalies are generally circular, range from 600-2000 m in diameter, and have magnetic high rims which distinguish them from the dominantly weakly magnetic metasedimentary country rocks. Field mapping in the vicinity of the stock suggests the magnetic high rims are granitic (Brozdowski et al. 2010). The inverse magnetic anomaly of the Conifer Lake stock may be explained by lack of magnetite in the mafic-ultramafic rocks.

Discussion

Previous exploration work in 1993 and 2010 focused on the immediate vicinity of the Conifer Lake stock. Workers in 1993 conducted diamond drilling of 2 holes totalling 218 m into the stock, possibly to test the disseminated sulphide potential as observed at the Werner–Rex lakes fault deposits (Walker and Wilson 1993). In 2010, workers conducted a field mapping and sampling program seeking mafic intrusion-hosted nickel-copper (Ni-Cu) magmatic sulphide mineralization (Brozdowski et al. 2010), likely to follow up on trace sulphide mineralization that was intersected within mafic intervals in the historic diamond drilling (Walker and Wilson 1993).

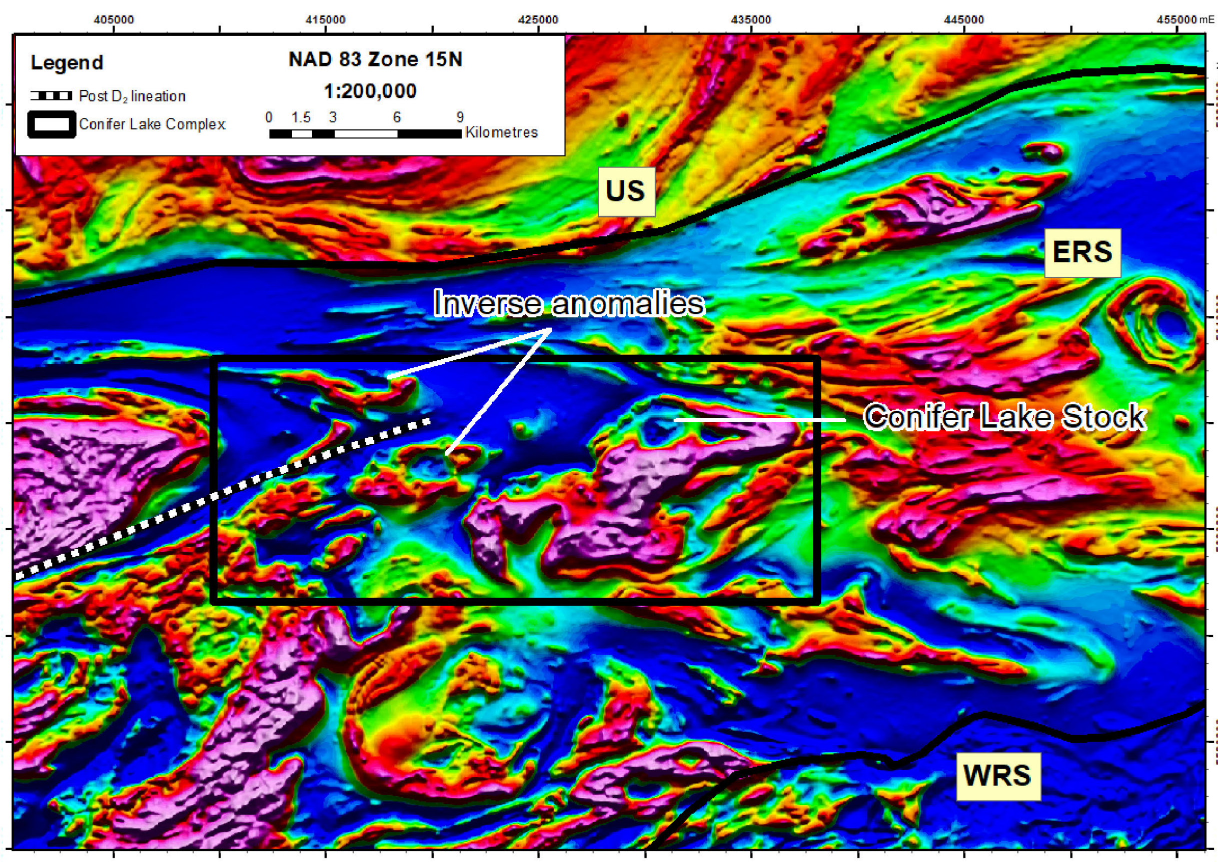

Figure 2. Residual total magnetic field map (*modified from* Ontario Geological Survey 2017) showing inverse magnetic anomalies in the Conifer Lake complex, including the Conifer Lake stock. Abbreviations: US, Uchi Subprovince; ERS, English River Subprovince; WRS, Winnipeg River Subprovince (*modified from* Hrabi and Cruden 2006). Subprovince boundaries are shown in heavy black lines.

While the Conifer Lake stock and deposits along the Werner-Rex lakes fault present similar intrusive mafic-ultramafic rocks and lie along the same major structure, there is a dissimilarity in the morphology of the mafic-ultramafic rocks in the respective areas. The Conifer Lake stock seems to represent an intact intrusion whereas at the Werner–Rex lakes fault deposits, the mafic-ultramafic rocks are remnants of an intrusion which has been tectonically dismembered and realigned (Scoates 1972; Parker 1998). The lack of tectonic dismemberment of the Conifer Lake stock presents the possibility that the intrusions of the Conifer Lake complex may be more closely associated with their underlying parental rocks, which can be targets for dynamically emplaced or basally accumulated intrusion-hosted nickel-copper-platinum group element (Ni-Cu-PGE) magmatic sulphide mineralization.

Conclusion

Mafic-ultramafic intrusive rocks observed along major structures in the English River subprovince represent prospective targets for Ni-Cu-PGE exploration. The Conifer Lake complex meets this criteria and underexplored mafic-ultramafic rocks may yield favorable assay results. To better understand the potential for mineralization within the Conifer Lake complex, future work could attempt to genetically relate the mafic-ultramafic rocks between the Conifer Lake complex and the Werner–Rex lakes fault deposits.

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Notes

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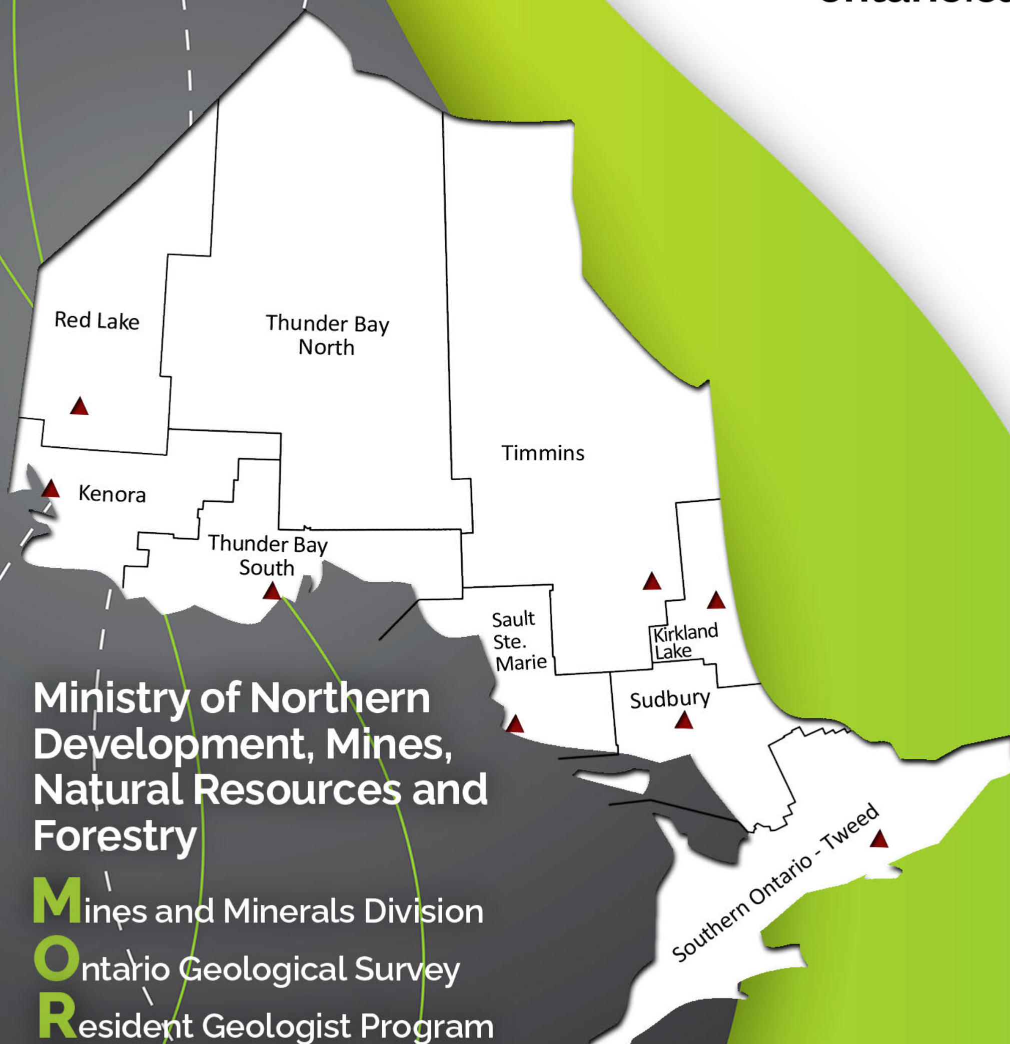

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