Recommendations for Exploration 2019–2020

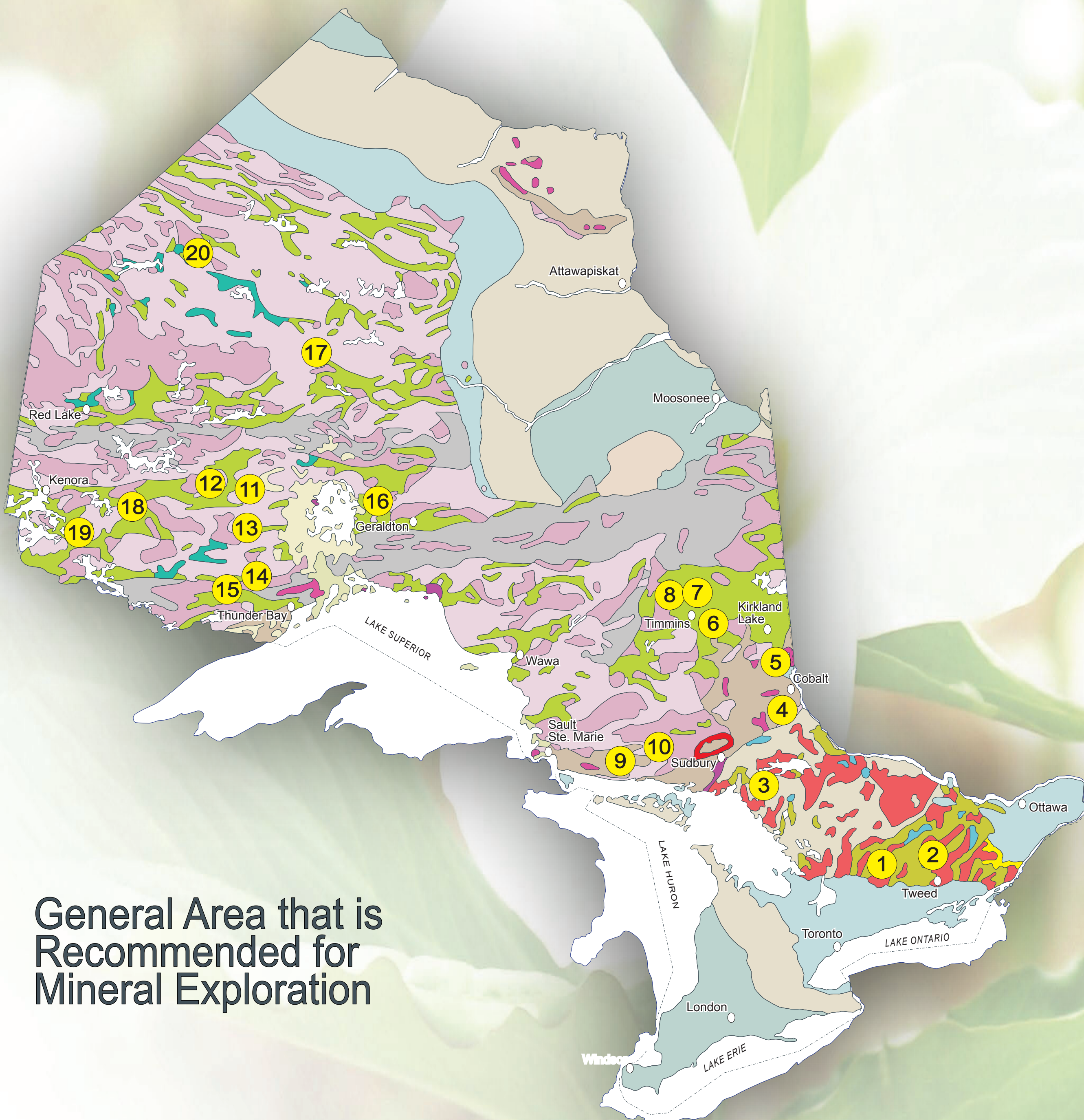
Ministry of Energy, Northern Development and Mines
Ontario Geological Survey
Resident Geologist Program

ONTARIO CANADA

Ontario

Recommendations for Exploration

2019-2020



General Area that is Recommended for Mineral Exploration

ONTARIO CANADA

Ontario

Photo courtesy of Karen Labonte

Ontario Geological Survey
Resident Geologist Program
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The Ontario Geological Survey is pleased to issue its 2020 Recommendations for Exploration. These recommendations are the product of the Ministry of Energy, Northern Development and Mines' dedicated and knowledgeable staff located across the province.

Each year, recommendations are developed based on the wealth of geological and exploration data available to our staff (and you) and any new information or concepts derived from the current year's activities.

Please review our current recommendations and feel free to discuss these in detail with any of our geoscientists.

Visit OGSEarth on the Ministry's Mines and Minerals Division Web site (www.ontario.ca/ogsearth) to see what else is available.

Rohan Millar
Senior Manager
Resident Geologist Program
Ontario Geological Survey
Ministry of Energy, Northern Development and Mines
Suite B002, 435 James Street South
Thunder Bay ON P7E 6S7
Tel. 807-475-1181
Email: Rohan.Millar@ontario.ca

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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 .

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.

Contents

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:

Puumala, M.A., Cundari, R.M. and Dorado–Troughton, M. 2020. Platinum group element potential in Thunder Bay north and south districts; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.53-56.

HIGHLIGHTS

- **More than 200 years of history of dimension stone production in southern Ontario**
- **Increasing interest in stone as a "green" building material**
- **Proven production from all geological regions of southern Ontario**
- **Good transportation infrastructure for moving large volume, large tonnage products and proximity to major residential markets**

Contact:

Peter LeBaron
Tel: 613-478-2195
Email: Peter.Lebaron@ontario.ca

Southern Ontario Stone: The Original "Green" Building Material

Dimension stone production in southern Ontario began during early European settlement of the province (Goudge 1938) and increased rapidly with the construction of the Rideau and Welland canals from local sandstone and limestone in the early 1800s (Hewitt 1964a). The stone industry in southern Ontario remains strong, with 60 quarries producing stone from both Paleozoic and Precambrian rocks, primarily for small building stone blocks (ashlar), flagstone, landscaping stone, polished tiles and armour stone (Tessier et al 2019).

Southern Ontario is well-situated with respect to excellent transportation networks (roads, rail and Great Lakes shipping) and close to large residential markets in eastern Canada and the northeastern United States.

Market Outlook

A new report on the global dimension stone market by Technavio Research states that the global construction stone market is anticipated to expand at a compound annual growth rate of 4% during the period 2019-2023, due in part to the growing emphasis on construction practices and their impact on the environment (Global Dimension Stone Market 2019-2023 | Rapid Shift Toward Sustainability is Driving Demand, November 20, 2018 | Technavio; www.businesswire.com accessed October 22, 2019).

Advantages of Natural Stone

The properties of durability, high strength, low maintenance cost, high thermal mass (contributes to passive heating and cooling) and the potential for recycling as building stone or aggregate are factors in the increasing preference for stone in construction projects (Marketwatch, press release April 2019, Construction Stone Market 2019 to Rise at CAGR of 9% Through 2023: Global Industry Overview By Size, Share, Trends, Growth Factors, Historical Analysis and Industry Segments Poised for Rapid Growth; https://www.marketwatch.com accessed October 22, 2019).

Leadership in Energy and Environmental Design (LEED) is a rating system for construction projects that awards points for reaching environmental standards with respect to site selection, water and energy efficiency and materials selection. The Canada Green Building Council provides links to government rebates and incentives that are designed to encourage LEED practices (https://www.cagbc.org/CAGBC/Programs/LEED/Incentives.aspx). One of the criteria for accumulating LEED points is the use of local building products, to reduce environmental impacts resulting from transportation. The local "region", as defined by LEED Canada, extends to a radius of 800 km from the project site (LEED Canada For New

LeBaron, P.S. 2020. Southern Ontario stone: The original "green" building material; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.1-6.

Construction and Major Renovations 2009, Rating System; https://www.cagbc.org/cagbcdocs/LEED_Canada_NC_CS_2009_Rating_System-En-Jun2010.pdf). All stone quarried in southern Ontario, between Windsor and Cornwall (800 km) and from Lake Erie to Sudbury (500 km) qualifies for LEED points as construction material for projects located within the southern region.

Dimension Stone Potential in Southern Ontario

Dimension stone quarries are licensed and regulated under the Aggregate Resources Act (ARA), administered by the Ministry of Natural Resources and Forestry. Private land must be acquired by purchase or by agreement with a landowner for extraction under the ARA. On Crown land, a mining claim must be registered and brought to Mining Lease under the Mining Act prior to issuance of an aggregate licence (https://www.ontario.ca/page/aggregate-resources).

Figure 1 shows the distribution of active dimension stone quarries and the general geology of southern Ontario. The 3 major geological subdivisions within southern Ontario—the Central Gneiss Belt (CGB), Composite Arc Belt (CAB) and the Paleozoic rocks (P) of the St. Lawrence Platform (Johnson et al. 1992)—each have distinct potential for dimension stone based upon predominant lithologies and structural history, as outlined below.

Paleozoic

The highest concentration of dimension stone quarries in southern Ontario is in the Owen Sound to Wiarton area on the Bruce Peninsula (Figure 1). Most quarries are within the Eramosa Member of the Middle Silurian Amabel Formation, a laminated dolostone. Although not technically a marble, the stone is often referred to as "Eramosa Marble" in the dimension stone trade (Rowell 2015).

The minor escarpment along the northern boundary of the Paleozoic bedrock area that extends from Kingston to Orillia area is host to several clusters of limestone dimension stone quarries. The preferred stone is limestone of the Ordovician Gull River Formation, a white-weathering, compact limestone which is well-represented in the buildings of Queen's University and the Royal Military College in Kingston, as well as in many municipal buildings and churches throughout southern Ontario (LeBaron and Williams 1990). The quarries are concentrated in the Orillia, Buckhorn, Tweed, and Kingston areas.

Sandstone of the Lower Devonian Whirlpool Formation is quarried in the Brampton area west of Toronto. Locally known as Credit Valley stone, it was used in the construction of the Parliament Buildings at Queen's Park in Toronto (Parks 1912). Sandstone is also quarried near Kingston from the Cambrian Nepean Formation at the base of the Paleozoic sequence and is exposed in many locations along the Paleozoic–Precambrian boundary south of the CAB in the Kingston area and north of the CAB in the Brockville–Perth areas (Keith 1946).

Composite Arc Belt

Precambrian granitic intrusive rocks and marbles have been quarried for dimension stone in the Composite Arc Belt of southern Ontario (*see* Figure 1).

Granite was quarried on islands in the St. Lawrence River near Gananoque in the late 1800s and used in the construction of Boldt Castle (https://boldtcastle.wordpress.com/). Pink to dark red granite was quarried for dimension stone near Lyndhurst and Battersea, north of Gananoque, intermittently into the 1980s (LeBaron et al. 1990). The Gananoque area lies within the Frontenac Terrane of the CAB, an area of granulite facies metamorphism (Easton 1992). The high metamorphic grade reflects temperatures and pressures which may have produced partial melting of the rocks, allowing late tectonic plutons to intrude under low stress conditions and resulting in relatively limited joint patterns (LeBaron et al. 1990). The granitic and syenitic plutons of the Frontenac Terrane are host to several former producers and are recommended for exploration for dimension stone.

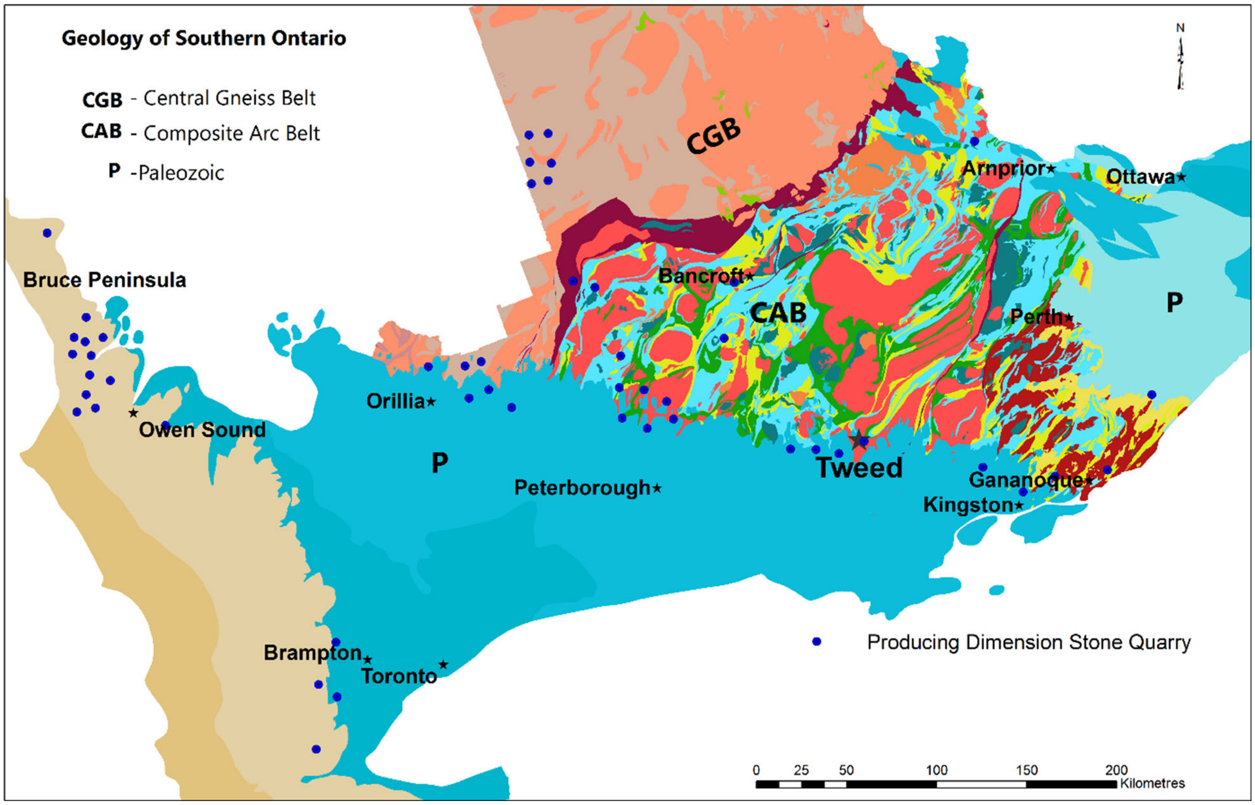

Figure 1. Geology of southern Ontario showing locations of producing dimension stone quarries (Geology *from* Ontario Geological Survey 2011; geological subdivisions *from* Easton 1992; quarry locations *from* Tessier et al. 2019).

Marble dimension stone was produced in the Arnprior area from about 1840–1900 and was used in the Parliament Buildings in Ottawa (Forsythe and Forsythe 2015). The Bancroft area was also an important marble quarrying centre from 1908 to about 1950, supplying much of the marble used for interior trim in the Parliament Buildings in Toronto and Ottawa (Hewitt 1964b).

Interest in marble quarrying was renewed in the 1960s and quarries were opened near Tweed and at Tatlock, north of Perth. The Tweed quarry, with a variety of white to green mottled marbles, was opened by the Ontario Marble Company and operated intermittently from 1963 to 1998 (Mineral Deposit Inventory file # MDI31C11SW0004, Ontario Geological Survey 2019). Polished stone panels from the quarry were used for interior walls of the Canada Trust Building in Toronto and the Royal Alberta Museum in Edmonton (Ontario Marble Company, undated brochure, Resident Geologist's Office, Tweed). The Omega marble quarry produced blocks of banded white, blue and pink marble from 1962–1971, marketed under the trade name, "Rideau Blue" (Storey and Vos 1981, Photo 1). The marble belts of the CAB host calcitic and dolomitic marbles with a wide range of colours and textures.

Central Gneiss Belt

The Central Gneiss Belt (*see* Figure 1) consists mainly of upper amphibolite and granulite facies, quartzofeldspathic gneisses, predominantly of igneous origin with subordinate paragneiss (Easton 1992). Numerous quarries have operated in the gneissic rocks since at least 1925, producing flagstone, landscaping stone and building stone (Hewitt 1964c). Several quarries continue to operate in the southern part of the CGB (*see* Figure 1).

Photo 1. "Rideau Blue" marble, Omega marble quarry; section with water applied to enhance colour is about 1 m wide (photo by P. LeBaron).

New Potential – Thin Stone Veneer

Thin stone veneer is split-face stone cut to a thickness of about 2 to 4 cm that gives the appearance of natural stone blocks at a much lower cost and weight than standard 10 to 15 cm thick ashlar (Penn 2006). Many deposits of limestone, dolostone, sandstone and gneiss in southern Ontario that may be unsuitable for large quarry block extraction due to excessive jointing may be suitable for thin stone production (Sangster et al. 2007).

There is potential for multiple products from a dimension stone operation. Waste rock from a granite dimension stone quarry may have use as construction or road-surfacing aggregate. Waste rock from marble and gneiss quarries that may not meet construction aggregate specifications has potential for use as decorative aggregate, particularly in the case of white or coloured marbles.

Selected References – Southern Ontario Dimension Stone Publications

The following reports document the results of several dimension stone studies conducted through the 1980s and 1990s by staff of the Resident Geologist Offices. The studies included both research and field investigations; sample cutting and polishing; and ASTM (American Society for Testing and Materials) testing for physical properties of the samples and provide more detailed recommendations for exploration.

Fouts, C.R. and Marmont, C. 1989. Gneisses of the Parry Sound–Muskoka area: flagstone resources; Ontario Geological Survey, Open File Report 5725, 72p.

LeBaron, P.S., Verschuren, C.P., Papertzian, V.C. and Kingston, P.W. 1990. Building stone potential in eastern Ontario; Ontario Geological Survey, Mineral Deposits Circular 30, 368p.

LeBaron, P.S. and Williams, D.A. 1990. Carbonate building stone resources of the Lake Simcoe–Kingston area, southeastern Ontario; Ontario Geological Survey, Open File Report 5730, 65p.

Marmont, C.R. 1991. Building stone, feldspar and limestone resources in central Ontario; Ontario Geological Survey, Open File Report 5760, 499p.

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Penn, M.W. 2006. Thin stone; article *in* Building Stone Magazine, v.29, no.2, summer 2006 issue.

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Sangster, P.J., Steele, K.G., LeBaron, P.S., Laidlaw, D.A., Lee, C.R., Carter, T.R. and Lazorek, M.R. 2007. Report of Activities 2006, Resident Geologist Program, Southern Ontario Regional Resident Geologist Report: Southeastern and Southwestern Ontario Districts, Mines and Mineral Information Centre, and Petroleum Resources Centre; Ontario Geological Survey, Open File Report 6206, 68p.

Storey, C.C. and Vos, M.A. 1981. Industrial minerals of the Pembroke–Renfrew area, Part 1: Marble; Ontario Geological Survey, Mineral Deposits Circular 21, 132p.

Tessier, A.C., LeBaron, P.S., Smith, A.C., Laidlaw, D.A., Bousquet, P. and Fortner, L. 2019. Report of Activities 2018, Resident Geologist Program, Southern Ontario Regional Resident Geologist Report: Southeastern Ontario and Southwestern Ontario Districts and Petroleum Operations; Ontario Geological Survey, Open File Report 6356, 94p

HIGHLIGHTS

- **Area hosts numerous stratiform, volcanic-associated sulphide deposits interpreted as VMS origin, some with significant zinc content**
- **Volcanic assemblages, some including FII and FIII rhyolites, are widespread throughout Grenville Province terranes in southeastern Ontario**
- **Minimal previous exploration utilizing modern exploration techniques aimed at VMS targets**

Contact:

Peter LeBaron
Tel: 613-478-2195
Email: Peter.Lebaron@ontario.ca

VMS Zinc Potential in the Grenville Province, Southeastern Ontario

Past production of zinc in southern Ontario is limited to the Long Lake zinc mine, a small, high-grade, marble-hosted deposit that produced 100 000 tonnes of ore averaging 11.6% Zn from 1973 to 1974 (Carter 1984). Several other carbonate-hosted zinc prospects in southern Ontario, thought to be of sedimentary exhalative origin, are described in Tessier et al (2019). Zinc occurrences are also associated with stratabound, pyritic sulphides in siliceous metasediments within or proximal to volcanic sequences, indicating a potential for volcanogenic massive sulphide (VMS) zinc mineralization in the Grenville Province of southeastern Ontario. The geology of southeastern Ontario and locations of the major stratabound, volcanic-associated sulphide deposits are shown in Figure 1.

Geology of volcanic-associated sulphide deposits, southeastern Ontario

The stratabound sulphide deposits are iron-rich with lesser zinc, copper, gold and silver mineralization in which sulphides form massive to disseminated layers and lenses conformable with foliation and lithologic layering in the host rocks. Pyrite and, less commonly, pyrrhotite are the primary sulphides, with locally significant amounts of sphalerite and chalcopyrite. Most are hosted by siliceous, clastic metasedimentary rocks with or without interlayered carbonate metasediments, in proximity to a metavolcanic sequence. The host rock sequence may include mafic to felsic metavolcanic or volcaniclastic rocks (including rusty schists), pyritic and/or graphitic argillite, and garnetiferous amphibolite (Carter 1984).

Although there has been no past production of zinc in southeastern Ontario from a VMS-type deposit, a significant past producer is located within the Grenville Province on Grand Calumet Island, Quebec, about 1 km east of the Ottawa River (*see* Figure 1). The Calumet zinc deposit produced 4 million tonnes of ore averaging 5.8% Zn, 1.6% Pb, 70 g/t Ag and 3 g/t Au between 1942 and 1968 (Sangster 1970). The deposit lies within a package of mafic gneisses with arc-tholeiite geochemical affinities and biotite-sillimanite quartzofeldspathic gneisses which structurally overlie calcitic and dolomitic marbles (Easton 2014). Migmatitic gneisses in the mine sequence contain garnet, cordierite and gahnite. The host rocks, alteration assemblage and metallic minerals (sphalerite, galena and pyrrhotite) are consistent with a VMS origin of the deposit (Easton 2014).

Carter (1984) documents 35 stratabound sulphide deposits in southeastern Ontario. Two deposits are zinc prospects and several others were mined as pyrite ore bodies to produce sulphur and sulphuric acid prior to 1920. The major zinc prospects and 2 of the pyrite-producing areas are described below.

LeBaron, P.S. 2020. VMS zinc potential in the Grenville Province, southeastern Ontario; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.7-11.

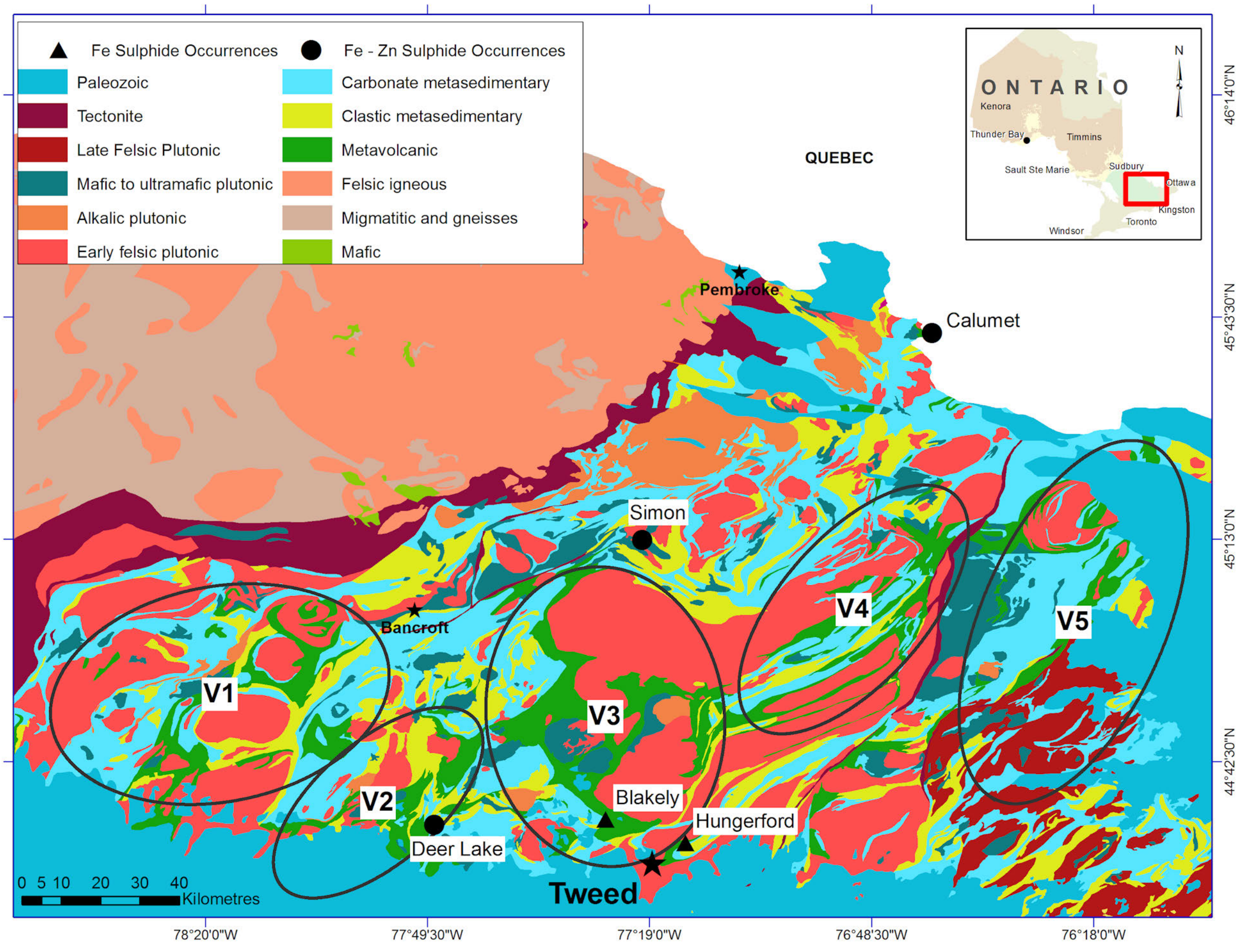

Figure 1. Geology of southeastern Ontario showing locations of major iron and zinc sulphide deposits and distribution of volcanic assemblages referred to in Table 1. (Geology *from* Ontario Geological Survey 2011; volcanic assemblages (V1 to V5) *from* Easton 1992).

- The Simon zinc-copper prospect in Lyndoch Township consists of several zones of massive to semi-massive sulphides totaling about 300 000 tonnes, averaging 1.1% copper, 4 to 5% zinc and 15 g/t silver (Taner 2008). It is hosted by amphibole-rich and quartz-feldspar-biotite–rich gneisses and is considered to be of VMS origin (Carter 1984). The main sulphide lens averages about 3 m thick, 180 m long and continues from surface to a depth of at least 100 m. Pyrrhotite is the predominant sulphide in the Simon prospect, with lesser amounts of chalcopyrite and sphalerite (Photo 1).
- The Deer Lake zinc-copper-silver prospect in Belmont Township consists of disseminated sulphides in a unit of rusty schist up to 50 m thick which has been tectonically thickened in the nose of a syncline to form a mineralized zone 200 to 250 m wide and up to 600 m long at surface. The zone occurs at the contact between a major volcanic sequence and overlying carbonate and siliciclastic sedimentary rocks. The mineralized sequence, lying above submarine basalts and subordinate intermediate pyroclastics, includes laminated mudstones, siltstones, pelitic sandstones and felsic tuffs, with minor interbeds of magnetite iron formation, chert, and thin seams of graphite. Pyrite, pyrrhotite, and minor sphalerite and chalcopyrite are disseminated throughout the metasediments in amounts ranging from 5 to 25%. All 8 diamond-drill holes that tested the zone between 1956 and 1968 encountered mineralization throughout the entire length, with values ranging up to 0.1% Cu, 1.13% Zn and 0.5 oz/ton (17 g/t) Ag (Carter 1984).

Four volcanic cycles have been identified in the Belmont Township area. The Deer Lake prospect is situated within Cycle III, however, stratiform sulphides within rusty metasediments in the upper parts of Cycles I and II are also anomalously enriched in base and precious metals (Bartlett and Moore 1985).

- The Madoc Township pyrite mines, the Blakely and Canadian Sulphur Ore, operated between 1908 and 1919. The 2 mines are about 2 km apart, and both are hosted by a succession of volcaniclastic metasediments, felsic to intermediate metavolcanics, garnetiferous amphibolite and rusty schists. Coarse felsic and intermediate pyroclastic rocks occur near both deposits at the top of a thick sequence of mafic metavolcanic rocks of the Tudor Formation (Carter 1984). Semi-massive pyrite, combined with fine-grained quartz, occurs in lenses up to 9 m wide and 20 m long. Although the sulphide zones were reported to be barren of other base and precious metals during the time of mining operations, Verschuren (1984) reported the presence of banded pyrite and sphalerite with significant jamesonite in a prospect pit about 70 m south of the Blakely open pit, from which a selected sample of heavily mineralized material assayed 1.3 oz/ton (44.5 g/t) Ag, 0.03 oz/ton (1.0 g/t) Au, 8.96% Zn and 0.34% Sb.
- The Hungerford pyrite area hosted 3 past-producing mines, located along the Sulphide Road about 7 to 10 km east of the village of Tweed. The Ontario Sulphur, Hungerford and Canada mines operated between 1903 and 1924 along a common horizon of sulphide-bearing, quartzofeldspathic gneiss between underlying mafic, locally pillowed metavolcanics and overlying siliceous, calcitic and dolomitic marble. The Hungerford deposit was the largest, consisting of 3 parallel lenses of massive pyrite, the largest of which was from 1.8 to 6.7 m wide, mined over a length of 190 m to a depth of 175 m (Hopkins 1916).

Photo 1. Massive sulphide intersection with pyrrhotite (brown), chalcopyrite (yellow) and sphalerite (dark grey) in Adroit Resources Inc. diamond-drill hole SC-20 (2007), Simon prospect, Lyndoch Township; from a section averaging 1.28% Cu and 0.38% Zn over 7.25 m, (Parry and Kleinboeck 2007); photo by P. LeBaron, August 2019.

Regional metamorphism in the Grenville rocks of southeastern Ontario ranges from greenschist to granulite facies (Easton 1992). Primary alteration halos such as argillic, sericitic and chloritic, are associated with VMS hydrothermal systems and may be subsequently altered by moderate- to high-grade regional metamorphism. The resulting metamorphic mineral assemblages may indicate proximity to a hydrothermal system and can be vectors to a VMS deposit. For example, suites of upper greenschist to amphibolite-facies minerals, including chloritoid, garnet, staurolite, kyanite, andalusite, phlogopite, and gahnite (zincian spinel), and upper amphibolite- to granulite-facies minerals such as sillimanite, cordierite, orthopyroxene, and orthoamphibole can define VMS hydrothermal alteration zones. Aluminous minerals (garnet, chloritoid, staurolite, kyanite, andalusite, and sillimanite) commonly occur close to high temperature alteration pipes (Dusel–Bacon 2012).

Distribution of metavolcanic assemblages

Easton (1992) subdivided the volcanic and volcaniclastic rocks into 5 main assemblages, based upon rock type, chemistry, related plutonic rocks, associated mineralization and geochronology (*see* Table 1). Figure 1 shows the distribution of of the various metavolcanic assemblages in southeastern Ontario. Assemblages V2 and V4 are more likely to host VMS deposits, with V3 and V5 more favourable for copper-nickel and gold deposits (Easton 1992). The V2 assemblage includes bimodal volcanic sequences, some of which are FII and FIII rhyolites, which are commonly associated with Archean VMS deposits (Easton 2017).

Table 1. Characteristic features of volcanic and volcanic–plutonic assemblages in the Grenville Province of southeastern Ontario (*from* Easton 1992).

Assemblage	Description	Age (Ma)	Tectonic Setting
V1	Basalt, dacite-rhyolite, pyroclastic rocks, related volcaniclastic rocks, tholeiitic to slightly alkalic chemistry. Mineralization: pyrite, rusty schists and black shales associated with the metavolcanics rocks locally show a variety of metal enrichment, including gold, copper, zinc. May be distal equivalent of assemblage V2.	?	?
V2	Basalt, andesite, dacite, rhyolite, abundant felsic pyroclastic rocks, related andesitic and dacitic volcaniclastic rocks; tholeiitic and calc-alkalic. Mineralization: pyrite, copper-zinc; associated rusty schists and black shales locally show a variety of metal enrichment, including gold, copper, lead, zinc, silver.	Volcanism 1260-1248 Plutonism 1245-1240	Back-arc and/or arc
V3	Basalt, gabbro sills, gabbro and pyroxenite plutons, mafic volcaniclastic sedimentary rocks, tholeiitic chemistry. Associated with gabbro-diorite-tonalite complexes and tonalite-granodiorite plutons; pillowed flows typically with very thin selvages; includes much of the classic Tudor Formation. Mineralization: gold, talc, copper, potential for copper-nickel.	Volcanism 1290-1285 Plutonism 1280-1270	Basal arc? and/or oceanic?
V4	Basalt, andesite, dacite, rhyolite, abundant pyroclastic rocks, volcaniclastic sedimentary rocks and quartzofeldspathic metasedimentary rocks; tholeiitic basalts and calc-alkalic, intermediate to felsic rocks. Mineralization: copper-zinc-pyrite.	<1270?	Arc and/or back-arc?
V5	Basalt, gabbro sills, mainly flows, minor mafic pyroclastic rocks, some exhalative rocks including black shales, sulphide-facies iron formation, pillowed flows typically with very thin selvages. Associated with gabbro-diorite intrusions; could be similar to V3 but not associated with large tonalite-granodiorite plutons. Mineralization: gold (particularly in deformed rocks), copper-zinc-pyrite; many zinc deposits are associated with dolomite marbles overlying the metavolcanics.	?	?

Summary

Stratabound sulphide deposits and occurrences, some of which are zinc-bearing, associated with volcanic assemblages and near volcanic-metasedimentary contacts in southeastern Ontario have been recognized as being of volcanogenic origin. There has been little exploration for zinc deposits since the 1970s, and very little modern exploration directed at the VMS model. Detailed prospecting, combined with geochemical and geophysical surveys in the vicinity of known occurrences and in extensions of the host rock sequences may assist in locating additional sulphide-rich zones, including barren iron sulphides which may be vectors to zinc mineralization.

Alteration assemblages including garnet, gahnite, cordierite, sillimanite and other aluminous minerals may indicate zones of hydrothermal alteration associated with VMS deposits in areas of moderate to high-grade regional metamorphism.

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HIGHLIGHTS

- **Feldspar is an extremely abundant mineral used in the manufacture of glass, ceramics, fillers, enamels and glazes, and specialty applications**
- **Feldspar is mined from granitoid and alkaline intrusive rocks (ranging from aplite through to pegmatite), anorthosites, gneisses and feldspathic sands**
- **Sudbury District: 71 Mineral Deposit Inventory records of feldspar occurrences, ranging from Occurrence to Past-Producing Mine with Resource, 65 of which are in pegmatites**

Contact:

Shirley Péloquin
Tel: 705-280-6042
Email: Shirley.Peloquin@ontario.ca

Feldspar in the Grenville Province, Sudbury District

Feldspar is an extremely abundant mineral group, making up approximately 60% of the earth's crust. It is used in the manufacture of glass, ceramics, fillers (paints, plastic, etc.), enamels and glazes, and specialty applications (United States Geological Survey 2019; Harben 2002; Industrial Minerals Association–Europe 2011). Glass and ceramics account for most of the global feldspar consumption (85 to 90%: Harben 2002), with glass overtaking ceramics in part because of the growth in solar glass production for use in solar panels (United States Geological Survey 2019). Future uses for feldspar currently under study are as fertilizer–potassic feldspar (Ciceri et al. 2019); as a source of aluminum–plagioclase feldspar, anorthosite (Knudsen, Wanvik and Svahnbert 2012); and in the production of CO_2 free cement–anorthosite (Hudson Resources Inc. 2018).

Feldspar is mined from granitoid and alkaline intrusive rocks (ranging from aplite through to pegmatite), anorthosites, gneisses and feldspathic sands (Harben 2002; Kangal et al. 2017; Industrial Minerals Association–Europe 2011). Harben (2002) gives the specifications for glass grade feldspar as 4 to 6 wt % K_2O, 5 to 7 wt % Na_2O, 19 wt % Al_2O_3, with Fe_2O_3 ≤0.08 wt %; and the specifications for ceramic and/or pottery grade feldspar as 4 to 14 wt % K_2O, with Fe_2O_3 ≤0.07 wt %.

In the Sudbury District there are 71 Mineral Deposit Inventory (MDI) records (more significant than Discretionary Occurrence) with feldspar as a primary commodity (Ontario Geological Survey 2019). Pegmatites account for 65 of those occurrences; anorthosites for 4; and gneisses for 2. Production and development have only occurred in pegmatites, and only pegmatite records are listed in Table 1.

The feldspar occurrences identified in the MDI records in the Sudbury Geologist District are located in the Grenville Province—mostly in the Southern Ontario Mining District. Approximately 13 500 km^2, representing 45% of the Grenville in the Sudbury District, is not affected by surface right holdings or land withdrawals. Of the 65 pegmatite feldspar MDI records, 11 are on open ground (Mining Lands Administration System (MLAS) data, October 7, 2019; Table 1; Figure 1).

Mining and development of feldspar prospects in the Sudbury District occurred between the 1910s and the 1940s. Hewitt (1952, 1967) provides a historical perspective of feldspar and pegmatites in Ontario. Both reports include tables of all known occurrences at the time. Marmot and Johnston (1987), and Vos, Smith and Stevenato (1981) also looked at pegmatites in their mineral deposit and industrial mineral studies, and include some mineral chemistry. A comprehensive report on pegmatite occurrences in southeastern Ontario, that includes the southern

Péloquin, A.S. and Kennedy, C.A. 2020. Feldspar in the Grenville Province, Sudbury District; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.13-17.

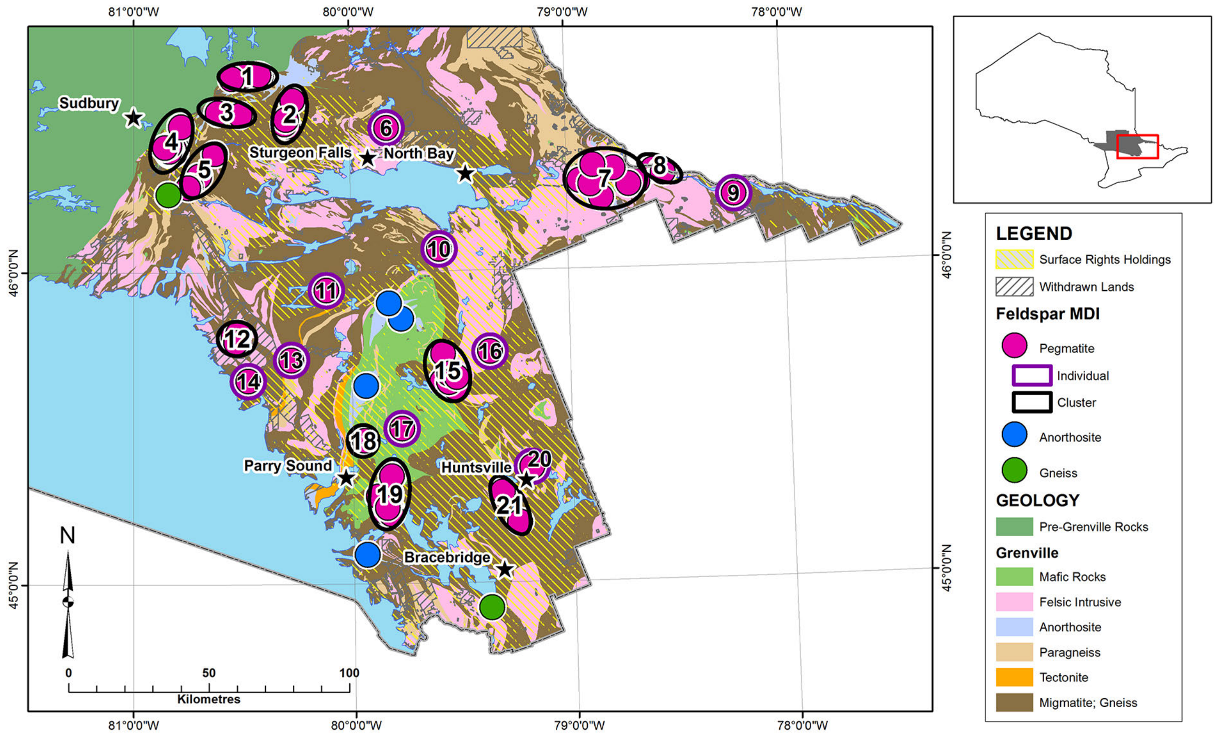

Figure 1. Map of Grenville Province feldspar occurrences (*see* Table 1; data *from* Mineral Deposit Inventory *in* Ontario Geological Survey 2019; region straddles UTM zones 17 and 18; geology *from* Ontario Geological Survey 2011).

part of the map in Figure 1, is given by Goad (1990). Ercit (1999) discusses the presence of niobium, tantalum and yttrium in the pegmatites of the Northern Grenville Province, indicating that they can be considered to fall into the niobium–yttrium–fluorine (NYF) series rather than that of lithium–cesium–tantalum (LCT) (Cerny and Ercit 2005). However, Cerny and Ercit (2005) caution that:

> …the assignment of pegmatite populations to the NYF or LCT signature does not necessarily mean that the elements characteristic of the other family are absent.

The past-producing feldspar mines in the Sudbury District are located close to the Grenville–Southern province boundary, whereas the developed prospects are more dispersed (*see* Table 1; Figure 1). The individual deposits were generally small, but pegmatites also occur in clusters (*see* Figure 1), and the possibility that there are previously unrecognized pegmatites in the vicinity of the isolated occurrences should be considered. The records also show that only 18 of the 65 pegmatite occurrences have been examined for other elements: uranium or thorium (n=10); rare earth elements (n=5); niobium (n=7); phosphate (n=3). This could be due to the time of the exploration and the availability of affordable analytical methods.

Recommendations

- Examine known pegmatite occurrences for feldspar potential, particularly in light of new applications, and for elements previously overlooked
- Explore area surrounding isolated feldspar occurrences for more pegmatites, defining a potential cluster of deposits that may be more favourable for development

Table 1. Feldspar occurrences in pegmatites, Grenville Province, Sudbury Resident Geologist District. Data *from* Ontario Geological Survey (2019). (Map # refers to numbers appearing on Figure 1).

Map #	Property Name	MDI Number	Host Rock	Occurrence Status	Land Status
1	Finlan Mines	MDI41I09NW00012	Pegmatite	Past Producer No Resources	Claim
1	Kabikotwia River E. Feldspar	MDI41I09NW00031	Pegmatite	Past Producer No Resources	Open
1	Wanup Feldspar	MDI41I09NW00013	Pegmatite	Prospect	Open
1	Loughrin Feldspar	MDI41I10SE00005	Pegmatite	Developed No Resources	Withdrawn
2	Deer Creek Pegmatite	MDI41I09SE00012	Pegmatite	Past Producer No Resources	Non-Mine Tenure
2	Carmichael, H.	MDI41I08NW00002	Pegmatite	Past Producer No Resources	Non-Mine Tenure
2	Consolidated Feldspar Mine Ltd	MDI41I08NW00005	Pegmatite	Developed With Resources	Non-Mine Tenure
2	Larcher Feldspar	MDI41I08NW00003	Pegmatite	Past Producer No Resources	Non-Mine Tenure
2	Lee, J.R.	MDI41I08NW00006	Pegmatite	Developed No Resources	Non-Mine Tenure
3	Veuve River Feldspar Deposit	MDI41I07NE00015	Pegmatite	Prospect	Non-Mine Tenure
3	Callum Feldspar Deposit	MDI41I10SE00013	Pegmatite	Developed No Resources	Non-Mine Tenure
4	McPhee	MDI41I07NW00003	Pegmatite	Past Producer No Resources	Non-Mine Tenure
4	Weisman Feldspar	MDI41I07NW00011	Pegmatite	Past Producer No Resources	Claim
4	Pelto, Oscar	MDI41I07NW00012	Pegmatite	Past Producer No Resources	Non-Mine Tenure
4	Wanup North	MDI41I07NW00013	Pegmatite	Occurrence	Non-Mine Tenure
4	Wanup Southwest	MDI41I07NW00009	Pegmatite	Occurrence	Non-Mine Tenure
4	Elizabeth Feldspar	MDI41I07NW00006	Pegmatite	Past Producer No Resources	Open
4	Northern Feldspar	MDI41I07NW00008	Pegmatite	Past Producer No Resources	Withdrawn
4	Vaillancourt Feldspar Quarry	MDI41I07NW00020	Pegmatite	Past Producer No Resources	Withdrawn
4	Wanup Feldspar	MDI41I07NW00007	Pegmatite	Past Producer No Resources	Withdrawn
5	Canada Flint & Spar Co.	MDI41I07NE00002	Pegmatite	Developed No Resources	Withdrawn
5	Graham Lake	MDI41I07SE00017	Pegmatite	Occurrence	Claim
5	Burwash Feldspar	MDI41I07SE00004	Pegmatite	Occurrence	Non-Mine Tenure
5	Mount Pleasant Mine	MDI41I07SE00003	Pegmatite	Developed No Resources	Open
6	Grant Feldspar	MDI31L05NW00004	Pegmatite	Occurrence	Withdrawn
7	Bergeron Mine	MDI31L02NW00002	Pegmatite	Prospect	Non-Mine Tenure
7	Harcourt & Patterson	MDI31L07SW00027	Pegmatite	Occurrence	Non-Mine Tenure
7	Purdy Mine	MDI31L07SW00006	Pegmatite	Developed No Resources	Non-Mine Tenure
7	Bobjo Mines Ltd.	MDI31L07SW00009	Pegmatite	Developed No Resources	Withdrawn
7	O'Brien & Fowler	MDI31L07SW00013	Pegmatite	Prospect	Non-Mine Tenure
7	Janveaux Property	MDI31L07SW00015	Pegmatite	Occurrence	Open
7	Lot 10 Conc. 9 Pit	MDI31L07SE00007	Pegmatite	Prospect	Non-Mine Tenure

Map #	Property Name	MDI Number	Host Rock	Occurrence Status	Land Status
7	Morin & Neault	MDI31L07SE00002	Pegmatite	Prospect	Non-Mine Tenure
8	Turcotte	MDI31L07SE00005	Pegmatite	Prospect	Non-Mine Tenure
8	J. Norreno	MDI31L07SE00003	Pegmatite	Prospect	Withdrawn
8	Turcotte Occurrence	MDI31L08SW00003	Pegmatite	Prospect	Withdrawn
9	Dewar & Gibson	MDI31L01NE00002	Pegmatite	Prospect	Open
10	Holden–Waltenbury	MDI31L04SE00003	Pegmatite	Prospect	Open
11	J. W. Keenan	MDI41H16NE00003	Pegmatite	Developed No Resources	Non-Mine Tenure
12	Mill Site A	MDI41H15SE00007	Pegmatite	Developed No Resources	Non-Mine Tenure
12	Ambeau Mine	MDI41H15NW00002	Pegmatite	Developed No Resources	Withdrawn
12	Besner Mine	MDI41H15SE00014	Pegmatite	Developed No Resources	Withdrawn
13	Magnetawan Feldspar Syndicate	MDI41H09NW00002	Pegmatite	Prospect	Non-Mine & Mine Tenure
14	General Mica Mining Co.	MDI41H09SW00003	Pegmatite	Occurrence	Withdrawn
15	Blue Star Mine	MDI31E12NE00022	Pegmatite	Occurrence	Non-Mine Tenure
15	Carmen Lake	MDI31E12NE00004	Pegmatite	Occurrence	Non-Mine Tenure
15	Cecebe Lake Quarry	MDI31E12NE00003	Pegmatite	Prospect	Non-Mine Tenure
15	Macdonald Mine	MDI31E12NE00008	Pegmatite	Prospect	Non-Mine Tenure
15	T.B. Tough	MDI31E12SE00005	Pegmatite	Prospect	Non-Mine Tenure
15	W. E. Brandt	MDI31E12NE00009	Pegmatite	Occurrence	Non-Mine Tenure
16	Bernard Lake Sunstone	MDI31E14SW00008	Pegmatite	Occurrence	Non-Mine Tenure
17	C. F. McQuire Pegmatite	MDI31E05NW00011	Pegmatite	Developed No Resources	Open
18	Bloom	MDI000000000618	Pegmatite	Prospect	Non-Mine Tenure
18	McDougall	MDI000000000617	Pegmatite	Prospect	Non-Mine Tenure
19	Industrial Minerals Corp. Feldspar	MDI31E05SW00003	Pegmatite	Prospect	Open
19	Brignall Mine	MDI31E04NW00010	Pegmatite	Prospect	Non-Mine Tenure
19	Conger Feldspar Mining Co.	MDI31E04NW00016	Pegmatite	Prospect	Non-Mine Tenure
19	Lot 10 Conc. 3 Feldspar	MDI31E05SW00004	Pegmatite	Occurrence	Non-Mine Tenure
19	McQuire Mine	MDI31E04NW00020	Pegmatite	Prospect	Non-Mine Tenure
19	Opeongo Mining Co.	MDI31E04NW00015	Pegmatite	Prospect	Non-Mine Tenure
19	Ojaipee Silica-Feldspar Co.	MDI31E04NW00008	Pegmatite	Prospect	Open
19	Standard Feldspar & Silica Co.	MDI31E04NW00012	Pegmatite	Occurrence	Open
20	International Ceramic	MDI31E06SE00076	Pegmatite	Occurrence	Non-Mine Tenure
21	McKay & Hammond	MDI31E06SW00007	Pegmatite	Occurrence	Non-Mine Tenure
21	McIntyre	MDI31E03NW00002	Pegmatite	Occurrence	Non-Mine Tenure

Acknowledgments

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HIGHLIGHTS

- **Past-producing mines, developed mineral prospects, and Au, Cu, Ni, Zn showings**
- **Exploration dormant for at least a decade**
- **New mineralization related to northeast-trending fault**

Explore for Gold and Copper in Briggs Township, Temagami Greenstone Belt

The Temagami greenstone belt (the Belt) is located approximately 40 km north of the Grenville Province in eastern Ontario. It has been described as an isolated, southerly exposure of the Abitibi Subprovince (Bowins and Heaman 1991). The Belt has been previously described by workers that include Moorehouse (1946), Bennett (1978) and Fyon and Cole (1989).

Strathy–Chambers–Briggs–Strathcona is a block of 4 contiguous townships in the Belt that is currently being mapped by the Earth Resources and Geoscience Mapping Section (ERGMS) of the Ontario Geological Survey. The resulting updated bedrock maps are expected to shed light on the chrono-stratigraphic assemblages, mineral potential, and the early volcano-tectonic evolution of the Belt. Although there are past-producing mines (Table 1), developed mineral prospects, and several gold, copper, nickel and zinc showings, exploration activity in the Belt has generally been dormant for decades.

Table 1. Past-producing mines and production in the Temagami greenstone belt (*from* Shklanka 1969 and Basa 1990).

Mine	Township	Production	Years of Production
Kanichee	Strathy	99 284 lb Cu, 65 434 lb Ni, 37.0 oz Au, 910.0 oz Ag, 82.7 oz Pt, and 196.3 oz Pd	1936
Sherman	Chambers, Strathy, Strathcona	22 244 212 tonnes of Fe pellets	1968 – 1990
Temagami Copper	Phyllis	67 084 858 lb Cu, 10 155 oz Au, and 186 861 oz Ag	1955 – 1967

Exploration may face certain challenges in the area, including limited bedrock exposure due to thick overlying Cobalt group sedimentary rocks (900 to 1600 m, Gupta 1985), with certain land areas requiring special permits, or land is not open to exploration (Guindon 2015). However, some parts of the Belt are accessible and relatively favorable with respect to outcrop exposure. Perhaps, one good example is Briggs Township, which is the focus of this recommendation for exploration. In the southwest quarter of Briggs Township, Seal River Explorations, in April of 2017, completed an 8.5 line-km ground magnetic and induced polarization survey on the Lake Temagami Northeast Arm property (Ploeger 2017). Preceding this geophysical work was the completion, in 2007, of 4 diamond-drill holes totaling 1136 m on the Niemetz property, which is in the same quarter of the township. The highest assay results returned 0.29% copper over 1.25 m, and 0.48 g/t gold over 1.2 m, in diamond-drill hole NZ 04 (Lussier 2009).

Contact:

James Suma-Momoh
Tel: 705-568-4517
Email: James.Suma-Momoh@ontario.ca

Suma-Momoh, J. 2020. Explore for gold and copper in Briggs Township, Temagami greenstone belt; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.19-22.

Despite the promising results, there has been neither any follow up work on the property nor any reported work activity in the rest of the township for the past 12 years. Such a gap in time warrants further investigation.

Briggs Township is located approximately 150 km south of the town of Kirkland Lake, and 5 km west along the Lake Temagami Access Road from Highway 11 in the adjacent Strathcona Township. It lies in the southwestern quarter of the Belt and is part of the Northeast Arm of Lake Temagami (Figure 1).

Bennet (1978) reported that the main geological feature of the northeast Temagami area is a northeast-trending metavolcanic–metasedimentary belt of early Archean age. This belt averages approximately 13 km across and 29 km long. The dominant structure is that of a northeast-trending syncline deformed by emplacement of granitic plutons. A thick sequence of Algoma-type iron formation lies just above the main felsic to intermediate pyroclastic assemblage. A variety of metamorphosed gabbros and diorites, and felsic porphyries intrude the metavolcanics. The Archean rocks are mainly of lower greenschist facies metamorphism.

There are 4 documented base metal and precious metal Mineral Deposit Inventory (MDI) occurrences in Briggs Township, namely, copper and gold from the Mark Lake occurrence (MDI31L13NW00021); copper, gold and silver from the Sturdy occurrence (MDI31L13NW00019); nickel and copper from the Niemetz prospect (MDI31L13NW00020); and gold and silver from the Titanic discretionary occurrence (MDI31M04SW00098).

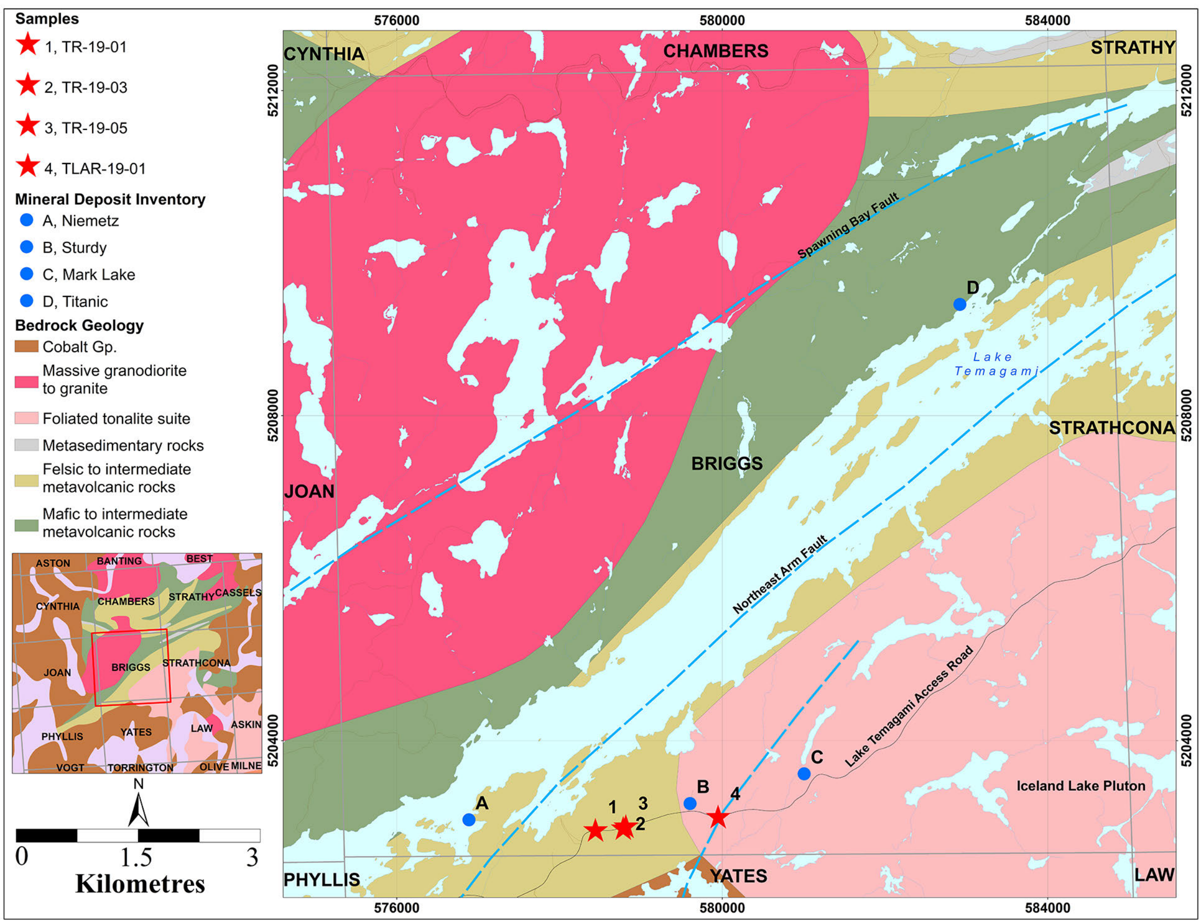

Figure 1. Geology map of Briggs Township showing documented Mineral Deposit Inventory (MDI) occurrences (*from* Ontario Geological Survey 2018) and selected sample locations. The inset township map shows part of the Temagami greenstone belt. Geology *from* Ontario Geological Survey 2011. Universal Transverse Mercator (UTM) co-ordinates are provided using North American Datum 1983 (NAD83) in Zone 17.

As part of the 2019 summer field activities, staff of the Resident Geologist Program visited the Sturdy and Mark Lake occurrences; and walked the entire length of Lake Temagami Access Road in the southern half of Briggs Township. The latter activity was undertaken with the primary intent to investigating the geology and any associated mineralization. The Sturdy showing is located on the Niemetz claims. It is a 3 m by 1 m outcrop of sheared and moderate to strong chlorite-epidote-altered basalt, displaying an average attitude of 38°/82° north. Finely disseminated pyrite and chalcopyrite mineralization occur along narrow (1 mm to <1 mm wide) epidote-fracture fills. A grab sample collected from the showing yielded 0.16% copper, 0.67 g/t gold, anomalous silver (2.34 g/t) and cobalt (107.3 ppm).

In connection to grab samples collected from outcrops along Lake Temagami Access Road, sample TLAR 19 01 yielded the best (so far, complete assays pending), returning 3.72g/t gold, 1.2% copper, and anomalous silver (10.84 g/t). The mineralization, which is possibly related to a northeast-trending fault (sample location 4 on Figure 1), consists of semi-massive to finely disseminated chalcopyrite occurring mainly along fractures (up to 7 mm wide), and subordinately as stringers (only up to about 1 mm wide) within the rock. Sometimes, the fractures are filled with carbonate-hosting malachite (Photo 1) and trace amounts of disseminated pyrite. Other selected sample assays are also given in Table 2.

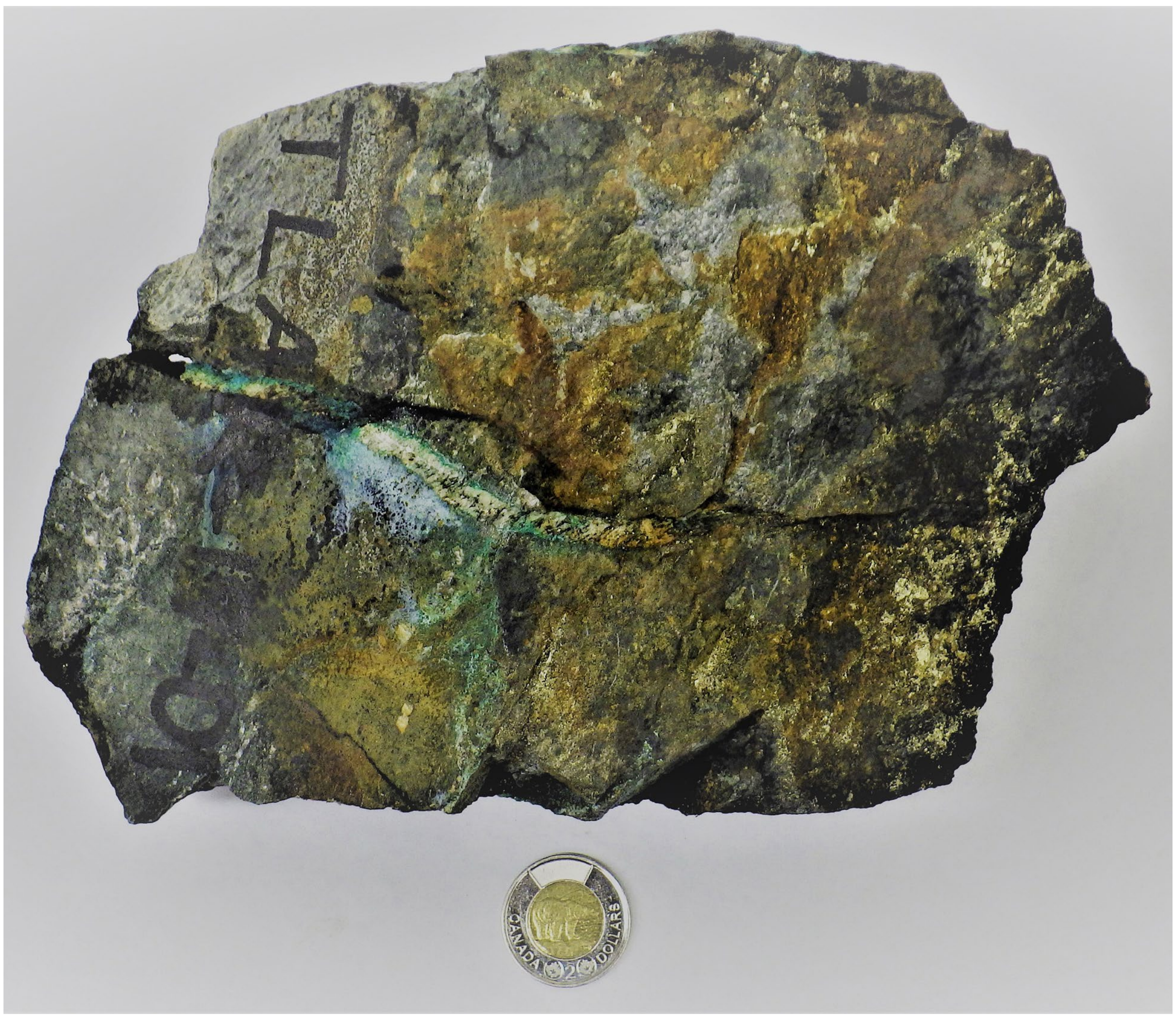

Photo 1. Sample TLAR-19-01 showing chalcopyrite on fractured face, and malachite in carbonate fracture fill. Sample co-ordinates: NAD83 579951 mE, 5203067 mN.

Table 2. Selected assays of grab samples from the Lake Temagami Access Road in Briggs Township. UTM co-ordinates are in NAD83.

Sample #	Easting (mE)	Northing (mN)	Gold (g/t)	Copper (%)	Silver (g/t)	Field Name
TLAR-19-01	579951	5203067	3.72	>1.2	10.84	tonalite
TR-19-01	578444	5202904	1.64	0.04	0.96	basalt
TR-19-03	578785	5202925	0.01	0.12	0.66	quartz vein
TR-19-05	578817	5202950	0.05	0.02	0.35	sandstone

Sulphide mineralization at the Mark Lake (sometimes known as Snowshoe Lake) occurrence consists of disseminated chalcopyrite in hornblende-quartz-diorite of the Iceland Lake pluton. Assay results of grab samples were pending at the time of writing. Historical assays of grab samples are reported as 0.08 oz/t (2.67 g/t) gold, 0.8 oz/t (26.67 g/t) silver, 0.96% copper, and trace amounts of lead, zinc and nickel (Bennett 1978).

To summarize, Briggs Township is located within the Temagami greenstone belt—an Archean greenstone belt which has historically produced copper, gold, silver, nickel, iron ore, platinum and palladium. Mineral exploration in the township has remained dormant for at least a decade. Assay results of grab samples collected from one of the showings and from along Lake Temagami Access Road in Briggs Township returned encouraging results, confirming the occurrence of both base and precious metals over a wide area. Further work is recommended to test for continuation of mineralization along the northeast-trending fault of the Iceland Lake Pluton, and within the mafic to intermediate metavolcanic rocks on the north side of the Northeast Arm of Lake Temagami.

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HIGHLIGHTS

- **Known diamondiferous occurrences present an excellent potential for discovery**
- **Relatively underexplored commodity in the Kirkland Lake District**
- **15 of 75 potential kimberlite targets available for staking**

Diamond Potential: Keating Anomalies to Delineate Kimberlites

Diamond exploration in the Kirkland Lake District has been relatively quiet for the past 20 years with most of the exploration having been completed in the late 1980s and early 1990s. This past spring however, interest in diamonds has grown because of the closure of the Victor diamond mine, the Province's sole producer. With this rise in interest, it seemed only fitting that kimberlites in the district should be revisited.

The objective of this study is to utilize publicly available data to delineate potential kimberlite targets in the Kirkland Lake District. As this is a baseline desktop study, the targets presented here should be considered as starting points only. The reader is reminded that kimberlite pipes serve as transport conduits for mantle-derived material, and that not all kimberlites are diamondiferous.

This study makes use of Keating correlation coefficients (KCC) as a means for kimberlite targeting. This tool is based on an algorithm derived by Keating (1995) for creating theoretical gravity and magnetic models of kimberlite pipes (vertical chimneys). It creates a representative model of a vertical pipe for a diameter (cylinder diameter) and buried depth (cylinder length) that can be preset. A cross-correlation kernel is then passed over an observed geophysical grid, comparing every cell with the measured signal. Only results with a correlation coefficient greater than 75% are retained, which would include both negative and positive correlation. This information is publicly available in the geophysical data set (GDS) series published by the Ontario Geological Survey (OGS) (Ontario Geological Survey 2002a, 2002b, 2003a-e, 2004, 2013).

It should also be noted that the larger the cluster of points and correlation value (of the KCC) the more favorable the target. Correlation values greater than 90% and a cluster size of 4+ points were used in this study. A simplified workflow used here for the analysis of Keating anomalies follows.

1. The OGS geophysical data for the area were downloaded, and the Keating *.csv* files were extracted, formatted and imported into GIS software as shapefiles.
2. Shapefiles were merged based on each focus area within the Kirkland Lake District (North Zone, Middle Zone and South Zone) and null values filtered out.
3. Merged shapefiles were queried for positive and negative correlation coefficients greater than 90%.
4. Queried shapefiles were manually scanned for point clusters of 4+ points and retained as targets.
5. Mining claim data was overlain, related to the targets and exported as a summary table.

Contact:

Peter Chadwick
Tel: 705-568-4518
Email: Peter.Chadwick@ontario.ca

Chadwick, P.J. 2020. Diamond potential: Keating anomalies to delineate kimberlites; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.23-29.

In the analysis presented here, 3 different target zones were chosen based on clusters of published Mineral Deposit Inventory (MDI) occurrences (Ontario Geological Survey 2019) of known kimberlite (both diamondiferous and non-diamondiferous) in addition to other non-kimberlite diamondiferous occurrences. These are shown in Figure 1 which includes a legend that applies to the maps of the individual target zones shown in Figures 2, 3 and 4. A detailed listing of individual targets is presented in Table 1.

Proposed Targets

The kimberlite targets shown in Figures 2, 3 and 4 are summarized in Table 1. Of the 75 targets, 15 are on lands open for staking, 2 are on First Nation reserves, 38 are on existing mining claims, 19 on current leases and patents and 1 is under a restriction notice (as of October 22, 2019).

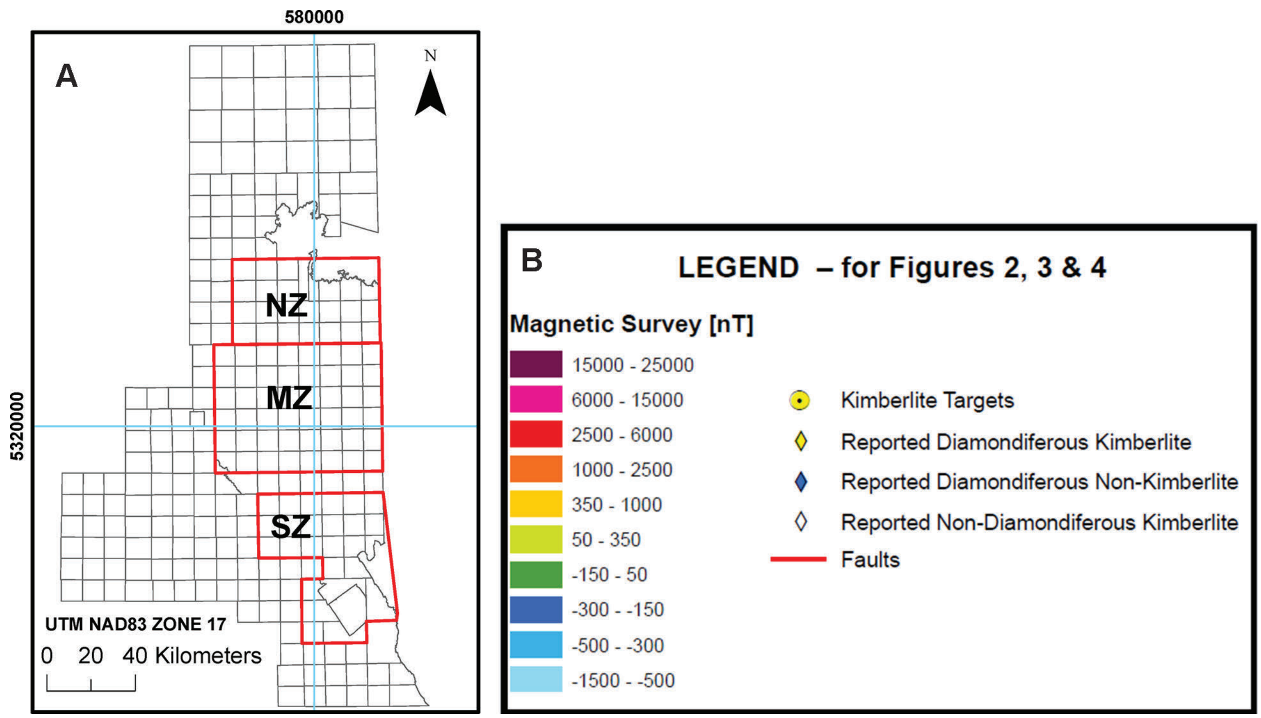

Figure 1. Simplified map of the Kirkland Lake District. **A)** Location map shows the target zones described in this study: North Zone (NZ), Middle Zone (MZ) and South Zone (SZ). **B)** Legend provides the description of symbols and the grid for the hill-shaded residual total magnetic intensity image in Figures 2, 3 and 4.

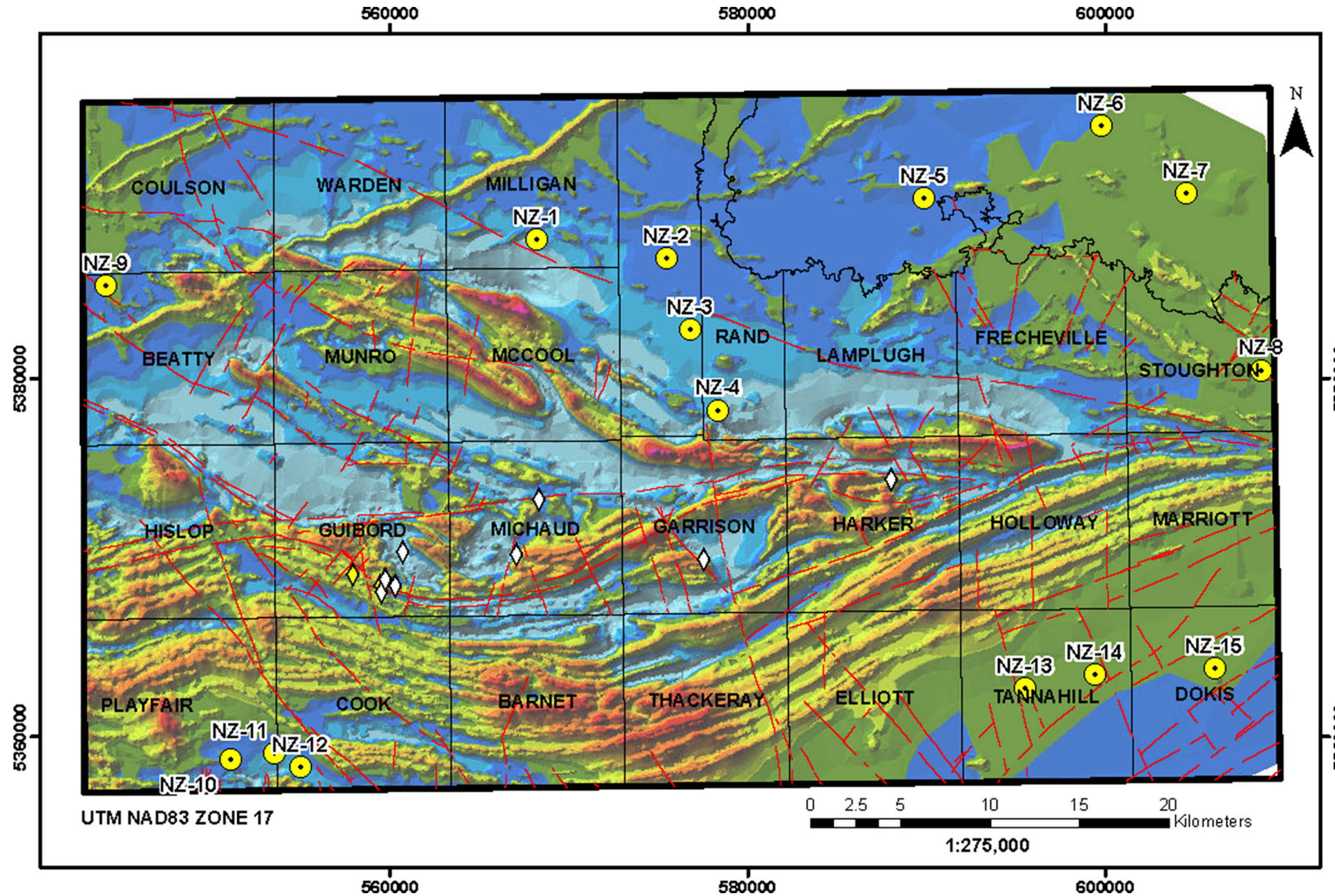

Figure 2. North Zone (NZ) kimberlite target map, showing the location of revised KCCs (Ontario Geological Survey 2003a, 2003b), layered over the hill-shaded residual total magnetic intensity image (Ontario Geological Survey 2017), structural data (Ayer and Chartrand 2011) and MDI points of reported kimberlite and diamond occurrences (Ontario Geological Survey 2019).

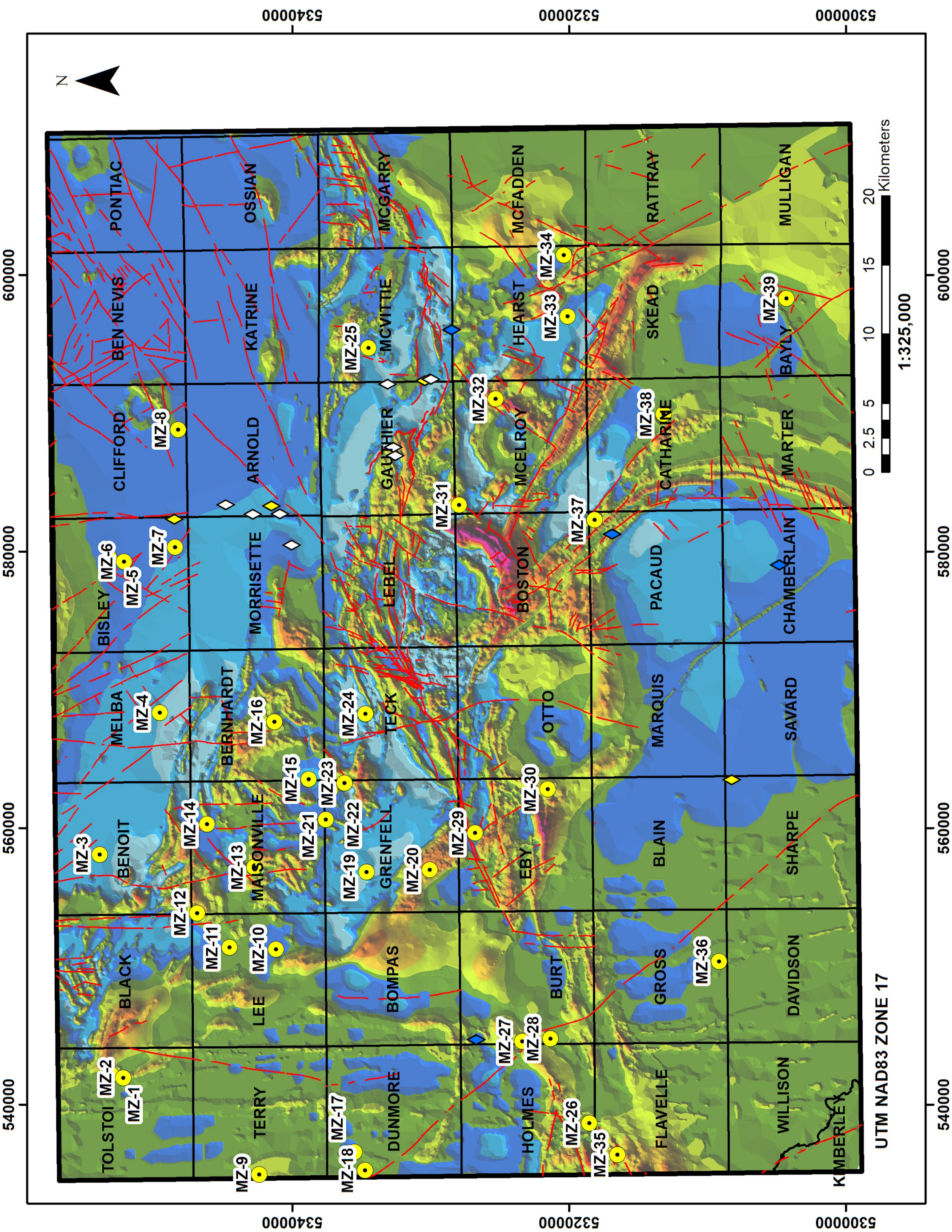

Figure 3. Middle Zone (MZ) kimberlite target map, showing the location of revised KCCs (Ontario Geological Survey 2002b, 2003b, 2003c, 2004), layered over the hill-shaded residual total magnetic intensity image (Ontario Geological Survey 2017), structural data (Ayer and Chartrand 2011) and MDI points of reported kimberlite and diamond occurrences (Ontario Geological Survey 2019).

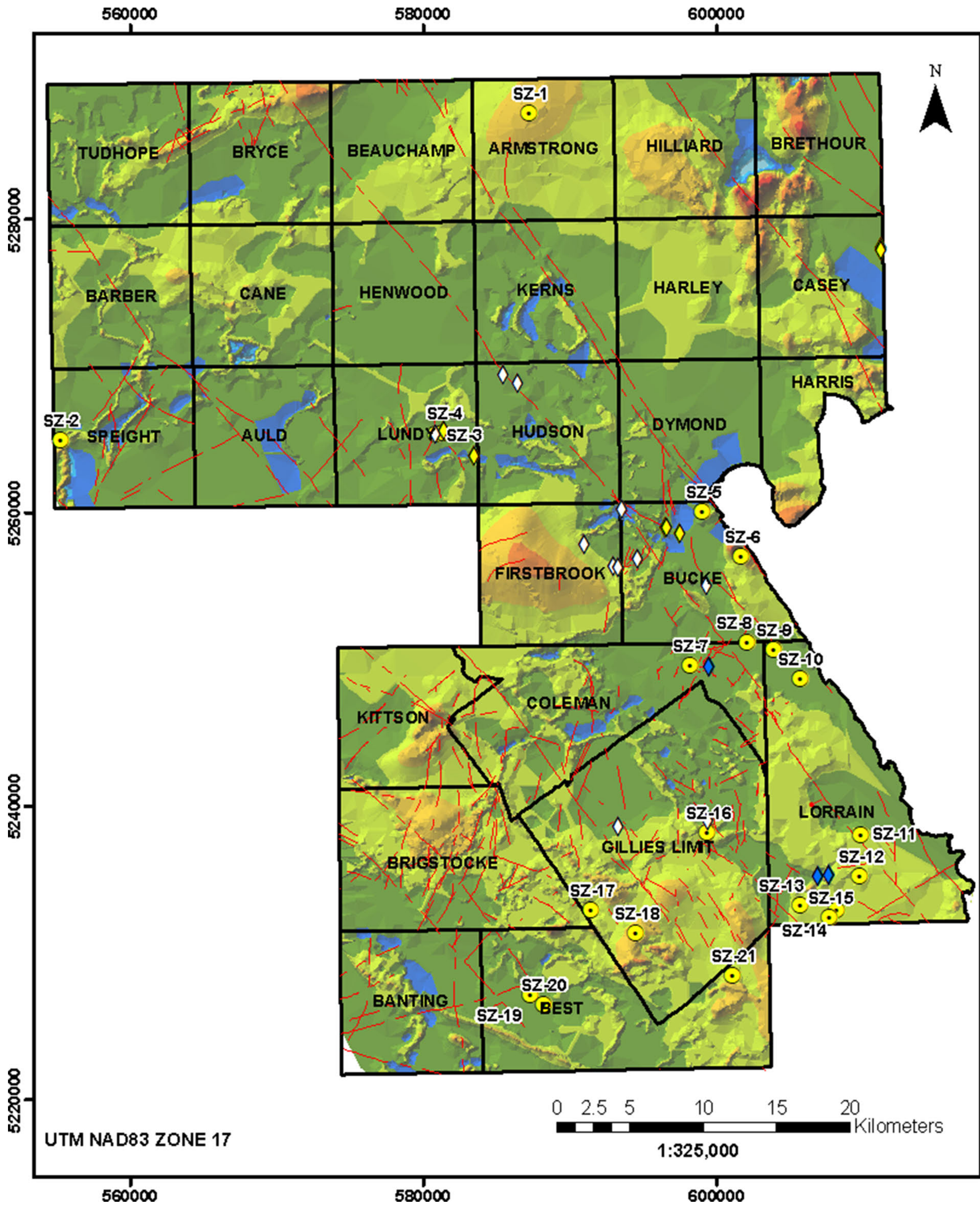

Figure 4. South Zone (SZ) kimberlite target map, showing the location of revised KCCs (Ontario Geological Survey 2002a, 2002b, 2003d, 2003e, 2004, 2013), layered over the hill-shaded residual total magnetic intensity image (Ontario Geological Survey 2017), structural data (Ayer and Chartrand 2011) and MDI points of reported kimberlite and diamond occurrences (Ontario Geological Survey 2019).

Table 1. Kimberlite target results for the North, Middle and South zones, Kirkland Lake District.

REF #	EASTING	NORTHING	CLUSTER #	AVAILABILITY	REF #	EASTING	NORTHING	CLUSTER #	AVAILABILITY
NZ-1	568168	5387788	5	OPEN	MZ-24	568279	5334714	5	LEASED
NZ-2	575448	5386708	4	FN RESERVE	MZ-25	594759	5334514	4	LEASED
NZ-3	576768	5382748	6	FN RESERVE	MZ-26	538679	5318554	4	CLAIMED
NZ-4	578328	5378228	6	CLAIMED	MZ-27	544599	5323394	6	LEASED
NZ-5	589808	5390069	5	CLAIMED	MZ-28	544799	5321354	4	CLAIMED
NZ-6	599728	5394109	4	CLAIMED	MZ-29	559679	5326794	7	LEASED
NZ-7	604488	5390349	4	OPEN	MZ-30	562839	5321554	6	OPEN
NZ-8	608728	5380469	4	CLAIMED	MZ-31	583399	5327954	4	CLAIMED
NZ-9	544088	5385188	5	LEASED	MZ-32	591079	5325314	4	CLAIMED
NZ-10	551048	5358748	4	LEASED	MZ-33	597039	5320114	4	CLAIMED
NZ-11	553488	5359068	6	LEASED	MZ-34	601479	5320394	5	LEASED
NZ-12	554968	5358268	4	LEASED	MZ-35	536399	5316514	5	CLAIMED
NZ-13	595488	5362668	4	CLAIMED	MZ-36	550380	5309160	4	LEASED
NZ-14	599408	5363468	6	CLAIMED	MZ-37	582319	5318154	4	CLAIMED
NZ-15	606088	5363788	4	CLAIMED	MZ-38	589959	5313194	4	CLAIMED
MZ-1	542199	5353115	4	OPEN	MZ-39	598329	5304288	8	CLAIMED
MZ-2	541959	5352235	5	OPEN	SZ-1	587318	5287318	4	LEASED
MZ-3	558105	5353935	4	OPEN	SZ-2	555300	5265060	5	CLAIMED
MZ-4	568365	5349585	4	OPEN	SZ-3	580890	5265480	5	CLAIMED
MZ-5	579555	5353245	4	OPEN	SZ-4	581460	5265570	6	CLAIMED
MZ-6	579285	5352165	4	CLAIMED	SZ-5	599108	5260127	6	LEASED
MZ-7	580335	5348475	5	CLAIMED	SZ-6	601757	5257072	4	LEASED
MZ-8	588825	5348265	4	CLAIMED	SZ-7	598277	5249712	4	LEASED
MZ-9	534959	5342394	4	OPEN	SZ-8	602117	5251272	4	LEASED
MZ-10	551239	5341194	4	OPEN	SZ-9	603957	5250752	4	LEASED
MZ-11	551399	5344554	4	CLAIMED	SZ-10	605757	5248752	4	LEASED
MZ-12	553862	5346874	5	OPEN	SZ-11	609877	5238112	6	CLAIMED
MZ-13	557199	5342754	4	CLAIMED	SZ-12	609837	5235312	4	CLAIMED
MZ-14	560295	5346165	4	LEASED	SZ-13	605757	5233352	5	CLAIMED
MZ-15	563559	5338834	4	CLAIMED	SZ-14	608237	5233032	4	CLAIMED
MZ-16	567719	5341314	4	CLAIMED	SZ-15	607757	5232512	4	CLAIMED
MZ-17	536599	5335514	4	OPEN	SZ-16	599437	5238272	5	CLAIMED
MZ-18	535279	5334754	4	OPEN	SZ-17	591517	5233032	5	CLAIMED
MZ-19	556839	5334634	4	OPEN	SZ-18	594557	5231432	4	CLAIMED
MZ-20	556999	5330074	4	LEASED	SZ-19	587397	5227192	4	CLAIMED

MZ-21	560639	5337594	4	CLAIMED	SZ-20	588237	5226592	4	OPEN
MZ-22	562759	5337274	5	CLAIMED	SZ-21	601197	5228512	4	RESTRICTED
MZ-23	563279	5336234	4	CLAIMED					

Acknowledgement

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——— 2003b. Ontario airborne geophysical surveys, magnetic and electromagnetic data, Kidd-Munro, Blake River area MEGATEM® II; Ontario Geological Survey, Geophysical Data Set 1044.

——— 2003c. Ontario airborne geophysical surveys, magnetic and electromagnetic data, Kirkland Lake area; Ontario Geological Survey, Geophysical Data Set 1102–Revised.

——— 2003d. Ontario airborne geophysical surveys, magnetic and electromagnetic data, Temagami area; Ontario Geological Survey, Geophysical Data Set 1103–Revised.

——— 2003e. Ontario airborne geophysical surveys, magnetic data, Kenabeek-Latchford-Redwater area; Ontario Geological Survey, Geophysical Data Set 1224.

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HIGHLIGHTS

- **Drilling holes in footwall rhyolites, parallel to a basalt–rhyolite contact, has a higher probability of finding VMS deposits by locating stockwork feeder zones than drilling holes through a basalt–rhyolite contact**
- **5 scenarios exist where explorationists might benefit by using this approach**

Contact:

Edmond van Hees
Tel: 705-465-1222
Email: Edmond.vanHees@ontario.ca

Grabbing a VMS Deposit by the Tail

Geology of Bimodal–Mafic Volcanogenic Massive Sulphide Deposits

Most Canadian volcanogenic massive sulphide (VMS) deposits are the bimodal–mafic type and account for the majority of VMS mineralization mined in Canada (Galley, Hannington and Jonasson 2007). They are found at the contact between rhyolite and pillow basalts and immediately above stockwork feeder zones (Figures 1 and 2). These deposits have average and median sizes of 6.3 million and 113.9 million tonnes, respectively, and an average grade of 1.7% Cu, 5.1% Zn, 0.6% Pb, 45 g/t Ag and 1.4 g/t Au (Galley, Hannington and Jonasson 2007). Sphalerite and chalcopyrite typically account for 75% and 25%, respectively, of the economic minerals in these deposits. These VMS deposits are zoned with the chalcopyrite occurring proximal to the stockwork feeder zone and the sphalerite distal (Franklin and Duke 1991). Stockwork feeder zones generally extend a few hundred metres stratigraphically below VMS deposits and are mappable but their diameters decrease with increasing distance from the deposit (Franklin and Duke 1991). Stockwork feeder zones typically have a chlorite core and a sericite rim (Franklin and Duke 1991). A geochemically altered halo, characterized by sodium and calcium depletion and potassium, magnesium and iron addition, is frequently present and extends out for 200 to 500 m from stockwork feeder zones (Lambert and Sato 1974; Date, Watanabe and Saeki 1983).

Historical Exploration and Drilling Strategy

Historically, exploration for VMS deposits involved flying airborne magnetic and electromagnetic surveys over a geologically favourable target area and plotting the flight path on air photos to establish an approximate location of geophysical anomalies. Geophysical targets that met criteria associated with a VMS deposit were then selected for further exploration. Ground with a geophysical anomaly was either staked on open Crown land (usually a block of 4 claims) or acquired from a land owner. The exact location of the anomaly was pinpointed by conducting ground magnetic and electromagnetic surveys on a grid cut over the claims. A VMS deposit must contain massive or semi-massive pyrite, pyrrhotite, chalcopyrite or graphite in order to be recognized by magnetic or electromagnetic surveys. The source of a geophysical anomaly was frequently tested by a single drill hole. Mineralized zones dominated by sphalerite, such as the Kidd Creek deposit, are often not recognized by magnetic and electromagnetic surveys (Donohoo, Podolsky and Clayton 1970; Bleeker and Hester 1999). Such deposits can be identified by gravity surveys that until recently were too expensive to be utilized routinely (Donohoo, Podolsky and Clayton 1970; Bleeker and Hester 1999; van Hees 2017).

van Hees, E.H. 2020. Grabbing a VMS deposit by the tail; in Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.31-36.

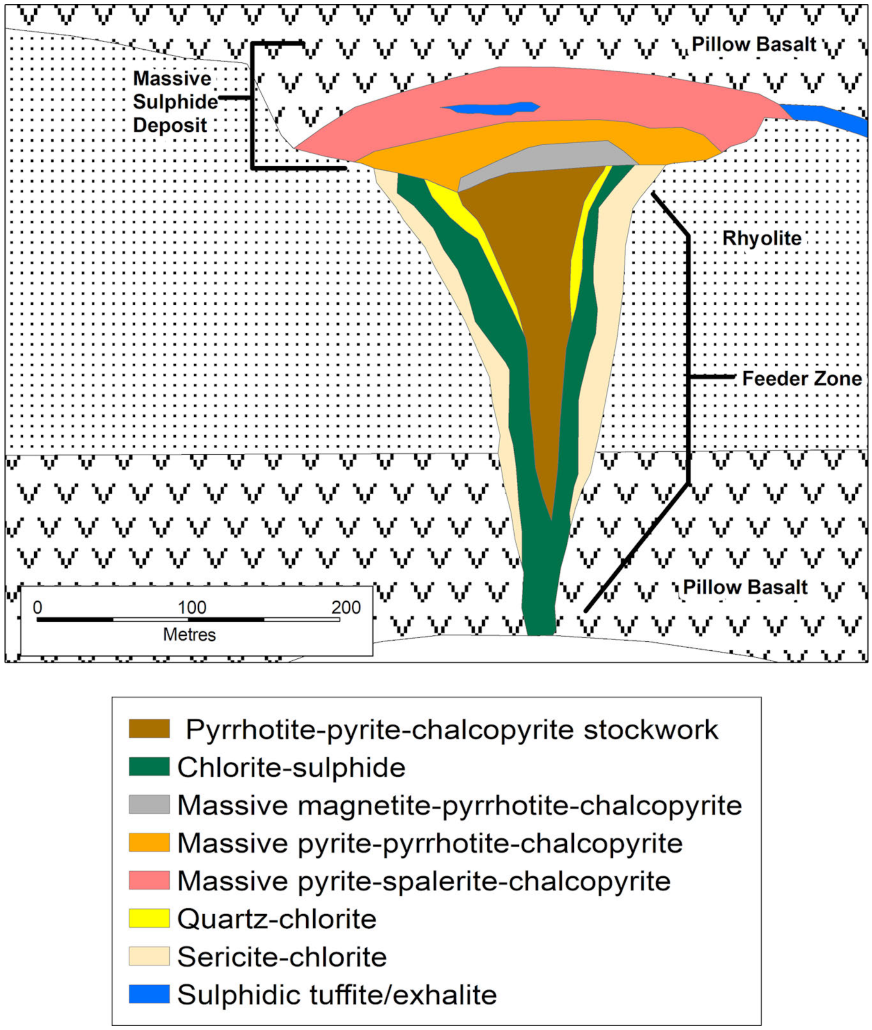

Figure 1. A cross section of a bimodal–mafic-type VMS deposit (after Galley, Hannington and Jonasson 2007). Legend also applies to Figures 2, 3 and 4.

Testing the cause of a geophysical anomaly usually involved drilling through the pillow basalt hanging wall rocks to pierce the basalt–rhyolite contact where bimodal–mafic-type VMS deposits occur (*see* Figures 1 and 2). A pattern of 12 or 15 holes (3 rows of 4 holes or 3 rows of 5 holes), respectively, drilled to pierce a contact at 150 m centres (Figures 2 and 3), to find a 250 by 300 m VMS deposit, would require about 10 000 m of core. This drilling approach and pattern has an 8% and 25% chance of encountering massive and marginal mineralization, respectively (*see* Figures 2 and 3). Moving holes 50 m to the left in Figures 2 and 3 can double the probability of encountering massive sulphide from 8 to 16% but decreases the probability of finding marginal mineralization from 25 to 16%. That means there is a 65% chance of not encountering any mineralization for the above scenario.

Alternative Exploration Drilling Strategy

An alternative approach to locating VMS deposits by drilling to pierce the basalt–rhyolite contact is to drill in the rhyolite footwall rocks to locate stockwork feeder zones that lie stratigraphically below the deposits. This approach would involve drilling holes just inside the rhyolite footwall rocks (≤50 m away) and parallel to the basalt–rhyolite contact, in order to identify either a 200 to 500 m wide geochemical alteration halo or the mineralogically zoned stockwork feeder zone at its centre (Figures 3 and 4). Alteration in a halo increases with closer proximity to the

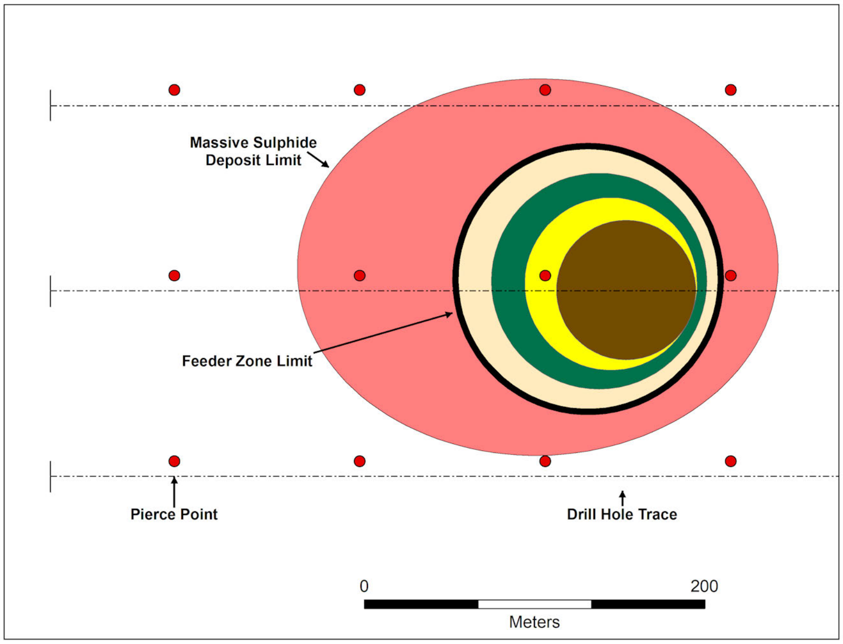

Figure 2. Plan view of a bimodal–mafic-type VMS deposit with the stockwork feeder zone located directly under the massive sulphide zone. Twelve drill holes piercing the basalt–rhyolite contact plane to explore for VMS mineralization (red dots) and 3 drill holes are drilled parallel to the basalt–rhyolite contact (3 dashed lines). See Figure 1 for legend.

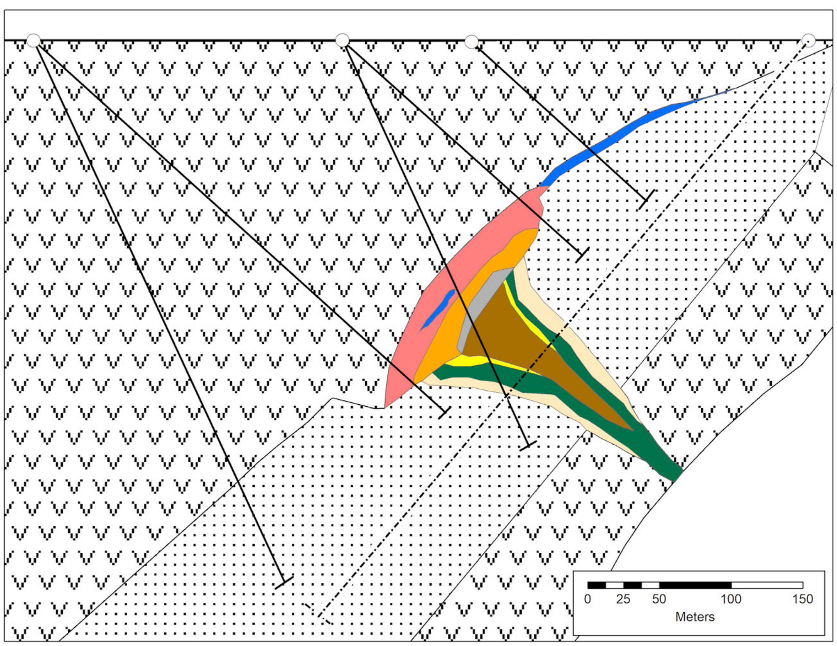

Figure 3. Cross-section diagram with 5 drill holes laid out to explore for VMS mineralization by piercing the basalt–rhyolite contact and 1 hole drilled in footwall rhyolite (dashed line), parallel to the basalt–rhyolite contact, to search for an underlying feeder zone. See Figure 1 for legend.

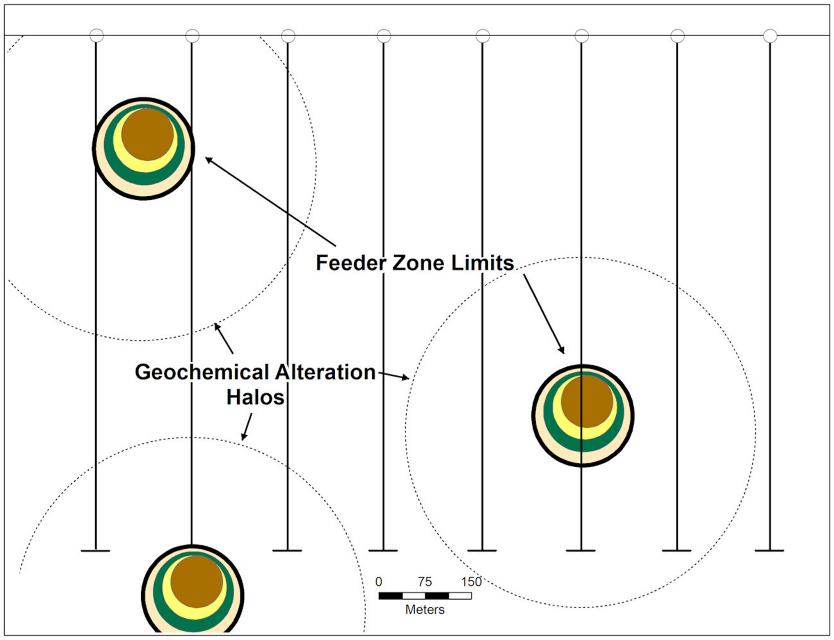

Figure 4. Cross-section diagram with 8 holes drilled in the footwall rhyolite that encountered feeder zones directly or just their margins. These drill holes also have a high probability of encountering much larger geochemical alteration halos around the stockwork feeder zone (inside dotted lines). Increasing alteration closer to the feeder zones could provide a vector toward the zones and VMS deposits. See Figure 1 for legend.

centre of a stockwork feeder zone and can act as a vector toward mineralization. Once a stockwork feeder zone is identified, it should be relatively easy to locate and explore for VMS mineralization at a basalt–rhyolite contact.

The benefits of trying to locate a stockwork feeder zone by exploring the footwall rhyolite below the basalt–rhyolite contact is that it has a higher probability of success and requires fewer metres of drilling. A single hole drilled in a footwall rhyolite can evaluate the same area tested by 5 holes drilled to pierce the basalt–rhyolite contact (*see* Figure 3). A single, 1000 m long hole will produce core that all comes from geologically interesting rock and requires about 70% less footage to explore the same area tested by 5 drill holes having a total length of 3600 m. Additionally, drilling to pierce the basalt–rhyolite contact at 5 locations only produces a few metres of geologically interesting core at the contact. Three holes drilled in the rhyolite parallel to the basalt–rhyolite contact beneath the 12 pierce points plotted in Figure 2 would have a 33% (1 in 3) chance to encounter the stockwork feeder zone. Locating the stockwork feeder zone would likely identify the location of the VMS deposit that stratigraphically overlies it.

An additional benefit of trying to locate the stockwork feeder zone by drilling in the footwall rhyolite is that the drill hole(s) might identify mineralization at the bottom of a hole or between 2 drill holes (*see* Figure 4). Additionally, encountering a much larger geochemical alteration halo might provide a vector toward a stockwork feeder zone (*see* Figure 4).

Possible Applications

Possible applications where drilling footwall rhyolites might help find a VMS stockwork feeder zone include exploration projects: (1) in current and past-producing mines that exploited VMS deposits; (2) where previous drill programs have defined favourable geology; (3) where drill holes have encountered zinc mineralization that might be the distal part of a VMS deposit; (4) that have been drilled but still have untested gravity or electromagnetic geophysical anomalies; and (5) only tested by a single, short (~150 m) drill hole.

Current or past-producing mines that exploited VMS deposits, such as those near the Kamiskotia Mine or in the Noranda camp, where the deposit geology is well understood, have the greatest potential to locate new stockwork feeder zones by drilling in the footwall rhyolite. The presence of multiple ore bodies in large VMS deposits (e.g., Walker and Mannard 1974) supports the possibility that smaller deposits could host additional undiscovered ore bodies.

Drilling in footwall rhyolites could also identify stockwork feeder zones in areas where the location of a basalt–rhyolite contact has been defined by previous exploration drilling. A well-defined geological setting would permit footwall drill holes to be well positioned. The Rusty Hill project in Prosser Township has multiple drill holes and might be a possible candidate for such an approach (Darke and Kelly 1963).

Drilling footwall rhyolites could also identify stockwork feeder zones in areas where previous drill programs have encountered zinc assays. National Exploration Ltd. drilled a target in the southwest corner of Prosser township that encountered silver assays up to 15.5 grams per tonne over 2.3 m and numerous zinc assays greater than 0.25 wt % over 0.76 m (Amendolagine 1964). These results might indicate that they encountered the distal part of a zinc-rich VMS deposit that is not accompanied by a geophysical conductor.

Drilling footwall rhyolites could also identify feeder zones in areas where there are untested gravity anomalies. The Halfmoon Lake exploration project, located northwest of Kamiskotia Lake, is such a target that is owned by International Explorers and Prospectors.

Drilling through footwall rhyolites could also identify feeder zones in areas where geophysical targets have been tested by a single, short diamond-drill hole. Carnegie Township, located immediately north of Kidd Township and the Kidd Creek Mine, was tested by at least 96 drill holes that had an average length of 222 m (728 feet).

Those holes tested at least 46 geophysical conductors by piercing basalt–rhyolite contacts. Although many of the geophysical conductors were tested by only a single drill hole, they encountered 8 mineralized intersections assaying more than 0.25 wt % zinc over 0.76 m. The drill holes that encountered zinc mineralization might indicate the margin of a massive sulphide deposit and benefit from additional exploration drilling in the footwall rhyolites.

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HIGHLIGHTS

- **Kamiskotia Gabbroic Complex a target for a potential vanadiferous titanomagnetite deposit**
- **Historical samples and current sample show anomalous vanadium**
- **Area of sampling situated above a strong and large magnetic anomaly**

Kamiskotia Gabbroic Complex: Looking at it Under a Different Lens

The area of Kamiskotia Lake, located 25 km northwest of the City of Timmins, is renowned for the presence of volcanogenic massive sulphide deposits (Barrie 2000). These deposits are sitting in the Kamiskotia Volcanic Complex (KVC), which surrounds the Kamiskotia Gabbroic Complex (KGC). Diamond-drilling conducted on the 4-Corners property by Claim Post Inc. encountered something peculiar in hole CP-10-12: a magnetite dike (Daxl 2010). According to the assessment file, the massive magnetite dike had an apparent thickness of 3.56 m and returned an assay of 63.4% Fe, 0.84% TiO_2 and 774 ppm V (Daxl 2010). Which begs the question—where is this dike coming from? Suspicions are aimed at the Kamiskotia Gabbroic Complex and its potential to host vanadium deposits.

Geology

The Kamiskotia Gabbroic Complex spans the northeastern Carscallen, northern Whitesides, eastern and central Massey, northeastern Enid, central Côté, southern Robb, western and northern Turnbull, and western Godfrey townships (Barrie 1992). The Complex consists of 4 zones as defined in Barrie 1992: a partly layered, olivine-bearing cumulate Lower Zone (LZ); gabbro-norite and anorthositic gabbro-norite cumulate of the Middle Zone (MZ); partly layered, ferroan gabbro-norite, anorthositic gabbro-norite and hornblende gabbro cumulates of the Upper Zone (UZ); and granophyric rocks of intermediate and felsic composition above and along strike with the UZ (Barrie 1992; Hart 1984).

The Kamiskotia Gabbroic Complex shares many similarities to other well-known complexes such as the Bushveld Complex (South Africa), the Stillwater Complex (United States of America) and Bell River and Doré Lake Complexes (Quebec) (Barrie 2000). There are outcrops of the KGC in the southwest of Kamiskotia Lake forming a noticeable elevation. This area shows as a magnetic high (Wolf 1970), probably related to the Upper Zone ferroan gabbro-norite. Cumulus magnetite crystals, which can be found in the Upper Zone, may contain up to 2.5% V_2O_3 (Barrie 1990).

This cumulus magnetite could be a vanadiferous titanomagnetite (VTM) deposit (Fisher 1975). The VTM deposits are associated with mafic igneous intrusions that are deep-seated stratiform sheets or complex intrusive bodies. The minerals forming the orebody crystallized with the rock-forming minerals in the magma and are disseminated forming large masses or segregated in extensive layers (Fisher 1975). The bodies can also be plugs or dikes that are injected as solutions or melts into these forms.

The dike interpreted from the assay of core in drill hole CP-10-12 can be theorized to be such a body. It may have been formed with the Kamiskotia Gabbroic Complex. The area showing a strong magnetic

Contact:

Pierre Bousquet
Tel: 705-235-1613
E-mail: Pierre.Bousquet@ontario.ca

Bousquet, P. 2020. Kamiskotia gabbroic complex: Looking at it under a different lens; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.37-39.

anomaly southwest of Kamiskotia Lake was sampled by Barrie (2000), and again in the summer of 2019 (Figure 1). The samples returned assays of Fe_2O_3 from 1.28% to 19.19%, TiO_2 from 1.11% to 3.23%, and vanadium from 318 ppm to 808 ppm, or from 0.058% V_2O_5 to 0.15% V_2O_5 (Table 1). Approximately 500 m separate the sample collection locations of Barrie (2000) and that of the summer of 2019. It is expected the mineralized zone would extend down to the occurrence documented in the Mineral Deposit Inventory, Walcoro Porcupine Mines Claim 31360 (MDI42A12SE00019), as the report by Bradshaw (1984) identifies the presence of disseminated magnetite on the property. The property lies within the magnetic anomaly in Wolf (1970). With this limited data for the Walcoro property, it is surmised that the magnetite is vanadiferous at that location.

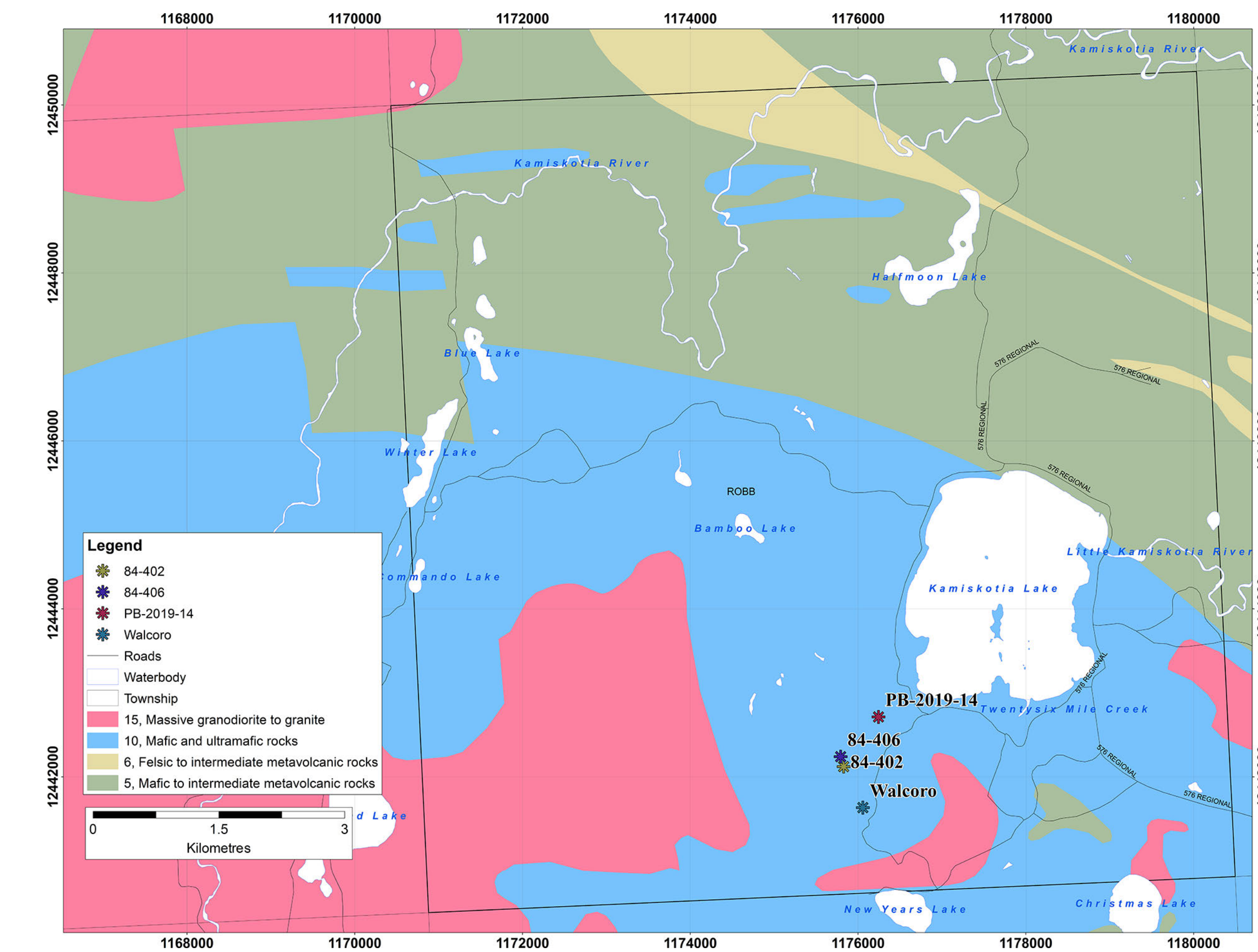

Figure 1. Bedrock geology of Robb Township with locations of samples and the Walcoro occurrence (recorded in the Mineral Deposit Inventory), Timmins Resident Geologist District.

Table 1. Samples originating from the Kamiskotia Gabbroic Complex, southwest from Kamiskotia Lake, Timmins Resident Geologist District.

Sample	Zone	Easting	Northing	Fe_2O_3 %	TiO_2 %	V ppm	V_2O_5 % (1)
84-402 (2)	17	451370	5377800	12.80	1.11	318	0.058
84-406 (2)	17	451340	5377920	17.30	2.29	860	0.16
PB-2019-14	17	451817	5378370	19.19	3.23	808	0.15

1-Calculated through stoichiometry

2-From Barrie (2000)

Recommendation

The Kamiskotia Gabbroic Complex does show potential for vanadium. The location of the mineralization, concordant with ilmenite as affirmed in Middleton (1973), is associated with the strong magnetic anomalies as shown in Wolf (1970) and Ontario Geological Survey (2003). The grades from the samples are situated at the low end of the values from selected vanadium deposits of the world published in Kelley et al. (2017), *see* Table 1. However, further research could identify zones of higher mineralization, and maybe discover mineralization related to platinum group elements.

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VMS Horizon in Côté Township and the Kamiskotia Volcanic Complex

HIGHLIGHTS

- **New development in last year's recommendation for exploration**
- **Rhyolite found in drill core in the proposed target area**
- **Geochemistry suggests an environment favorable for VMS deposits**

In the follow-up of last year's recommendation for exploration (Bousquet 2018), more data has been released on the rhyolite sample collected in the field. Additionally, some results from core samples stored at the Timmins District Core Library are worth highlighting.

The rhyolite sample was found along the Whitesides esker in Côté Township. Initial results indicated the rhyolite may be strongly altered due to a high calculated Ishikawa alteration index of 91% (Ishikawa et al. 1976; Bousquet 2018). It was suggested from its location (Figure 1, NAD 83, Zone 17, 445159 mE, 5379576 mN) together with its size and angular nature, that the sample probably originated from a point located 5 to 10 km north from the point of collection (Bousquet 2018).

Further results

Trace element analysis (using X-ray fluorescence and inductively coupled plasma mass spectrometry) reveal interesting results (Table 1). Barium content is above the upper limit of detection, while the cadmium and zinc contents are 2.5 times the average crust concentration (Wedepohl 1995). This suggests that the silicified rhyolite may have formed in a favorable environment for volcanogenic massive sulphide (VMS) deposits. This is also supported by the felsic volcanic rock classification diagram (Zr/Y) in Figure 2, where the samples of the rhyolite boulder plot inside the area of overlap between the FIIIa and FIV fields. These rhyolites are known to be found in environments favorable for VMS formation (Hart, Gibson and Lesher 2004).

Core from a drill hole in the Côté Township target area (Bousquet 2018) was found in the Timmins District Core Library. The Tesluk Property located in this township, was explored in the 1960s and some of the core ended up in the Timmins Core Library, like hole 65-10 (*see* Figure 1). The drill hole collar is located at 445900 mE, 5484305 mN (Zone 17); Timmins Core Library identification number TI3194. Hole 65-10 core is telescoped, and only 2 pieces of rock core were present. A sample of rhyolite and a sample of basalt were collected for analysis. The rhyolite composition of hole 65-10 (*see* Table 1) shows comparable values to the rhyolite boulder collected in Côté Township. Furthermore, it plots in the same area of the FIIIa and FIV fields (*see* Figure 2) according to the Hart, Gibson and Lesher's classification of felsic volcanic rocks (2004). The basalt in hole 65-10 returned anomalous values in copper and zinc, compared to the average crust values from Wedepohl 1995. Similar anomalies are observed in the vicinity of VMS type copper–zinc deposits. This reinforces the suggestion of the presence of a favorable environment for VMS deposits in the area as concluded by Bousquet (2018).

Contact:

Pierre Bousquet
Tel: 705-235-1613
E-mail: Pierre.Bousquet@ontario.ca

Bousquet, P. 2020. VMS horizon in Côté Township and the Kamiskotia volcanic complex; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.41-44.

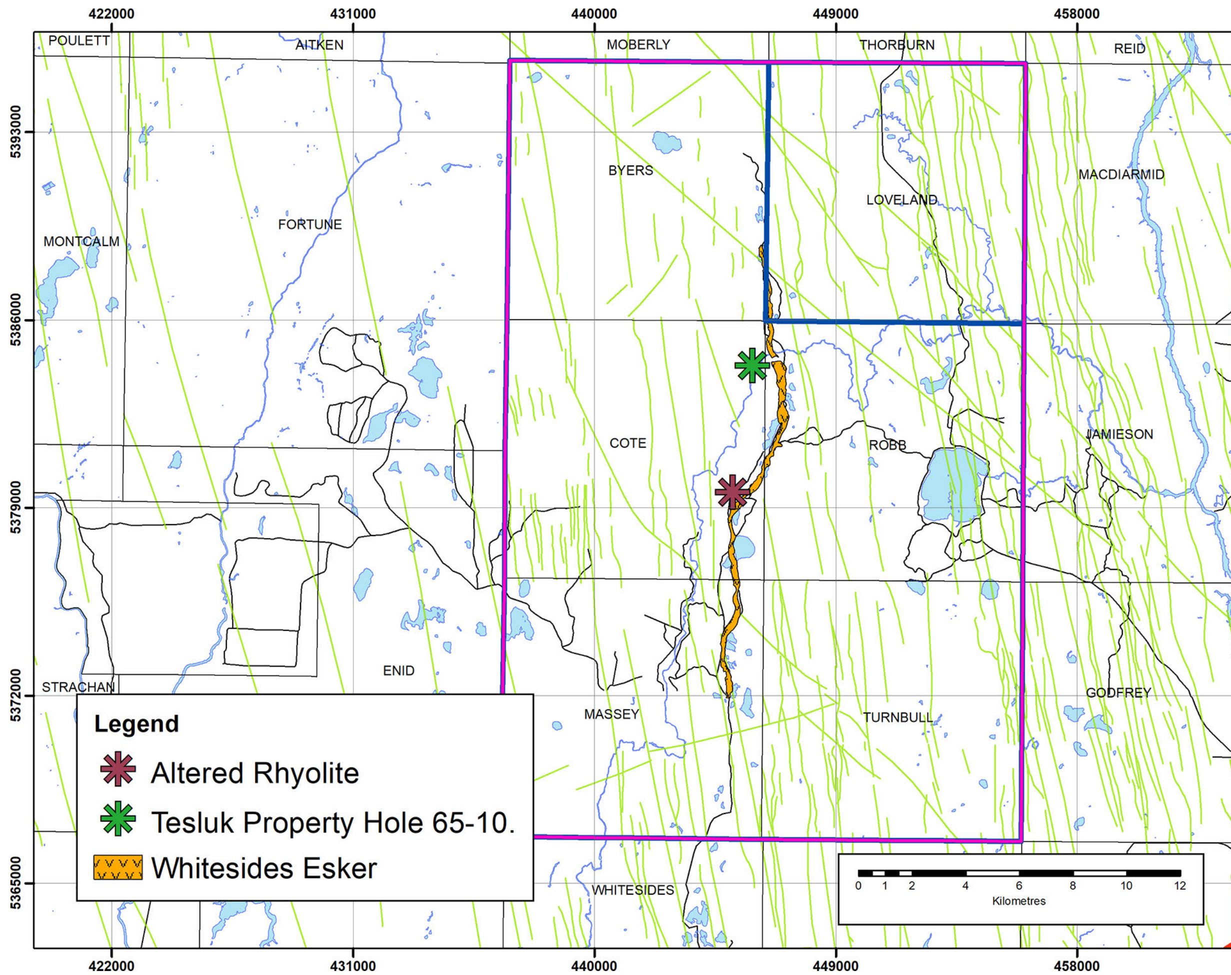

Figure 1. Spatial location of drill hole 65-10 relative to the altered rhyolite collection point, in Côté Township, Timmins Resident Geologist District.

Table 1. Trace element chemistry in ppm for the altered rhyolite (4 samples from the same boulder) and for samples taken from drill hole 65-10 drilled on the Tesluk property in Côté Township. Analysis method in brackets: ICP–MS inductively coupled plasma mass spectrometry; XRF, X-ray fluorescence. The numbers in brackets for the rhyolite samples are plotted on Figure 2.

Trace elements	Ba ppm (ICP-MS)	Cd ppm (ICP-MS)	Cu ppm (XRF)	Nb ppm (XRF)	Ni ppm (XRF)	Sr ppm (XRF)	Y ppm (XRF)	Zn ppm (XRF)	Zr ppm (XRF)
Silicified Rhyolite (1)	1701.6	0.92	10.5	20.419	2.5	53.4	41.6	153.9	95
Silicified Rhyolite (2)	>1740	0.56	6.5	21.058	<0.7	60	67.22	686.1	94
Silicified Rhyolite (3)	>1740	0.48	5.2	20.72	0.9	59.9	40.8	852.8	93
Silicified Rhyolite (4)	>1740	0.29	5.3	21.681	0.7	56.6	57.57	937.7	94
Tesluk Property, Hole 65-10, 325ft Rhyolite (5)			15	21.1	4.1	28.4	67	124	106.5
Tesluk Property, Hole 65-10, 350ft Basalt			111	2.7	63.4	185.4	18.1	517	81.9

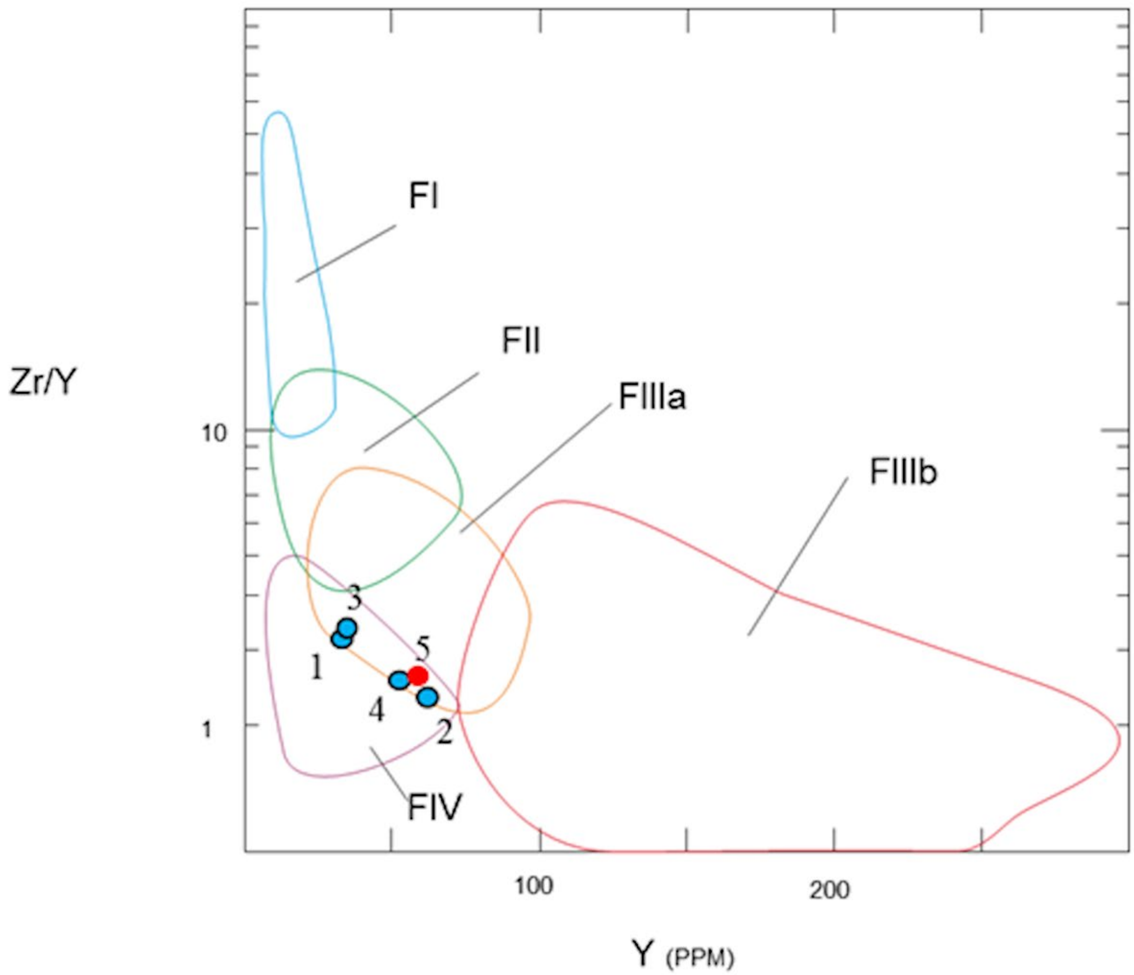

Figure 2. Zr/Y vs Y plot showing the classification of the rhyolite samples collected in Côté Township, Timmins Resident Geologist District (represented by numbers) keyed to the bracketed numbers in Table 1 (classification zones *modified from* Hart 2016; Lesher et al. 1986; and Hart, Gibson and Lesher 2004). Boulder rhyolite samples are the light blue dots (1 to 4) and Hole 65-10 rhyolite is the red dot (5).

Recommendation

The target area in northern Côté township seems promising for volcanogenic massive sulphide as suggested by Bousquet (2018) and from the results from drill hole 65-10 on the Tesluk property. It is recommended that further research using geophysics and geochemistry to identify targets at depth (van Hees et al. 2017). It is important to note that the depth of overburden recorded in the drill holes of that region is over 80 feet (Tesluk 1965), which may be a significant obstacle.

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HIGHLIGHTS

- **High concentrations of rare earth elements associated with uranium discovered in the Matinenda Formation of the Huronian Supergroup**
- **Uranium-rich Matinenda Formation rocks, mineral deposit occurrences, and mine tailings should be investigated for potential rare earth elements mineralization**

Contact:

Sheree Hinz
Tel: 705-235-1614
Email: Sheree.Hinz@ontario.ca

REE Potential in the Huronian Supergroup Matinenda Formation

The quartz-pebble conglomerate of the Matinenda Formation hosts uranium mineralization within the Paleoproterozoic Huronian Supergroup. Over the years, exploration in this region has been mainly focused on uranium, however this recommendation will focus on rare earth element (REE) potential. Due to the increased demand for REEs, further exploration in the area is warranted. Pele Mountain Resources Inc. (now Bhang Inc.) discovered high concentrations of REEs associated with uranium in the Ryan Member of the lower Matinenda Formation of the Huronian Supergroup (Pele Mountain Resources Inc. 2012).

Pele Mountain Resources Inc. released an NI 43 101 technical report in June 2012 which was subsequently revised in June 2013 (Pele Mountain Resources Inc. 2012, 2013). They reported Indicated Resources of 31 382 000 tonnes at 1674 ppm total rare earth oxides (TREO), and Inferred Resources of 57 426 000 tonnes at 1613 ppm TREO (Table 1). TREO includes light rare earth oxides (La_2O_3, CeO_2, Pr_6O_{11} and Nd_2O_3) and heavy rare earth oxides (Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_4O_7, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Y_2O_3, Lu_2O_3 and Sc_2O). Appia Energy Corp. has also been active in the Elliot Lake area, developing their Elliot Lake uranium and REE property. An NI 43-101 technical report released by Appia in 2013 delineated Indicated Mineral Resources of 14 435 000 tons grading 0.554 lbs U_3O_8/ton and 3.30 lbs TREE/ton for a total of 8.0 million lbs U_3O_8 and 47.7 million lbs TREE (total rare earth elements, the sum of La+Ce+Pr+Nd+Sm+Eu+Gd+Tb+Dy+Ho+Er+Tm+Yb+Lu+Y; Workman, Breede and Goode 2013). This type of uranium-associated REE mineralization is not exclusive to the Elliot Lake area. Appia Energy Corp. has several projects in the Athabasca Basin of Saskatchewan that have similar mineralization, including Alces Lake, North Wollaston and Loranger projects.

Since it was common practice that REEs were not assayed during uranium exploration, there is the possibility that high concentrations of REEs have been overlooked in the Elliot Lake camp, see Figure 1 for the geology of the area. According to Resident Geologist Program files, the Elliot Lake camp produced 461 055 600 lbs of uranium between 1956 and 1997. Considering the high REE to uranium ratio (3.5:1) found in Pele Mountain Resources Inc. Mineral Resource Estimate (see Table 1), there is potential for similar high concentrations of REEs to be found elsewhere in the Ryan Member.

Pele Mountain Resources Inc. found the higher grade mineralized zones to be within thicker sections of the main conglomerate bed, near more permeable zones, and associated with pyrite and pyrrhotite. Recent mapping done by Lewis (2012) has identified the Matinenda Formation in Albanel Township where it was previously classified as unmineralized Mississagi Formation by Grunsky, Siemiatkowska and Berger (1975) when

Hinz, S.L.K. 2020. REE potential in the Huronian Supergroup Matinenda Formation; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.45-48.

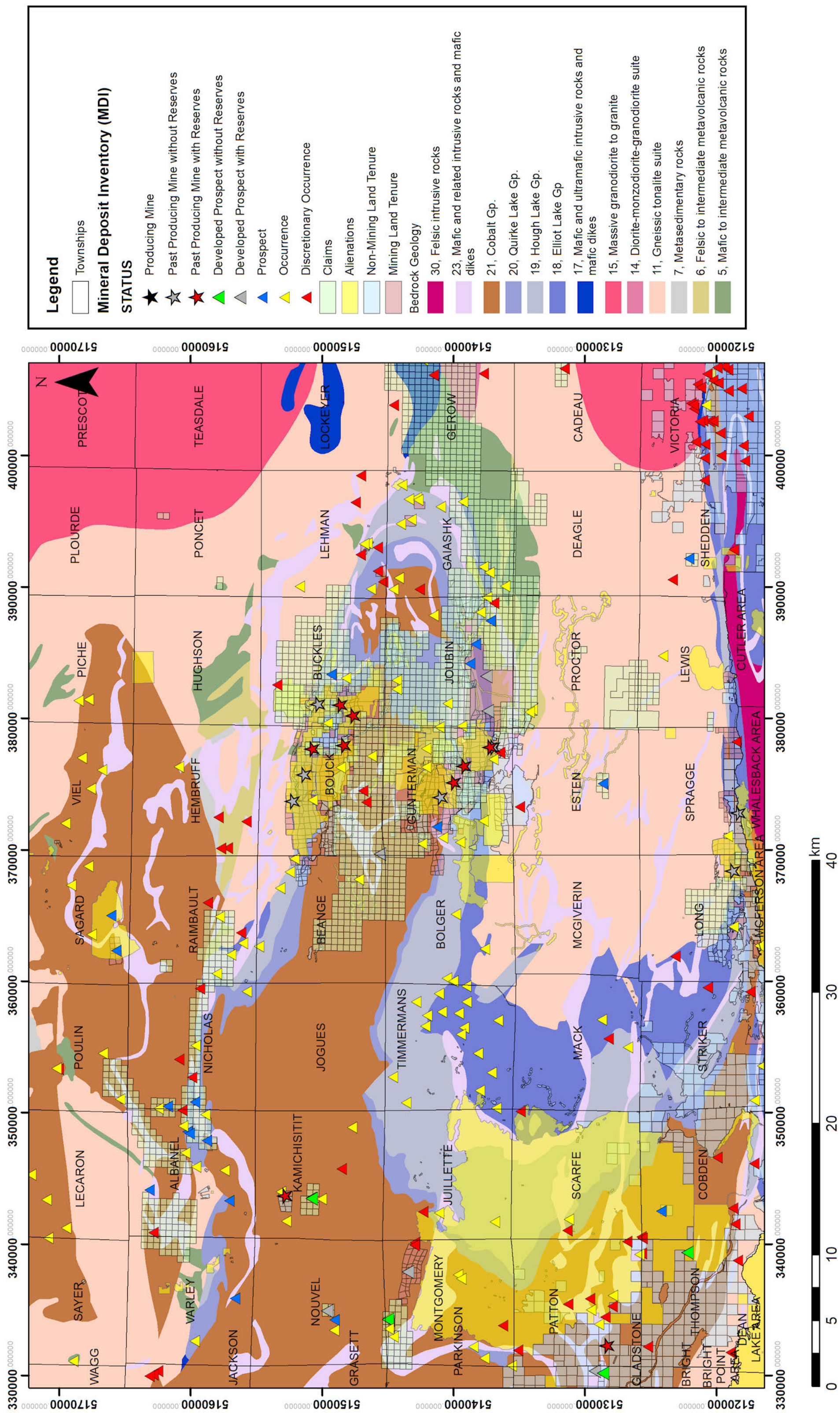

Figure 1. Geology map of the Elliot Lake area overlain with occurrences documented in the Mineral Deposit Inventory (*from* Ontario Geological Survey 2019) and land tenure. Matinenda Formation is included in the geological unit 18. Elliot Lake Group (*see* legend), exposures of which can be seen in Mack, Timmermans, Bolger, Beange, and Raimbault townships.

they mapped the area in 1974.

As the high REE concentrations were found to correlate with uranium mineralization, there are several exploration strategies that are recommended. Unclaimed exposures of the Matinenda Formation, including those found in Mack, Timmermans, Bolger, Beange, and Raimbault townships, should be investigated for the REE content of the rocks (Figure 1). Another exploration focus should be on unclaimed ground in proximity to the occurrences documented in the Mineral Deposit Inventory (MDI) (Ontario Geological Survey 2019) with uranium listed as a primary commodity (Table 2). Finally, tailings from Elliot Lake's former uranium mines should be considered as an unconventional source of REEs through mine tailings reprocessing.

Table 1. Mineral resource estimate within the Main Conglomerate Bed (MCB) and for the higher grade zones (HGZ).

Classification and Zone	Tonnes (thousands)	U_3O_8 (%)	U_3O_8 lbs (thousands)	TREO (ppm)	TREO lbs (thousands)	U_3O_8 Equivalent (%)	U_3O_8 Equivalent (thousand lbs)	REE to Uranium Ratio
	Indicated							
MCB	22 743	0.045	22 554	1606	80 510	0.099	49 827	3.5:1
HGZ	8 639	0.055	10 417	1852	35 279	0.117	22 235	3.4:1
	Inferred							
MCB	36 560	0.047	37 623	1554	125 248	0.102	81 842	2.2:1
HGZ	20 866	0.053	24 236	1715	78 903	0.111	51 260	2.1:1

Table 2. Occurrences in the Elliot Lake area with uranium listed as the primary commodity on land open for staking, as listed in the Mineral Deposit Inventory (*from* Ontario Geological Survey 2019).

MDI Number	Deposit Status	Township	Name	Primary Commodity	UTM Datum	UTM Zone	Easting	Northing
MDI41J10SW00019	Discretionary Occurrence	Albanel	Fort Norman Exploration Area E	Uranium	NAD83	17	350191	5160640
MDI41J10SW00052	Occurrence	Albanel	Arco Triller DDH #2	Uranium	NAD83	17	349853	5158894
MDI41J10SW00062	Occurrence	Albanel	Little White River Occurrence	Uranium	NAD83	17	348995	5160586
MDI41J10SW00057	Occurrence	Beange	Consolidated Callinan	Uranium	NAD83	17	362657	5154804
MDI41J10SE00028	Occurrence	Beange	Span-North	Uranium	NAD83	17	367097	5153207
MDI41J10SE00026	Occurrence	Beange	Candore	Uranium	NAD83	17	368311	5152477
MDI41J07NW00057	Occurrence	Bolger	Peerless	Uranium	NAD83	17	362479	5137619
MDI41J07NW00055	Occurrence	Bolger	Moon Lake	Uranium	NAD83	17	360227	5140516
MDI41J07NW00056	Occurrence	Bolger	Nordic Group West	Uranium	NAD83	17	365099	5139828
MDI41J08NW00070	Occurrence	Gaiashk	Canuc	Uranium	NAD83	17	396804	5142790
MDI41J08NW00066	Occurrence	Gaiashk	Corner Lake	Uranium	NAD83	17	389837	5144560
MDI41J07NE00086	Occurrence	Gunterman	North American Nuclear	Uranium	NAD83	17	370575	5139502
MDI41J07NE00112	Occurrence	Gunterman	Kamis	Uranium	NAD83	17	370944	5140821
MDI41J07SW00018	Occurrence	Juillette	Fano	Uranium	NAD83	17	350353	5136746
MDI41J07NW00053	Occurrence	Kamichisitit	Kee #2	Uranium	NAD83	17	348884	5147739

MDI41J06NE00050	Discretionary Occurrence	Kamichisitit	Superior Northwest Inc. Imperial Option DDH 2	Uranium	NAD83	17	345724	5148530
MDI41J08NW00064	Occurrence	Lehman	Bracemac	Uranium	NAD83	17	389865	5146290
MDI000000001405	Discretionary Occurrence	Long	Tungsten Corp. DDH 7	Uranium	NAD83	17	361896	5123117
MDI41J07SW00019	Occurrence	Mack	Black Lake Occurrence	Uranium	NAD83	17	354993	5126741
MDI41J10SW00056	Occurrence	Raimbault	Zenmac	Uranium	NAD83	17	362898	5156019
MDI41J02NW00017	Discretionary Occurrence	Striker	New Kelore Mines Property	Uranium	NAD83	17	359524	5120673
MDI41J07NW00049	Occurrence	Timmermans	Martin, D.R.	Uranium, Thorium	NAD83	17	356489	5139198
MDI41J07NW00041	Occurrence	Timmermans	Jeanette	Uranium	NAD83	17	356594	5142133
MDI41J07NW00058	Occurrence	Timmermans	Little Moon Lake	Uranium	NAD83	17	357679	5140895
MDI41J07NW00045	Occurrence	Timmermans	Buffana	Uranium	NAD83	17	359078	5141108
MDI41J07NW00044	Occurrence	Timmermans	Denison	Uranium	NAD83	17	357399	5142006
MDI41J07NW00051	Occurrence	Timmermans	Moon Lake	Uranium, Thorium	NAD83	17	358442	5139005
MDI41J07NW00050	Occurrence	Timmermans	Coffee Lake	Uranium, Thorium	NAD83	17	350778	5143615
MDI41J07SW00021	Occurrence	Timmermans	Pistol Lake	Uranium	NAD83	17	357029	5136607
MDI41J07SW00020	Occurrence	Timmermans	Fano	Uranium	NAD83	17	353062	5137123
MDI41J07NW00043	Occurrence	Timmermans	Dominion	Uranium	NAD83	17	354508	5138148
MDI41J07NW00047	Occurrence	Timmermans	Picton	Uranium	NAD83	17	352731	5144618
MDI41J07NW00048	Occurrence	Timmermans	Zenmac	Uranium	NAD83	17	355951	5139464
MDI41J07NW00042	Occurrence	Timmermans	Big Game	Uranium	NAD83	17	359640	5139044
MDI41J07NW00046	Occurrence	Timmermans	Fort Norman	Uranium	NAD83	17	358452	5142860
MDI41J07NW00052	Occurrence	Timmermans	Anuwon	Uranium	NAD83	17	357575	5139621

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HIGHLIGHTS

- **Proterozoic mafic intrusions in the Elliot Lake area have potential for Ni-Cu-PGE mineralization**
- **There are several underexplored Paleoproterozoic intrusions in Lockeyer and Mademin townships that should be re-examined for Ni-Cu-PGE potential**

Contact:

Sheree Hinz
Tel: 705-235-1614
Email: Sheree.Hinz@ontario.ca

Ni-Cu-PGE Mineralization in Proterozoic Mafic Intrusions

Proterozoic mafic intrusions in the Elliot Lake area have varying potential for Ni-Cu-PGE mineralization. According to work compiled by Easton (2015), the 2 intrusions most likely to host high concentrations of Ni-Cu-PGE mineralization are the Nipissing gabbro and East Bull Lake layered intrusions. These 2 intrusive complexes host contact-style Cu-PGE mineralization that is characterized by disseminated sulphides within layered gabbro to gabbronorite complexes (Easton 2015).

21C Metals Inc. holds claims on part of the East Bull Lake intrusions in Gerow Township. On August 6, 2019, they released an NI 43-101 technical report on their East Bull Platinum Group Metals Property, outlining an Inferred Mineral Resource Estimate (Table 1). The Mineral Resource Estimate was based on drilling and channel samples done by Mustang Minerals Corp. in 1999, Freewest Resources Inc. in 1999-2000, and Pavey Ark Minerals Inc. in 2017. In total, 41 diamond-drill holes and 6 surface channels were utilized, for a total of 2864 drill core assays and 79 surface channel assays (Puritch, Yasa and Barry 2019).

The East Bull Lake intrusions extend to the east in Lockeyer and Mandamin townships (Figure 1), where there is potential for further Ni-Cu-PGE mineralization to be found. Over the past decade, minimal staking and exploration has taken place in this area, especially compared to the uranium-rich Elliot Lake camp directly to the west. The last geological survey project to map the area was done by Ontario Department of Mines geologists in 1943 (Moore and Armstrong 1943). On satellite imagery, there appears to be an abundance of outcrop exposure accessible by logging roads approximately 40 km north of the town of Massey. It is recommended that these underexplored Paleoproterozoic intrusions be re-examined for Ni-Cu-PGE potential.

Table 1. East Bull PGM deposit pit Constrained Mineral Resource Estimate at 0.8g/t PdEq cut-off (from 21C Metals Inc., classification: Inferred).

Tonnes (M)	11.1
Au (g/t)	0.05
Pt (g/t)	0.26
Pd (g/t)	0.58
Rh (g/t)	0.04
Cu (%)	0.14
Ni (%)	0.05
Co (%)	0.01
3PGM + Au (g/t)	0.93
PdEq (g/t)	1.46
PdEq (koz)	523

Hinz, S.L.K. 2020. Ni-Cu-PGE mineralization in Proterozoic mafic intrusions; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.49-51.

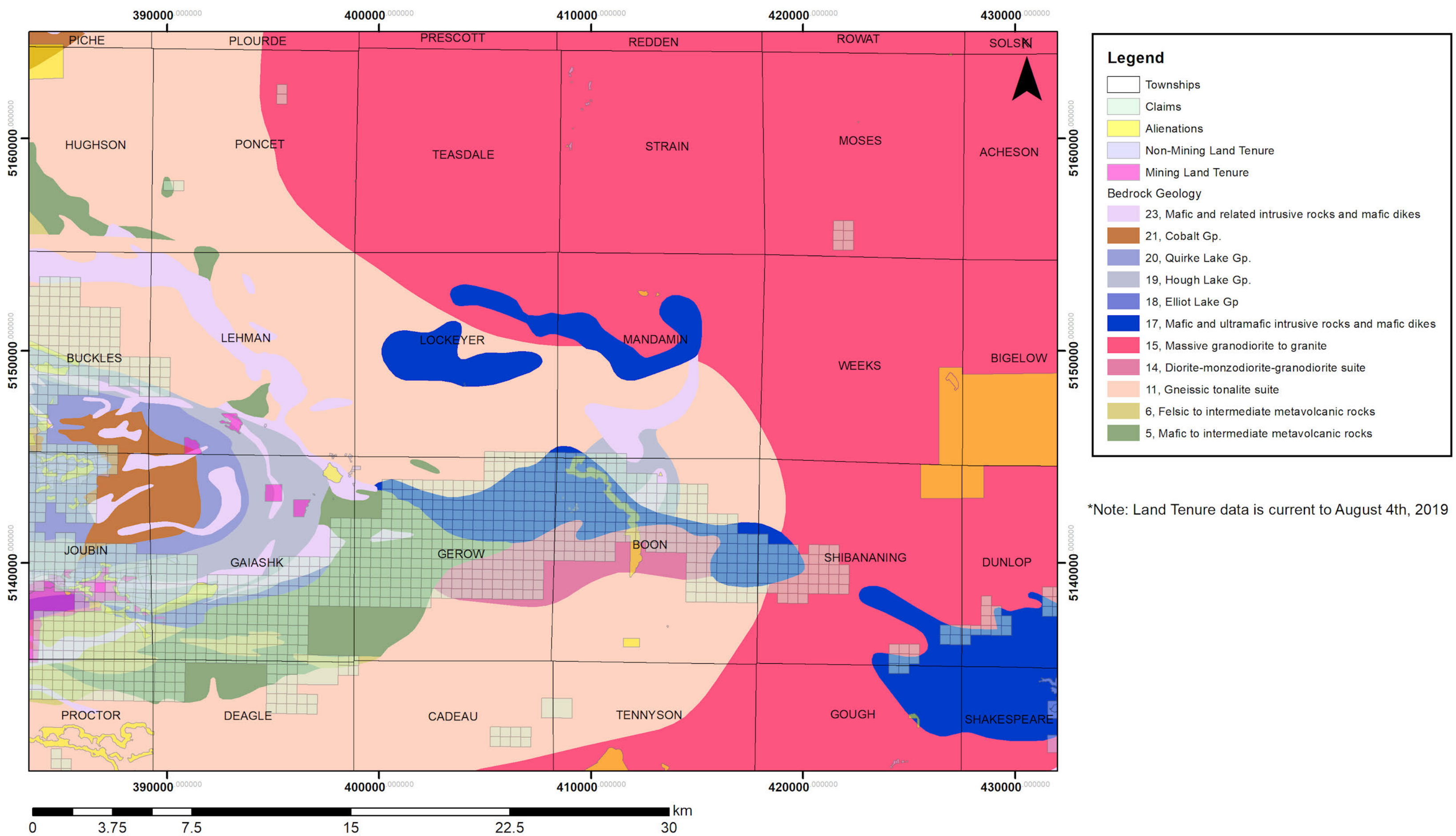

Figure 1. Geology map showing the area east of Elliot Lake overlain with land tenure. Four East Bull Lake intrusions are identified as geological unit 17. Mafic and ultramafic intrusive rocks and mafic dikes (*see* legend).

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HIGHLIGHTS

- **Economic outlook for PGEs and specifically palladium is increasingly positive**
- **Although most known PGE occurrences in the Thunder Bay North and South districts are currently staked, the area still has significant potential for new discoveries**
- **Numerous past recommendations for exploration are available to provide guidance on areas that should be considered for greenfield PGE exploration**

Contact:

Mark Puumala
Tel: 807-631-1032
Email: Mark.Puumala@ontario.ca

Robert Cundari
Tel: 807-475-1101
Email: Robert.Cundari@ontario.ca

Platinum Group Element Potential in Thunder Bay North and South Districts

The platinum group elements (PGEs), which include platinum, palladium, rhodium, ruthenium, iridium, and osmium, are critical to the production of catalytic converters, which decrease harmful emissions from automobile exhaust. Since October 2017, the average price of palladium has been higher than the price of platinum (United States Geological Survey 2019), making palladium a priority in exploration for PGEs. Palladium's price has since been continuing to perform strongly, increasing by 54% over the course of 2019 (www.bloomberg.com, *under* Markets, "Palladium Is Now More Than Gold Has Ever Been", December 12, 2019 [accessed December 12, 2019]). According to a poll by Reuters, palladium prices continue to be primed for record highs and are expected to continue the price lead over platinum to $595/oz in 2020. The poll also forecasts a 770 000 oz deficit in the palladium market, indicating that PGE exploration, and specifically palladium exploration can be expected to become increasingly profitable (www.reuters.com, *under* Business News, "Palladium Primed for Record Highs as Oversupply Batters Platinum: Reuters Poll", August 1, 2019 [accessed October 28, 2019]).

The Thunder Bay area has long been recognized as a favourable location to explore for PGEs (especially palladium), with prime targets including the following (Smyk et al. 2002).

- Pretectonic mafic to ultramafic intrusions occurring in Archean greenstone belts of the Wawa and Shebandowan subprovinces (e.g., Shebandowan Mine)
- Syntectonic to posttectonic Archean mafic to ultramafic intrusions of the "Lac des Iles"-type (e.g., Lac des Iles Mine), "Quetico"-type (e.g., Samuels Lake and Elbow Lake intrusion occurrences) and sanukitoid-type (e.g., Roaring River Complex occurrences)
- Proterozoic mafic to ultramafic intrusions of the Midcontinent Rift (e.g., Marathon PGM, Crystal Lake, Thunder Bay North and Sunday Lake deposits)

Numerous platinum group element exploration recommendations have been made over the years for the areas covered by the Resident Geologist Program in the Thunder Bay North and South districts. While some of the prospective areas are currently being actively explored, there is still a considerable amount of open ground that is well-suited for greenfield PGE exploration in both districts. Many areas that are currently staked are also available for option. Selected examples of past PGE exploration recommendations that warrant re-visiting are compiled in Table 1. Additional information about the PGE potential of the Thunder Bay area can be obtained by contacting the authors.

Puumala, M.A., Cundari, R.M. and Dorado–Troughton, M. 2020. Platinum group element potential in Thunder Bay north and south districts; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.53-56.

Table 1. Select PGE recommendations from previous Recommendations for Exploration (RFE) and Report of Activities (ROA) publications for the Thunder Bay North and South districts. Reports of Activities can be downloaded through the Ministry of Energy, Northern Development and Mines' online search application *GeologyOntario* (www.geologyontario.mndm.gov.on.ca); and previous years' *Recommendations for Exploration* can be retrieved from the Ministry's website at https://www.mndm.gov.on.ca/en/mines-and-minerals-article-categories/recommendations-exploration. Abbreviations: TBS, Thunder Bay South; TBN, Thunder Bay North; ROA, Report of Activities; OFR, Open File Report; RFE, Recommendations for Exploration.

Recommendation Title	RGP District	Year	Author(s)
Base Metal and Gold Potential in Adrian Township	TBS	ROA 2017 (OFR6338)	M.A. Puumala, D.A. Campbell, R.D. Tuomi, T.K. Pettigrew and S.L.K. Hinz
Copper-Nickel-Platinum Group Elements, Carbonatite and Diamond Potential in the Quetico Subprovince North of Lake Superior as Highlighted by New High-Resolution Geophysical Data	TBN/TBS	RFE 2015-2016	M.A. Puumala and R.M. Cundari
Copper-Nickel-Platinum Group Element Potential in the Area Between Northern Light Lake and Batwing Lake	TBS	RFE 2015-2016	M.A. Puumala and D.A. Campbell
Cu-Ni-PGE and Ti-V Potential in the Mesoproterozoic Badwater Intrusive Complex; Armstrong, Ontario	TBN	RFE 2014-2015	R.M. Cundari and G.D. White
Exploration Potential of the Garden Lake Area	TBS	RFE 2014-2015	M.A. Puumala and D.A. Campbell
Copper, Nickel and Platinum Group Element Potential in the Atikokan—Quetico Area	TBS	RFE 2014-2015	M.A. Puumala and D.A. Campbell
Exploration Potential in the Area Northeast of Killala Lake	TBS	RFE 2013-2014	M.A. Puumala and D.A. Campbell
Cu-Ni-PGE Mineralization in the Quetico-Eastern Wabigoon Domain Boundary	TBN	RFE 2013-2014	G.D. White
Targeting Contamination Centres and Structure in Search of Midcontinent Rift Related Conduit-Hosted Ni-Cu-PGE Deposits	TBN/TBS	RFE 2013-2014	R.M Cundari
Cu-Ni-PGE Mineralization in the Quetico-Marmion Domain Boundary	TBN	RFE 2011-2012	G.D. White
Ni-Cu-PGE Potential in Conmee Township - Eastern Shebandowan Belt	TBS	RFE 2009-2010	J.F. Scott and D.A. Campbell
Magmatic Cu-Ni-PGE Mineralization, Southeast Lake Nipigon Area	TBN	RFE 2009-2010	M.C. Smyk and G.D. White
Obonga Greenstone Belt: Ni-Cu-PGE and VMS Potential	TBS	RFE 2007-2008	J.F. Scott
PGE Potential of the Nipigon Embayment	TBS	RFE 2005-2006	T.R. Hart
Platinum Group Element Exploration Models	TBS	ROA 2001 (OFR6081)	B.R. Schnieders, J.F. Scott, M.C. Smyk, M.S. O'Brien, R. Debicki and A. Drost
Platinum Group Elements in Quetico Intrusions	TBS	ROA 2000 (OFR6049)	B.R. Schnieders, J.F. Scott, M.C. Smyk and M.S. O'Brien
Copper-Nickel-Platinum Group Element Deposits Associated with the Midcontinent Rift	TBS	ROA 2000 (OFR6049)	B.R. Schnieders, J.F. Scott, M.C. Smyk and M.S. O'Brien
Mafic and Ultramafic Rocks in Adrian and Conmee Townships	TBS	ROA 1999 (OFR6005)	B.R. Schnieders, J.F. Scott, M.C. Smyk and M.S. O'Brien
Copper-Nickel-Platinum Group Element Targets on the Southern Margin of the Crosman lake Batholith	TBS	ROA 1998 (OFR5989)	B.R. Schnieders, J.F. Scott, M.C. Smyk and M.S. O'Brien
Copper-Nickel-Platinum Group Element Potential in the Nipigon Basin – Thunder Bay Southwest Area	TBS	ROA 1997 (OFR5971)	B.R. Schnieders, J.F. Scott and M.C. Smyk
Copper-Nickel-Platinum Group Element Potential Near the Margins of the Black-Pic Batholithic Complex	TBS	ROA 1995 (OFR5943)	B.R. Schnieders, M.C. Smyk and D.B. McKay

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PEG: A New Tool for Referencing Historical Geological Information

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

The Property Examination Geodatabase (PEG) has been developed to serve as a tool that will allow users to more easily discover RGP property examination articles. These articles are currently easy to overlook, as they are included as relatively brief articles embedded within the annual Report of Activities (ROA) reports that have been published in various formats over the years. From 1967 to 1996, the respective Resident Geologists' reports were compiled within single volumes covering the entire province (as Miscellaneous Papers until 1992 and Open File Reports from 1993 to 1996), while individual Open File Reports have been published for each district since 1997. Resident Geologist District boundaries have also changed numerous times over the years, adding to the challenge of locating articles for specific areas of interest. The PEG simplifies the process of locating property examinations by providing a spatially referenced point for each article, presented as a KML layer in Google Earth (Figure 1). A pop-up for each point displays metadata which includes a link to the article, location information, report references, availability of assay data and information on associated Mineral Deposit Inventory occurrences and Assessment Files (Figure 2).

This product is being made available for the Thunder Bay North and South districts as a pilot project to highlight potentially overlooked sources of geological interpretations and data that are available in historical government reports. The product also highlights the value of the expert geological evaluation services, and the research-quality laboratory services that are provided by the Ontario Geological Survey. PEG can be useful for immediate and adjacent property holders who may not be aware of the availability of applicable property examination articles. PEG can also be useful for targeting purposes as several PEG points relate to properties or portions of properties that are currently open for acquisition.

Cundari, R.M. and Puumala, M.A. 2020. PEG: A new tool for referencing historical geological information; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.57-58.

HIGHLIGHTS

- **New compilation for Thunder Bay North and Thunder Bay South districts highlights historical property examination articles from past annual Resident Geologist Reports of Activities dating back to 1967 and makes them much easier to locate**
- **Property examinations included in the Resident Geologist Program (RGP) reports of activities contain valuable geological interpretations and data from field work completed by government geoscientists**
- **Property examination articles provide information that can be used to inform decision-making for investments in new and existing mineral exploration projects**

Contact:

Robert Cundari
Tel: 807-475-1101
Email: Robert.Cundari@ontario.ca

Mark Puumala
Tel: 807-631-1032
Email: Mark.Puumala@ontario.ca

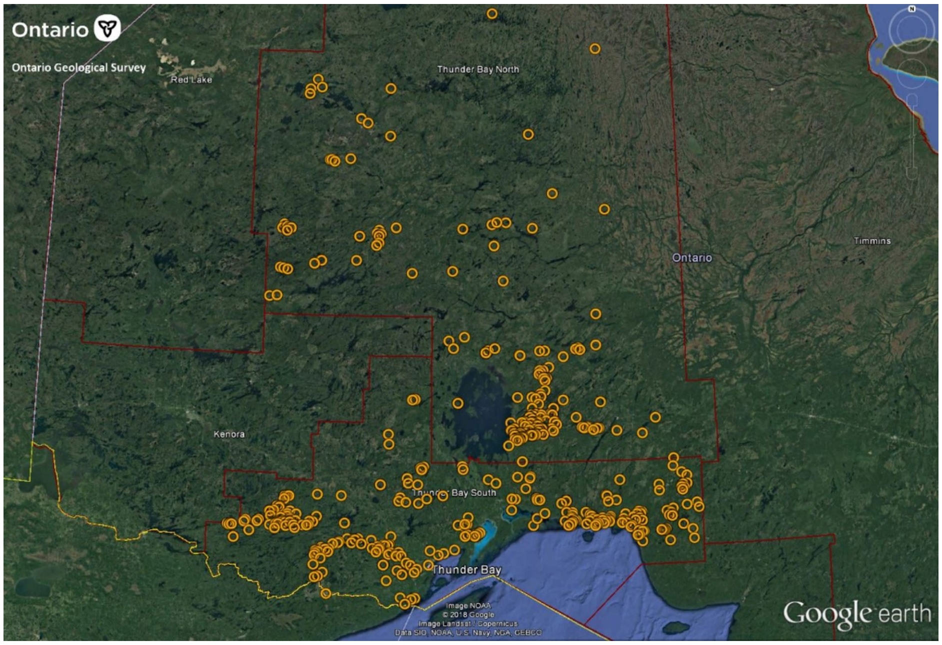

Figure 1. Map showing the pilot Property Examination Geodatabase KML and the distribution of points in the Thunder Bay North and South districts.

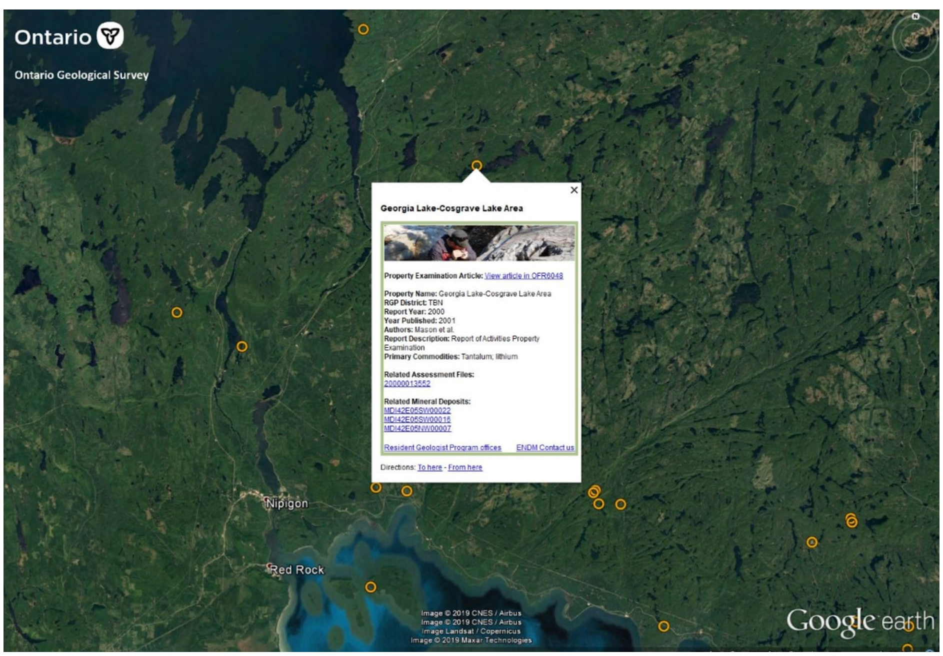

Figure 2. Map with a pop-up showing the metadata displayed for a point in the Property Examination Geodatabase KML.

The PEG KML layer is now available online through OGSEarth, under the Northern Ontario heading, at (http://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth). The entire geodatabase, which includes an Excel spreadsheet and corresponding Google Earth KML files, is also available directly from the authors of this article (contact information provided in this article).

Fe-Ti-V Potential in the Roaring River Complex near Allely Lake

HIGHLIGHTS

- **Recent geochemical sampling in the Allely Lake area has identified magnetite-rich intrusive rocks with elevated concentrations of vanadium**
- **Nearby magnetic anomalies indicate potential for the occurrence of massive magmatic oxide iron-titanium-vanadium (Fe-Ti-V) mineralization**
- **Rocks in this area have similarities to those of the Fe-Ti-V mineralized Empire Lake intrusion, located 20 km to the northeast**

Contact:

Mark Puumala
Tel: 807-631-1032
Email: Mark.Puumala@ontario.ca

Dorothy Campbell
Tel: 807-620-2290
Email: Dorothy.Campbell@ontario.ca

An area near the western limit of the Roaring River Complex near Allely Lake was recently recommended for Fe-Ti-V oxide exploration by the Ontario Geological Survey Resident Geologist Program (Puumala and Campbell 2019). This recommendation was based on a combination of favourable lake sediment survey data, aeromagnetic features and geochronology. During the 2019 field season, personnel from the Thunder Bay Resident Geologist Program office completed a geological reconnaissance program in the Allely Lake area. The purpose of this work was to collect additional information about the geology and geochemistry of this area in order to further establish its Fe-Ti-V oxide mineralization potential.

The 2019 field program was focussed on the area (Figures 1 and 2) where Stone et al. (2002) reported geochronology results from a sample of gabbroic anorthosite. The results from this sample provided an age that is comparable to that obtained from the Fe-Ti-V mineralized Empire Lake intrusion (Flank 2014), which is located approximately 20 km to the northeast. The field area was accessed by travelling approximately 69 km north (from Highway 17) along Graham Road to the intersection with Moberly Road, and then travelling west along Moberly Road for approximately 3 km. From here, outcrop exposures were examined along Moberly Road and on a secondary logging road that extends for approximately 1 km to the south (*see* Figure 2). This area has seen recent logging activity, with excellent access and outcrop exposure.

The area examined was dominated by intrusive rocks, with an intrusive contact with amphibolite noted at one location. The intrusive rocks displayed wide textural and compositional variability. Lithologies that were tentatively identified in the field included gabbro, anorthositic gabbro, quartz diorite, tonalite and granite. Most of the intrusive rocks, except for the granites, are magnetite-rich and appear to comprise separate phases of a single intrusion (presumably the Roaring River Complex). The granites typically occur as late, cross-cutting pegmatite and aplite dikes.

Layered gabbro with centimetre-scale magnetite-rich melanocratic layers was observed in one outcrop located immediately south of Moberly Road at UTM co-ordinates 15 U, 687621E, 5496182N. The layered gabbro has been brecciated and intruded by coarse-grained to pegmatitic leucogabbro (Photo 1). An adjacent outcrop immediately to the east exposes medium-grained, magnetite-rich quartz diorite that appears to display some crude layering. At UTM co-ordinates 15 U, 687704E, 5495743N, on the secondary logging road south of Moberly Road, an outcrop of gabbro containing fragments of massive magnetite was also observed.

Puumala, M.A. 2020. Fe-Ti-V Potential in the Roaring River Complex near Allely Lake; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.59-63.

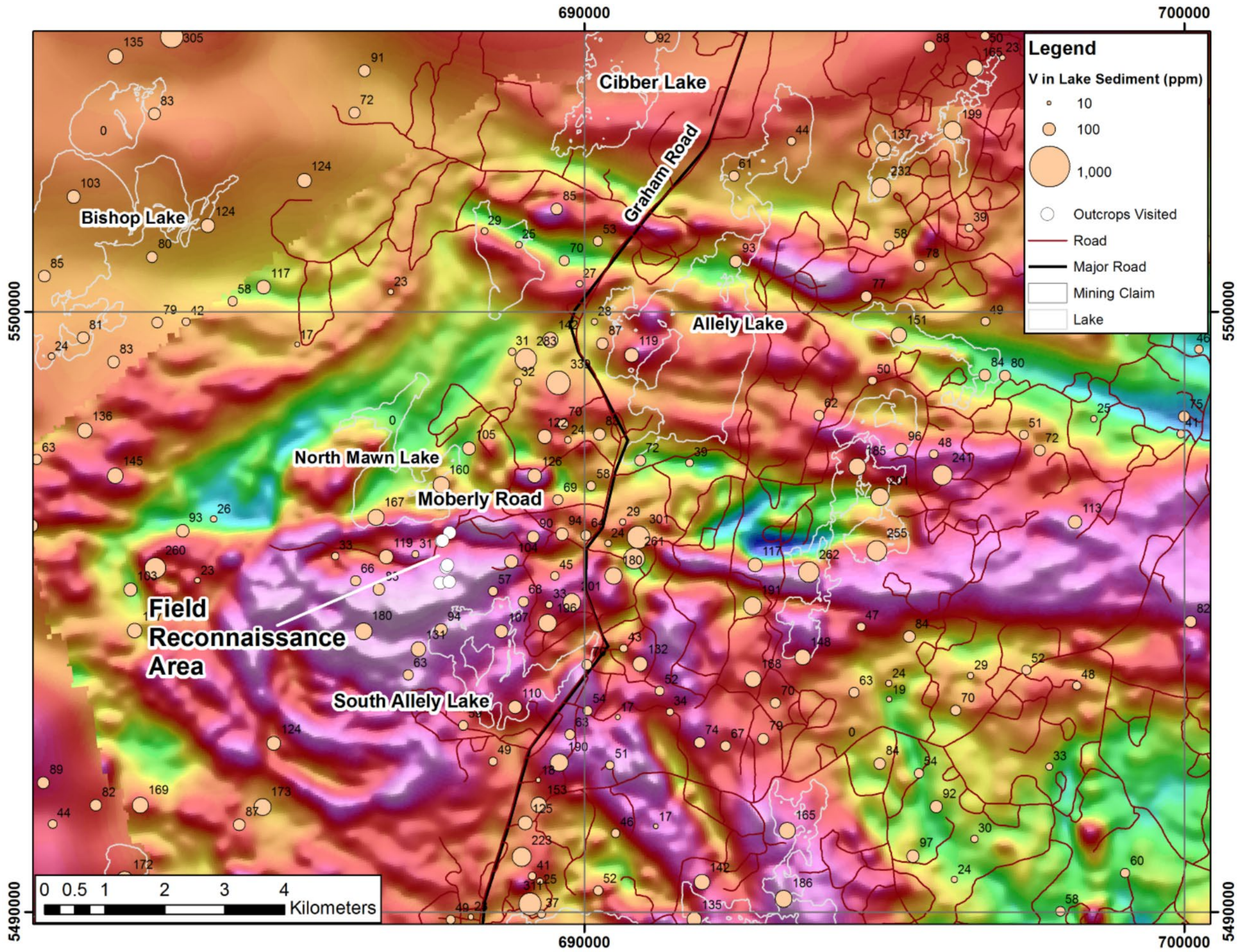

Figure 1. Total residual magnetic field map (Ontario Geological Survey 2003) of the Allely Lake area illustrating the field reconnaissance sampling area and the vanadium results from Ontario Geological Survey lake sediment sampling (Dyer and Jackson 2000). Pink shaded areas represent magnetic 'highs', while blue represents magnetic 'lows'.

Most of the outcrops that were observed on the secondary logging road were dominated by coarse-grained, magnetite-rich quartz diorite and tonalite. In places, these rocks are intruded by irregular bodies of amphibole-bearing pegmatite. These tonalitic to gabbroic pegmatites display wide variability in their relative proportions of felsic minerals to amphibole, although most are leucocratic (*see* Photos 2A and 2B). The quartz diorite is also cross-cut by numerous granitic dikes that are often garnet bearing and appear to be the latest intrusions.

Rock samples were collected for geochemical analyses at 5 locations where the lithology appeared likely to be related to the Roaring River Complex. One of the goals of this sampling was to determine if anomalous vanadium concentrations are present in any of the magnetite-rich rocks. Sample locations and hand specimen descriptions are provided in Table 1, while the analytical results for major elements and base metals are tabulated in Tables 2 and 3.

The most notable geochemical results were obtained from sample MP19WPT403. This sample of gabbroic rock contained xenoliths of massive magnetite and returned an elevated vanadium value of 708 ppm (equivalent to 1264 ppm V_2O_5), along with Fe_2O_3 and TiO_2 values of 21.82% and 2.9%, respectively. This result, along with the field observation of layered, magnetite-rich gabbro in outcrop reinforce the prospectivity of the Allely Lake area for the discovery of massive Fe-Ti-V oxide mineralization. The total field magnetic imagery shown on Figures 1 and 2

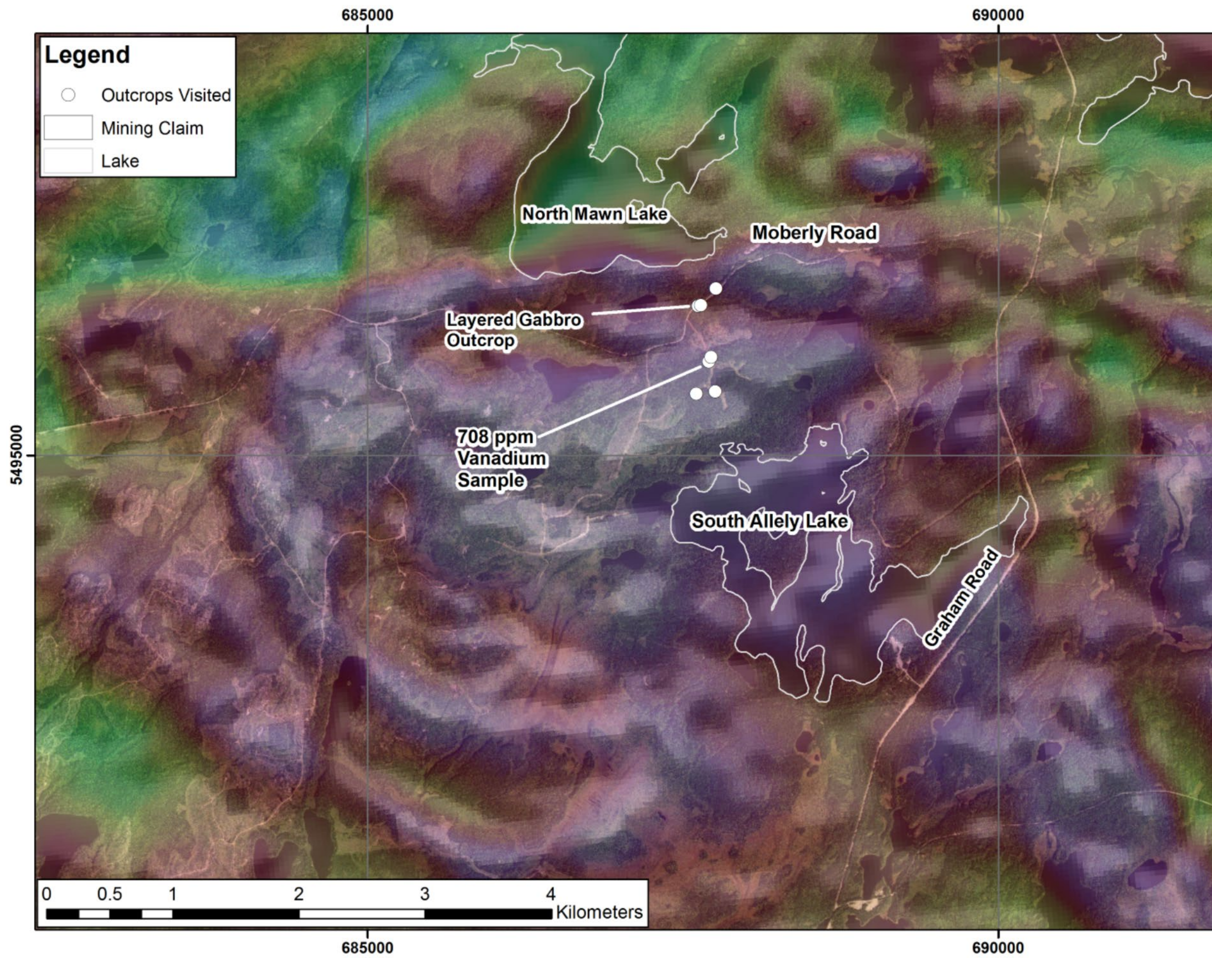

Figure 2. Map showing the Allely Lake area, overlain by total residual magnetic field imagery (Ontario Geological Survey 2003), examined during the 2019 RGP field reconnaissance program. Aerial imagery shows logging roads which provide excellent access for prospecting.

indicates the presence of east-trending magnetic 'highs' (denoted in pink) both to the north and south of the area investigated. It is recommended that local Fe-Ti-V prospecting efforts be focussed on these areas. Additional target areas for prospecting in the wider Allely Lake area can be identified by using a combination of Ontario Geological Survey lake sediment geochemistry and aeromagnetic data, both of which are highlighted on Figure 1. It is also worth noting that the logging roads visible on Figure 2 provide excellent access to many of the magnetic 'highs'.

Table 1. Location and description of rock samples collected in the Allely Lake area.

Sample	Easting	Northing	Rock Type (field)	Sample Description
MP19WPT398A	687764	5496320	Gabbro	Medium-grained, magnetite-rich, minor carbonate alteration.
MP19WPT398B	687764	5496320	Quartz monzodiorite	Coarse-grained to pegmatitic, crude layers of hornblende and magnetite (<1cm wide), minor rusty pyrite stringers.
MP19WPT400	687644	5496191	Quartz gabbro	Medium-grained, magnetite-rich, 5% disseminated very fine-grained sulphides.
MP19WPT403	687704	5495743	Gabbro	Moderately magnetic groundmass, massive magnetite lenses 1 cm wide and 3-4 cm long, 1% disseminated very fine-grained sulphides.
MP19WPT404	687723	5495778	Leucogabbro	Extremely variable texture (fine-grained to pegmatitic), trace pyrrhotite.

Photo 1. Brecciated, layered gabbro intruded by coarse-grained leucogabbro.

Table 2. Major element analytical data of rock samples collected in the Allely Lake area. Values are provided in weight percent.

Sample	Al_2O_3	BaO	CaO	Cr_2O_3	Fe_2O_3	K2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2
MP19WPT398A	15.84	0.025	8.734	0.047	13.41	0.87	6.84	0.218	3.18	0.104	48.25	0.82
MP19WPT398B	23.41	0.047	7.847	0.003	5.67	1.43	2.11	0.082	5	0.015	53.45	0.26
MP19WPT400	20.63	0.017	8.321	0.008	12.81	0.46	4.98	0.196	3.57	0.281	46.68	1.50
MP19WPT403	14.73	0.013	9.01	0.008	21.82	0.42	4.27	0.273	2.7	0.37	43.42	2.90
MP19WPT404	15.31	0.03	8.833	0.082	13.81	0.59	6.42	0.283	2.6	0.023	50.5	1.08

Table 3. Base metal analytical data of rock samples collected in the Allely Lake area. Values are provided in parts per million (ppm).

Sample	Co	Cu	Ni	Pb	Sr	V	Zn	Zr
MP19WPT398A	37	27	88	<12	368	263	167	44
MP19WPT398B	12	27	21	<12	524	104	71	23
MP19WPT400	34	53	50	<12	428	274	125	38
MP19WPT403	49	54	25	73	350	708	234	158
MP19WPT404	40	43	57	<12	253	208	173	280

Photo 2. A) Leucocratic, amphibole-bearing pegmatite intruding quartz diorite. **B)** Melanocratic amphibole-bearing pegmatite.

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Exploration Potential in the Quetico Subprovince Near Far Lake

The recent discovery of high-grade copper mineralization at Far Lake by White Metal Resources Corp. has identified a new mineralized geological structure west of Thunder Bay. One sample collected by White Metal from a zone of semi-massive chalcopyrite returned an assay value of 22% copper, 30.2 g/t silver and 215 ppb gold from a 0.7 metre channel sample (White Metal Resources Corp., *news release*, September 30, 2019). This discovery was made in a virtually unexplored portion of the Quetico Subprovince that warrants further attention for its mineral potential, especially considering the availability of recent aeromagnetic survey data for this area (Ontario Geological Survey 2015).

Copper mineralization at Far Lake is associated with a northwest-striking fault zone that crosscuts Neoarchean metasedimentary rocks of the Kashabowie Group and white muscovite-biotite granite (Morin 1973). The granite occurs as migmatitic segregations within the metasedimentary rocks and as discrete intrusive bodies. The fault zone is strongly silicified, with variable carbonatization and chlorite alteration that is associated with sulphide mineralization. Sulphide mineralization consists largely of pyrite and chalcopyrite and ranges from disseminated to semi-massive. The most significant mineralization appears to occur in breccia zones where the fault crosscuts the more competent granitic rocks.

The Far Lake fault zone parallels, and may be related to, a larger northwest-striking structure that is marked by a pronounced magnetic discontinuity that occurs approximately 1.5 km to the west of the Far Lake copper occurrence and coincides with a previously mapped lineament (Morin 1973). Another northwest-striking magnetic discontinuity that occurs to the east is also highlighted on Figure 1. Each of these structures (and any nearby, subsidiary ones) are prospective for hydrothermal copper-silver-gold (Cu-Ag-Au) mineralization and warrant further prospecting.

As shown on Figure 1, the larger northwest-striking structure west of Far Lake extends between the east-striking Quetico fault to the north, and the east-southeast-striking Postans fault to the south, suggesting that it may be a splay that links these 2 major regional faults. Such a linkage indicates the possibility of a significant hydrothermal mineralization system having developed in this area. The Postans fault marks the southern boundary of the Quetico Subprovince, where it meets the Shebandowan greenstone belt of the Wawa Subprovince (*see* Figure 1). The Quetico fault passes through the centre of the Quetico Subprovince, north of Far Lake, and marks the northern boundary with the Wabigoon Subprovince farther to the west, where it merges with the northeast-striking Shelby Lake fault (Stone 2010).

HIGHLIGHTS

- **High-grade copper mineralization was recently discovered by White Metal Resources Corp. in a virtually unexplored portion of the Quetico Subprovince north of Far Lake**
- **The mineralization occurs in a northwest-striking fault zone that may be part of a splay system connecting the Quetico and Postans faults**
- **This, and other parallel structures in the area warrant further exploration for similar copper-silver-gold mineralization**
- **The area also has potential for mafic to ultramafic intrusion–hosted copper-nickel-platinum group element mineralization**

Contact:

Mark Puumala
Tel: 807-631-1032
Email: Mark.Puumala@ontario.ca

Dorothy Campbell
Tel: 807-620-2290
Email: Dorothy.Campbell@ontario.ca

Puumala, M.A. 2020. Exploration potential in the Quetico Subprovince near Far Lake; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.65-68.

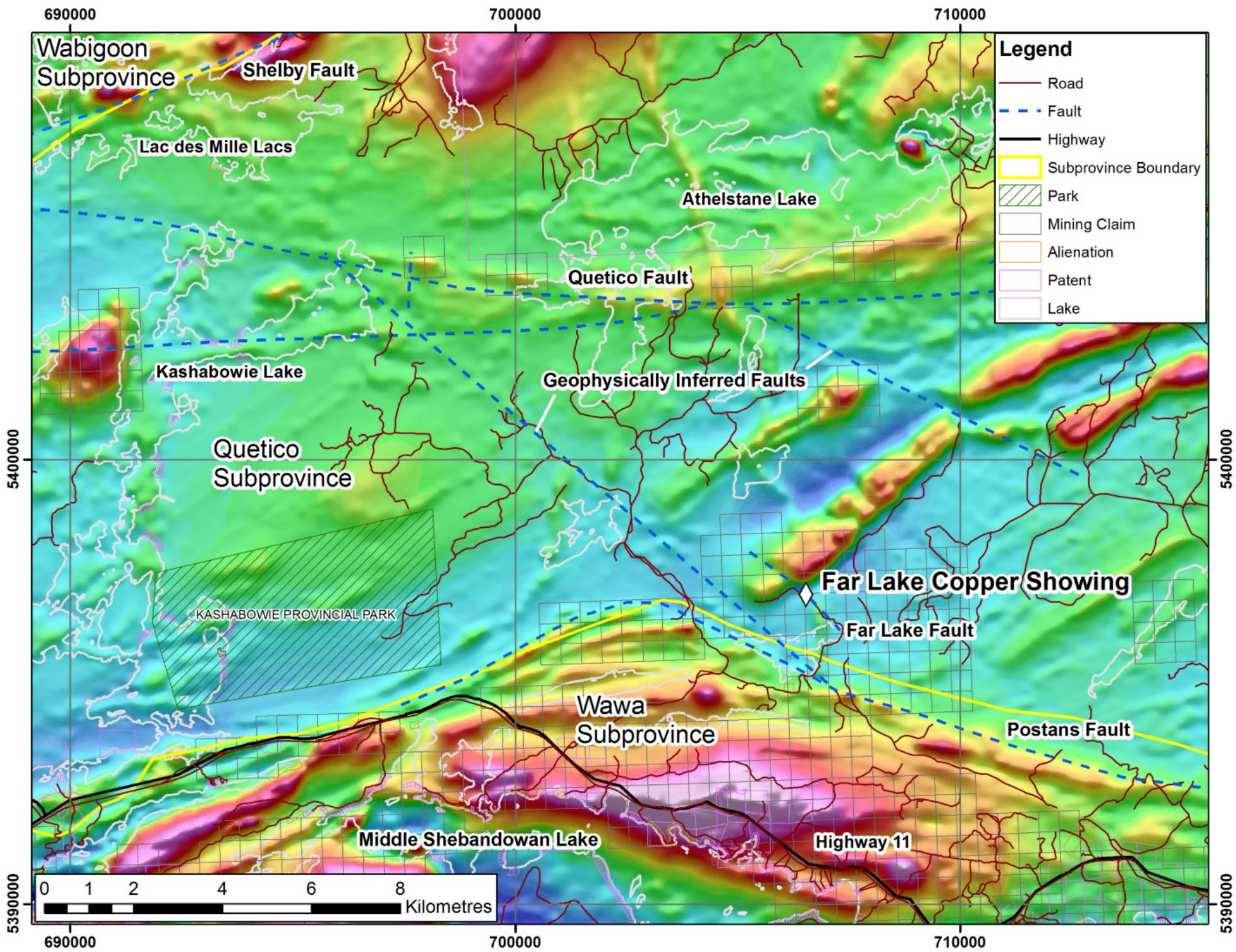

Figure 1. The total field magnetic image overlain on a map of the Far Lake area (Ontario Geological Survey 2003, 2015). The Far Lake copper showing and fault are illustrated along with 2 parallel structures that have been inferred from the geophysical data. The Quetico and Postans faults are major regional faults.

The Far Lake area should also be prospected for mafic to ultramafic intrusion-hosted copper–nickel–platinum group element (Cu-Ni-PGE) mineralization. This is because numerous PGE rich intrusions of this type (commonly referred to as Quetico intrusions) are known to occur elsewhere in the Quetico Subprovince proximal to the Quetico fault (MacTavish 1999). These intrusions, which typically occur as relatively small stocks (Stone 2010), often display distinctive positive or negative signatures in airborne magnetic survey data (Puumala et al. 2015). Therefore, areas that are underlain by magnetic “highs” in the Far Lake area (pink areas, highlighted in Figure 2) warrant prospecting for Quetico-type intrusions. Another factor that points to the potential for Quetico intrusions in this area is the presence of several lake sediment sampling sites (Jackson 2001) that show elevated palladium values (*see* Figure 2).

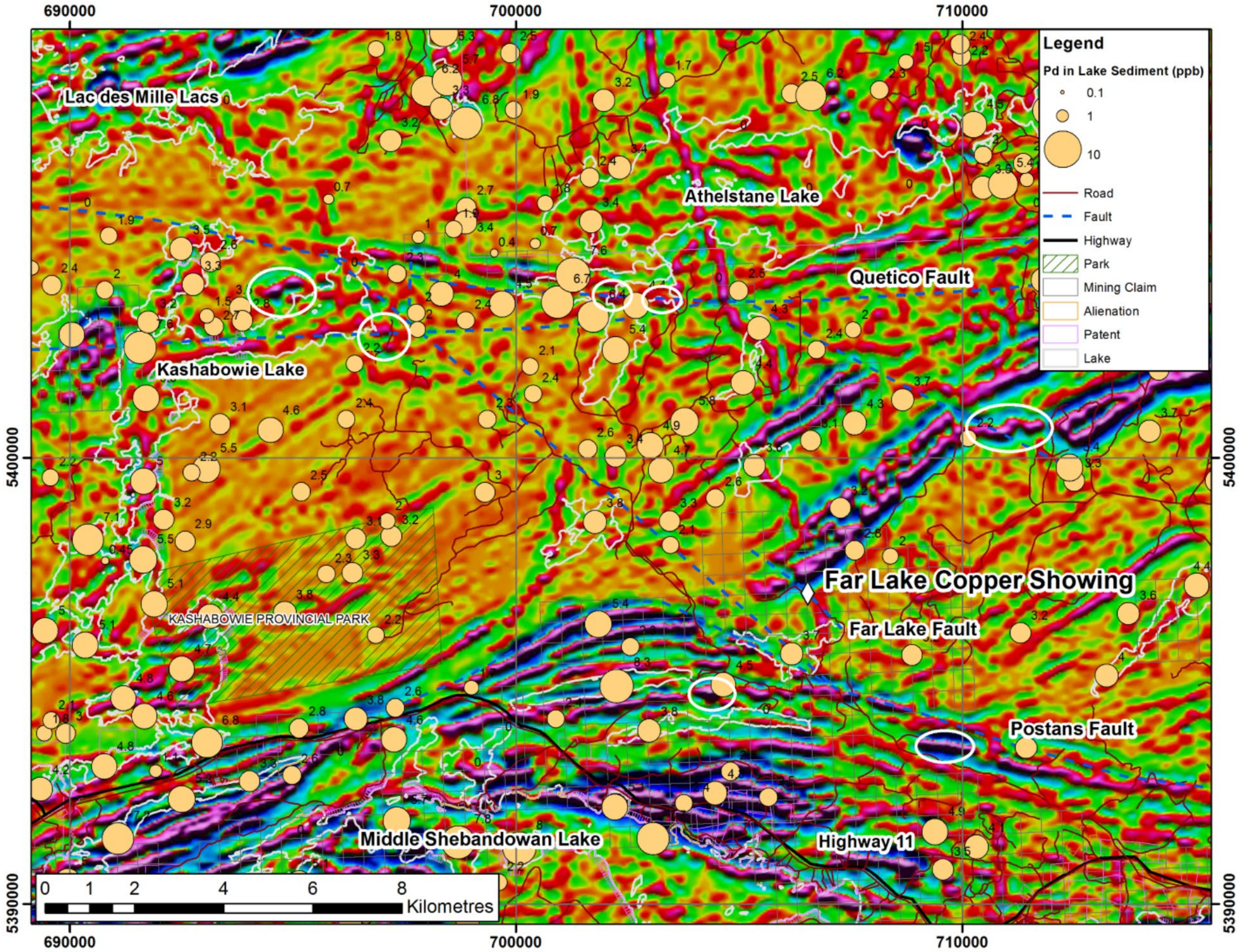

Figure 2. The shaded image of the second vertical derivative of the total magnetic field of the Far Lake area (Ontario Geological Survey 2003, 2015) overlain with proportional dots representing palladium concentrations in lake sediment (Jackson 2001). White circles illustrate areas with interesting magnetic anomalies where prospecting for mafic to ultramafic intrusions is warranted. Magnetic 'high' is represented by pink and the magnetic 'low' in blue in this image.

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HIGHLIGHTS

- **Ultramafic rocks located west-southwest of past-producing Cu-Ni-Co-PGE Shebandowan Mine have seen limited exploration over the past 60 years**
- **Historical assessment files include drill log information describing 100s of feet of serpentinization and disseminated sulphides in some of these ultramafic rocks**
- **Drill core intercepts up to 100 m with elevated nickel values (500 to 950 ppm) are hosted by disseminated sulphide-bearing pyroxenitic komatiites**
- **Coincident geophysical anomalies warrant further (re-)investigation for potential Cu-Ni-Co-PGE deposits**

Contact:

Dorothy Campbell
Tel: (807) 620-2290
Email: Dorothy.Campbell@ontario.ca

Desmond Rainsford
Tel: (705) 670-5997
Email: Des.Rainsford@ontario.ca

Nickel-Copper-Cobalt-PGE Potential in the Shebandowan Greenstone Belt

Limited exploration has been undertaken in Archean ultramafic rocks west of the past-producing Shebandowan nickel-copper-cobalt-PGE Mine (Figure 1). The geology in this area consists of an east-trending package of Archean rocks of the west-central Shebandowan greenstone belt of the Wawa Subprovince (Osmani 1997). Nickel-copper ore was discovered on the shoreline of Lower Shebandowan Lake, at Discovery Point by prospector Julian Cross in 1913. Little to no exploration was carried out until 1936. Subsequently, it was another 30 years before the Shebandowan Mine was developed, as most of the deposit was located under the lake. The average width of the ore body was approximately 7.5 m and was mined over a strike length of 3.5 km to a maximum depth of 1000 m (Inco 2001). The Shebandowan Mine produced 9.29 million tonnes of ore at 1.75% nickel, 0.88% copper, 0.063% cobalt, 0.0533 oz/ton PGEs and 0.0575 oz/ton silver (Inco 2001).

Osmani (1997) mapped several peridotites west and southwest of the Shebandowan Mine that have seen limited Cu-Ni-Co-PGE exploration (*see* Figure 1, outlined with red circles and ovals). The Shebandowan deposit has been traditionally considered to be hosted by a serpentinized peridotite sill that forms part of a mafic metavolcanic rock-dominated sequence (Osmani 1997). New evidence suggests these host rocks may in fact be komatiitic flows (Aubut and Campbell 2012) with implications for the possible localization of magmatic sulphide Cu-Ni-Co-PGE mineralization at the basal contacts.

Historical information from diamond-drill core in assessment reports filed by Steep Rock Iron Mines (Hawkins 1957), Goldale Mines Limited (1957), Orolea Mines Ltd (1952), Avenue Syndicate (1960), Canadian Nickel Co. Ltd. (1970) and others indicate there are peridotites with sections of serpentinization, shearing, disseminated pyrrhotite, pyrite and traces of chalcopyrite in the target area. The peridotite(s) described in drill logs are the same type of rocks that host the Shebandowan Cu-Ni-Co-PGE deposit. In the late 1950s and 1960s, most exploration companies did not provide assay data in the assessment reports and may not have sampled potential Cu-Ni-Co-PGE mineralized and/or altered zones as described in historical drill logs. These peridotites warrant further (re-)investigation based on geological models of magmatic ore deposits, descriptions of alteration and mineralization of peridotites, geophysical anomalies, proximity to the Cu-Ni-Co-PGE Shebandowan Mine and the fact that the area has seen limited exploration over the past 60 years.

This recommendation will highlight mafic–ultramafic rocks located west-southwest of Loch (lake) Erne (outlined with a red oval on the Holbik property shown in Figure 1).The property is held by Ed Holbik and Barry

Campbell, D.A. and Rainsford, D.R.B. 2020. Nickel-copper-cobalt-PGE potential in the Shebandowan greenstone belt; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.69-74.

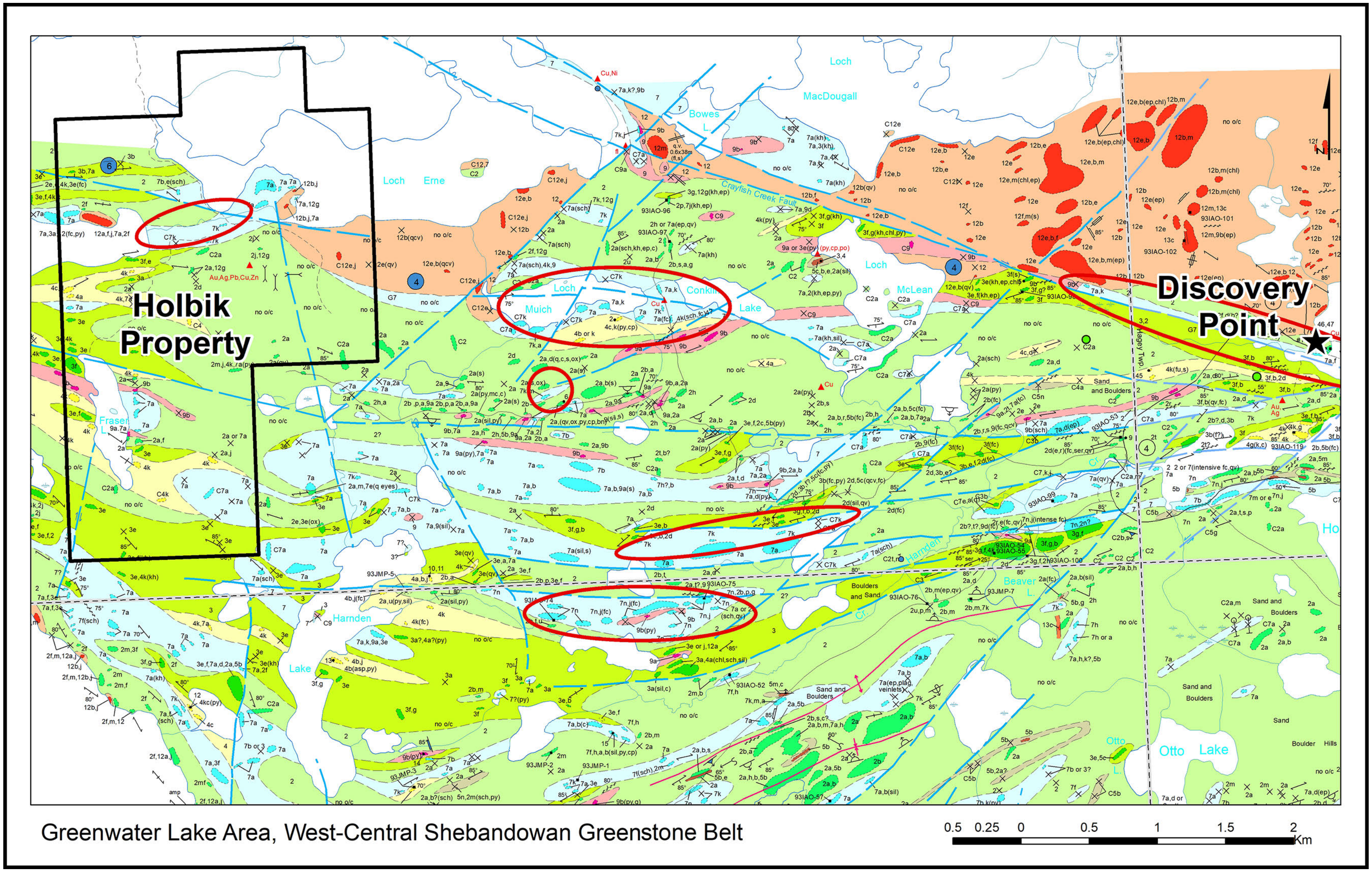

Figure 1. Geology map modified from Osmani (1997) showing Holbik property outline and areas mapped as peridotites (geological units 7k, 7n). Peridotite bodies are highlighted with red circles and ovals west and southwest of the Shebandowan Cu-Ni-Co-PGE mine.

Holbik. This property is available for option while all the other mafic–ultramafic rocks outlined with red ovals and circles are located on patented mining lands. Steep Rock Iron Mines (Hawkins 1957) completed 3 diamond-drill holes (ddh) (yellow dots, Figure 2) on the Holbik property, reporting hundreds of feet of serpentinized peridotite with sections of shearing, pyrrhotite, pyrite and traces of chalcopyrite in the drill logs; however, no assays were provided. These drill logs are available from assessment file 52B09SW0025 (Hawkins 1957). All assessment files discussed in this article are listed in the references and are available from the Ontario Assessment File Database (OAFD) through the Ministry of Energy, Northern Development and Mines' online search application *GeologyOntario* (www.geologyontario.mndm.gov.on.ca).

The property was visited in the fall of 2019 by prospector Ed Holbik and Resident Geologist Program (RGP) District Geologist D. Campbell. A broken-down core rack and pieces of AQ drill core were located on the southwest shore of Loch Erne. Samples were collected from the spilled core pile. A total of 7 grab samples were collected from outcrops of peridotite located between Loch Erne and Greenwater lakes and 1 sample of gabbro was collected on the north side of Loch Erne. Geochemistry results for these samples are pending. The peridotite is dark-grey to black, fine- to medium-grained, massive to foliated, strongly magnetic, carbonate altered, serpentinized and has trace to minor disseminated sulphide mineralization.

Steep Rock tested the southern portion of the peridotite; however, there are electromagnetic (EM) and induced polarization (IP) geophysical anomalies to the north that have not been tested (Figures 4A and 4B). Third party geochemical results from grab samples of ultramafic rocks returned magnesium (MgO) values >18%, anomalous nickel (Ni) >400 ppm and chromium (Cr) >800 ppm, values typical of komatiites, as shown in Table 1 (values for SiO_2, K_2O and incompatible elements were not provided) (E. Holbik, unpublished data, 2011).

Agnico Eagle optioned the property from 2006 to 2009 with exploration programs consisting of trenching, sampling, diamond-drilling (8 ddh), induced polarization and magnetic surveys. Agnico Eagle carried out exploration programs that focused primarily on the gold potential in quartz veins, shear zones and iron formation hosted by metavolcanic and metasedimentary rocks, south of where Steep Rock drilled the peridotite in 1957. However, 3 drilled holes (369-08-05, 369-08-06 and 369-08-07, white dots, Figure 2) intersected ultramafic rocks at depth (logged as pyroxenitic komatiites) with associated disseminated pyrite and pyrrhotite (Figure 3). Agnico Eagle (Lavoie 2008) analysed the ultramafic rocks for copper and nickel by aqua regia–atomic absorption mass spectrometry. Anomalous nickel values (ranging from 500 up to 950 ppm) were returned and are shown in Table 2.

Airborne magnetic and electromagnetic (EM) surveys were flown over the area by the Ontario Geological Survey (2003). A circular magnetic high response, located on the west side of Loch Erne, has 2 EM anomalies (blue dots) flanking the west side and 1 EM anomaly on the northeast side of the magnetic anomaly (*see* Figure 2). These anomalies may be accounted for by conductive lake bottom sediments, but bedrock sources cannot be ruled out without further investigation. Desmond Rainsford, Geophysicist with the Ontario Geological Survey (OGS) compiled a detailed electromagnetic map of this area indicating coincident EM apparent resistivity and EM anomalies, as shown on Figure 4A. Agnico Eagle (Lambert 2007) completed an IP survey on the southside of the peridotite. Rainsford suggests a potential alternative alignment of an IP axis to conform with a northwest aeromagnetic trend (Figure 4B). In the northwestern part of the grid, a significant gold intercept (3208 ppb Au over 1.3 m) was discovered in the diamond-drill hole 369-08-01 by Agnico Eagle1 (Figure 4B). This intercept occurs in an area with a strong IP anomaly and is associated with disseminated sulphides (7% pyrrhotite). The hole was drilled oblique to the interpreted axes of the IP anomaly and, because the IP anomaly was intercepted with only a single hole, there seems to be good reason to drill the same anomaly further with holes oriented perpendicular to the IP trend. Also, extending the IP coverage to the north and west in order to trace the sulphide horizon along strike seems to be warranted.

Agnico Eagle drilled tested the northeast IP anomaly with drill hole (369-08-08) intersecting metavolcanic rocks with disseminated sulphides and an intercept of 6.6 m of pyroxenitic komatiite with up to 15% pyrite near the end of the drill hole at 181.8 m to 188.4 m; assay values for nickel were not provided.

The Ni-Cu-Co-PGE deposits are generally too small to be readily identified in regional-scale geophysical

Table 1. Geochemical analyses from a third party indicate ultramafic rocks returned MgO >18%, Ni >400 ppm, Cr >800 ppm, values typical of komatiites (E. Holbik, unpublished data, 2011). Abbreviations: Qz vn, quartz vein; Upd, peridotite.

Sample	Easting	Northing	Lithology	MgO %	Al_2O_3 %	CaO %	Fe_2O_3 %	TiO_2 %	Ni ppm	Co ppm	Cr ppm	Cu ppm	S %	Au ppb	Pt ppb	Pd ppb
J554009	692860	5386888	Felsic tuff	3.9	7.9	5.2	18.3	0.4	55	26	73	138	6.69	54	2	1
J554010	692774	5386694	Upd	27.5	4.0	1.7	13.6	0.3	920	109	2230	26	0.03	3	4	4
J554011	692580	5386754	Upd	25.4	5.1	3.8	13.1	0.3	822	95	1900	18	0.06	4	3	4
J554012	693472	5387304	Upd	28.3	3.8	2.6	14.2	0.3	821	113	2680	8	0.01	4	3	5
J554013	693462	5387196	Upd	20.8	3.9	8.0	10.5	0.2	767	70	1615	47	0.43	2	2	2
J554014	693186	5387338	Upd	29.8	3.7	2.5	13.9	0.2	872	116	2060	1	0.01	2	3	3
J554015	693517	5387121	Qz vn	2.3	3.7	0.1	2.4	0.1	40	9	255	1140	0.21	57	1	3
J554016	692971	5387348	Upd	28.3	4.0	2.3	14.4	0.3	694	112	1410	30	0.01	2	3	4
J554017	693588	5387805	Upd	29.2	3.6	1.4	14.7	0.2	874	119	2040	22	0.03	2	27	4
J554018	693621	5387739	Upx	19.9	8.4	6.4	14.4	0.7	546	78	960	20	0.07	2	5	6
J554019	693589	5387973	Upd-shear	21.1	1.9	11.1	14.2	0.1	2000	136	2590	116	0.47	8	31	106

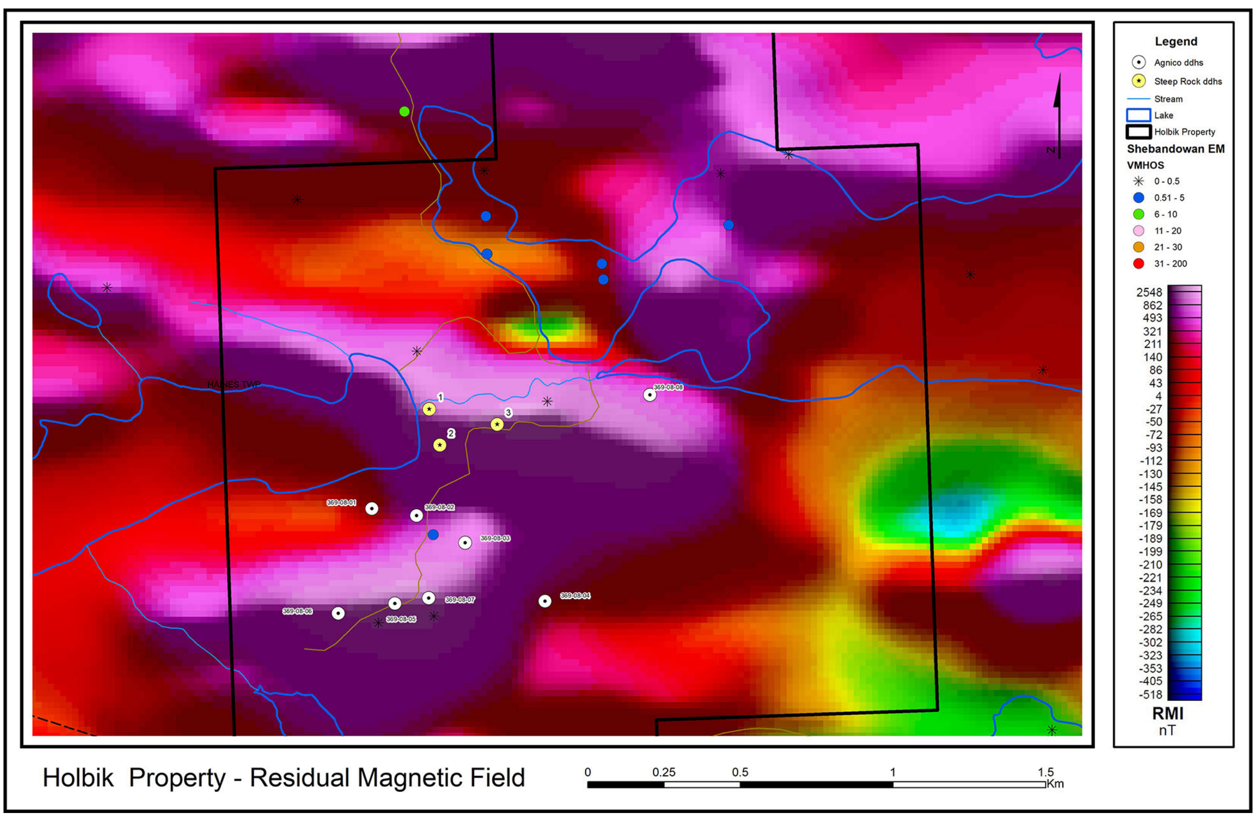

Figure 2. Image of the total residual magnetic field data, over the Shebandowan area, with electromagnetic (EM) anomalies (blue and green dots and black asterisks) *from* Ontario Geological Survey 2003; and locations of diamond-drill holes by Steep Rock Mines Inc. (Hawkins 1957, yellow dots) and Agnico Eagle (Lavoie 2008, white dots).

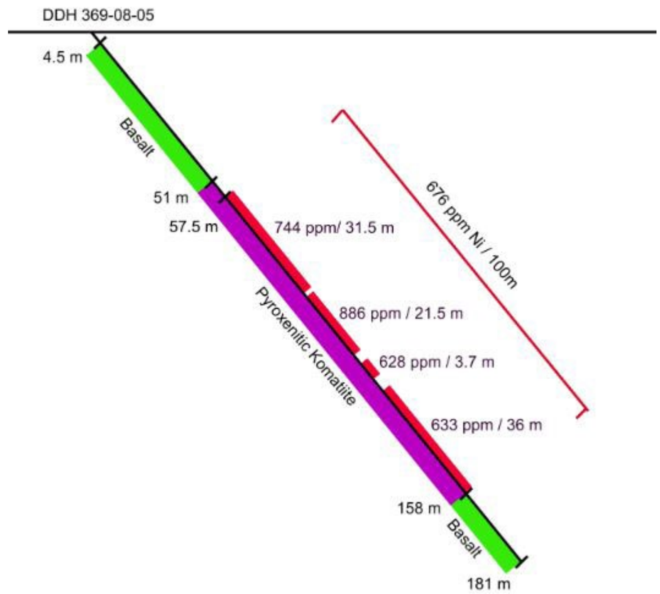

Figure 3. Drill section of Agnico Eagle diamond-drill hole 369-08-05 showing pyroxenitic komatiite with associated disseminated sulphides returned anomalous Ni values ranging from 628 ppm up to 950 ppm Ni with an average of 676 ppm Ni over 100 m, Lavoie 2008.

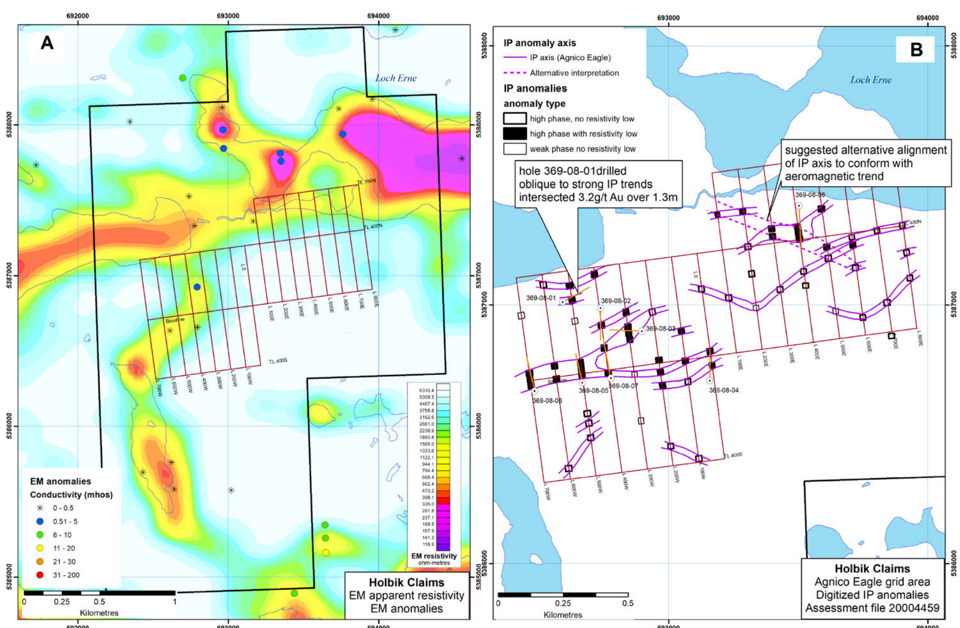

Figure 4. EM and IP survey maps *compiled by* D.R.B. Rainsford (Ontario Geological Survey) with data *from* Lambert 2007. **A)** Map shows EM apparent resistivity anomalies and EM anomalies and **B)** a map that shows Agnico Eagle IP survey with IP anomalies and suggested alternative alignment of IP axis to conform with a northwest aeromagnetic trend. Note that drill hole 369-08-01 returned 3.2 g/t Au over 1.3 m intersects an IP anomaly. programs; however, regional surveys are an effective tool for reconnaissance-scale exploration. Considering new advances in geophysics, geological concepts, geochemical analysis, lower detection limits, increased demand for Ni and PGEs, increased commodity prices and increased metal recovery methods; areas that were previously explored for base metals west and southwest of the Shebandowan Mine warrant (re-)investigation.

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Table 2: Pyroxenitic komatiite with associated disseminated sulphides, returned anomalous nickel values ranging from 500 ppm up to 950 ppm Ni in 3 Agnico Eagle diamond-drill holes (369-08-05, 369-08-06 and 369-08-07, Lavoie 2008).

DDH	Samples	From (m)	To (m)	Length (m)	Ni (ppm)
369-08-05	A-109578 to A-109647	57.5	158.1	100.6	676
	Incl A-109578 to A-109598	57.5	89.0	31.5	744
	Incl A-109600 to A-109610	90.0	106.0	16.0	921
	Incl A-109611 to A-109614	106.0	111.5	5.5	788
	Incl A-109616 to A-109618	113.0	116.7	3.7	628
	Incl A-109623 to A-109647	121.8	158.1	36.3	633
369-08-06	A-108467 to A-108500 & A-109501 to A-109507	63.0	152.9	89.9	513
369-08-07	A-109671 to A-109719	13.0	84.0	71.0	532

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HIGHLIGHTS

- **Underexplored, regional-scale structure with high potential for new gold discoveries**
- **Splays off the main HBDZ should be investigated for gold mineralizing systems**

The Humboldt Bay Deformation Zone: An Overlooked, Crustal-Scale Feature

The Humboldt Bay Deformation Zone (HBDZ) is a major, regional-scale structure which extends eastward approximately 24 km from Humboldt Bay in Lake Nipigon through the Onaman–Tashota greenstone belt (Figure 1).

A description of the HBDZ was described and termed the HBHSZ by Stott et al. (2002):

> … the Humboldt Bay High Strain Zone (HBHSZ) – the most prominent shear zone in the greenstone belt…. This intense deformation zone extends east from Lake Nipigon as an 800 m wide schistose zone of dextral transpression that overprints the boundary between the Elmhirst-Rickaby and Willet assemblages.
> The deformation zone appears to split into several shear zones farther east, deflecting near the Conglomerate assemblage.

The HBDZ is proposed to be a long-lived, reactivated structure which marks a possible terrane boundary between the Eastern Wabigoon and the Winnipeg River terranes (Tomlinson et al. 2004). Known tectonic activity along the HBDZ postdates the formation of its host rocks by more than 35 my (Tóth et al. 2019). They further state that syntectonic, atypical orogenic gold–molybdenum mineralization was introduced early during the deformation history but postdates the emplacement of the quartz–feldspar porphyry dikes (Tóth et al. 2019). The 2 most significant gold occurrences present within the HBDZ (i.e., the Kenty occurrences) are located in the eastern portion of the structure south of Conglomerate Lake; the Kenty North (i.e., Centurion Zone; CWL10-08, 1.2 g/t Au over 5.05 m; grab samples up to 8.09 g/t Au) and the Kenty South (Leopard Zone; CWL10-07, 1.86 g/t Au over 11.43 m; Roach 2011; *see* Figure 1).

The Brennan showing is also reported to occur along the HBDZ and is located 5 km west-southwest of Little John Lake in the western portion of the HBDZ (*see* Figure 1). A 50-pound composite bulk grab sample was reported from the Brennan showing taken from multiple quartz veins which assayed 0.49 oz/ton gold (Hopkins 1976). Staff of the Resident Geologist Program (RGP) investigated the area surrounding the historical Brennan showing and found multiple, discrete, boudinaged quartz veins with up to 5% local disseminated sulphides (pyrite, pyrrhotite and galena) hosted within highly deformed supracrustal rocks (felsic pyroclastic rocks, siltstones and conglomerates). Local iron-carbonate alteration was observed proximal to several quartz veins, most notably in those hosted within metamorphosed siltstones. Assay results are pending.

Two lake sediment gold anomalies were identified in the vicinity of the HBDZ (Sample 12 RDD-0564, 21 ppb Au and sample 12 RDD-0512, 13 ppb Au; Handley and Dyer 2018; *see* Figure 1). Although both sample

Contact:

Robert Cundari
Tel: 807-475-1101
Email: Robert.Cundari@ontario.ca

Cundari, R.M. 2020. The Humboldt Bay deformation zone: An overlooked, crustal-scale feature; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.75-78.

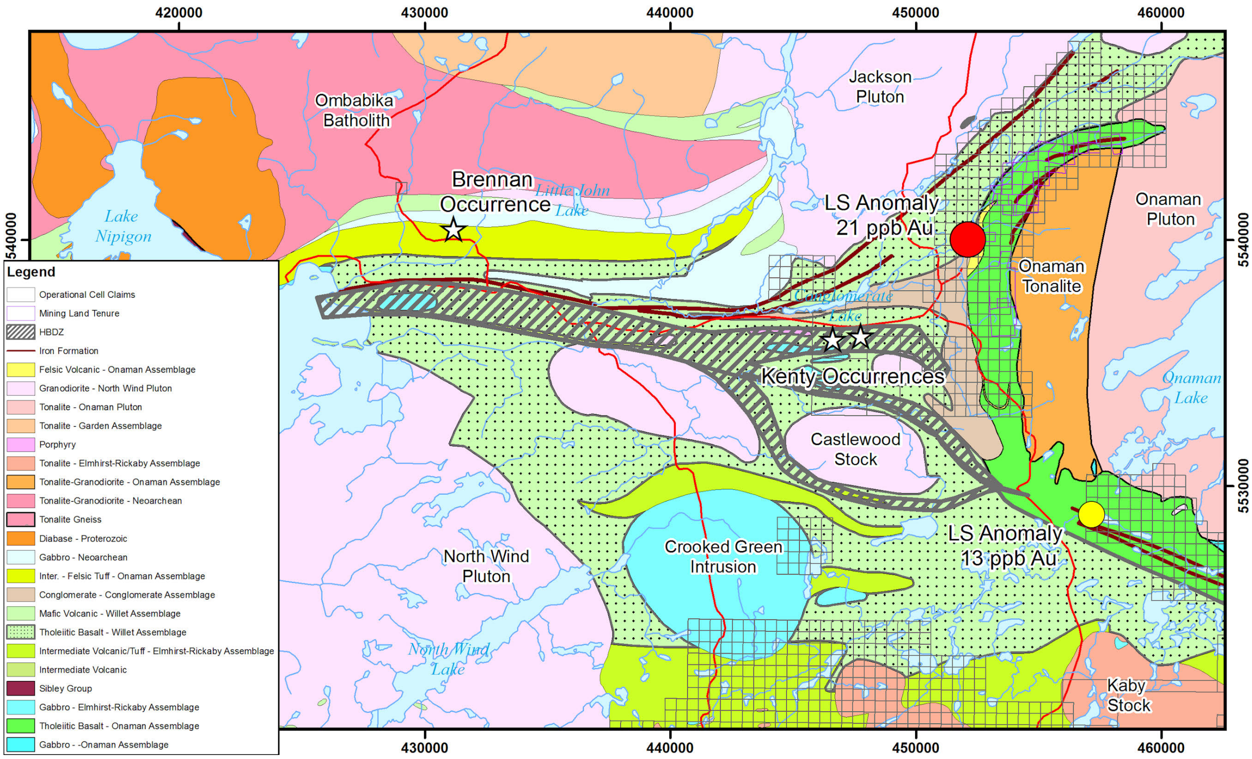

Figure 1. Geological map of the Onaman–Tashota greenstone belt showing major tectonostratigraphic assemblages and the location of the Humboldt Bay Deformation Zone. HBDZ outline *from* Stott et al. (1995). Geology *from* Lemkow et al. (2005); Stott et al. (2002). UTM co-ordinates in NAD83, Zone 16. Claim units as of November 1, 2019.

locations were covered by claims at the time of publication, the lake sediment data further supports the potential for gold mineralization along the HBDZ.

The HBDZ represents a large-scale, overlooked exploration opportunity in an otherwise well-explored district. Very little exploration activity has been focussed towards the HBDZ although the presence of known gold mineralization highlights the HBDZ as a favourable environment to host mineralizing systems. The HBDZ should be investigated to better understand its controls on mineralization, and to understand its tectonic significance within the architecture of the Onaman–Tashota greenstone belt. Structural splays off the HBDZ should be targeted for potentially new gold mineralizing systems. Iron formation extending east-northeast along the north boundary of the HBDZ to the southeast margin of the Jackson pluton are visible in the second vertical derivative magnetic imagery (Figure 2). Possible intersections of iron formation with structures emanating from the HBDZ, are excellent targets for iron formation-hosted gold mineralization. Splays off major crustal structures are known hosts for gold deposits in the eastern Wabigoon. The Brookbank deposit (Indicated Resource of 600 000 oz gold) is interpreted to be hosted within a splay off the Paint Lake Deformation Zone which marks the boundary between the Beardmore–Geraldton and Onaman–Tashota greenstone belts (Canadian–American Mining Handbook, 2016–2017, p.345; DeWolfe, Lafrance and Stott 2000).

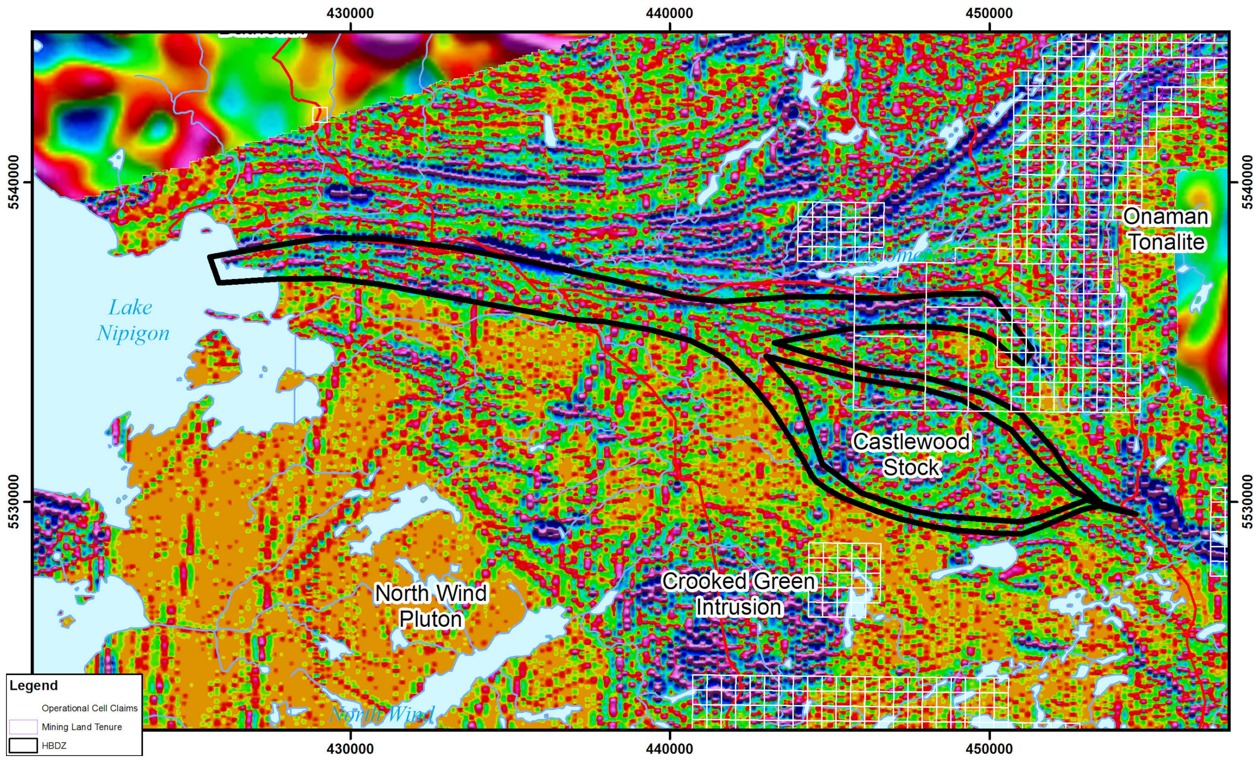

Figure 2. Map of the Onaman–Tashota greenstone belt, overlain by the second vertical derivative magnetic image shows the magnetic expression of the Humboldt Bay Deformation Zone. HBDZ outline *from* Stott et al. (1995). Geophysical data *from* Ontario Geological Survey (1999, 2003a, 2003b). UTM co-ordinates in NAD83, Zone 16. Claim units as of November 1, 2019.

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HIGHLIGHTS

- **Dig is a GIS-based geoprocessing tool, developed to quantify Assessment Files, Drill Holes and MDI for areas available for acquisition**
- **Dig can be used as a targeting tool to highlight areas subjected to considerable exploration**

Contact:

Robert Cundari
Tel: 807-475-1101
Email: Robert.Cundari@ontario.ca

Genevieve Dorland
Tel: 807-475-1108
Email: Genevieve.Dorland@ontario.ca

Therese Pettigrew
Tel: (807) 632-4539
Email: Therese.Pettigrew@ontario.ca

DIG: A Tool to Quantify Publicly Available Geoscience Data Sets

The Ontario Geological Survey's Resident Geologist Program (OGS-RGP) are the caretakers of numerous, publicly available, geological data sets which historically, have been extremely useful in supporting the mineral exploration industry. OGS-RGP products provide explorationists with baseline data sets and references that are vital to mineral targeting and compilation efforts in Ontario. Dig is a GIS-based geoprocessing tool, developed to quantify multiple, publicly available OGS-RGP data sets in areas that are open for claim registration.

The Dig Tool uses the Mining Lands Administration System (MLAS) provincial cell grid as a base grid for calculating the quantity of data for individual cells. Before calculations, the Dig Tool removes any areas that are not available for claim registration from the MLAS provincial cell grid. These areas include operational mining claims, leases and dispositions, alienations, provincial parks and First Nation reserves. This results in a data set that shows all cells that are available for claim registration (Figure 1).

The Dig Tool considers the Ontario Assessment File Database (OAFD) polygon features, the Ontario Drill Hole Database (ODHD) point features and Mineral Deposit Inventory (MDI) database point features to assess the robustness of the data overlapping available claim cells. Dig counts how many features overlap each of the available cells and multiplies them by a weight value called the "Dig Weight" (*see* Table 1 and Figure 2). Features that do not meet certain criteria are removed before counting, e.g., MDI points that are identified as Discretionary Occurrences and overburden drill holes are omitted from the totals. A buffer distance of 200 m is applied to MDI points as each point generally represents an area larger than a point location.

The Dig Tool takes the counts of overlapping features (OAFD, ODHD and MDI) and multiplies them by their respective Dig Weights (2, 5 and 10) for each available cell. These results are added together to give each cell a "Dig Score" (*see* Figures 1 and 2).

The Dig Score gives an indication of the quantity of data available for a given cell i.e., the robustness. To assess the quality of data available and prioritize areas for targeting, a percentile threshold is applied to the Dig Scores. To further highlight significant areas that have appreciable Dig Scores, contiguous areas that display Dig Scores in the 85th percentile or greater, and cover an area of 500 hectares or greater, are identified as "Dig Targets" (outlined in black; Figures 3, 4 and 5).

Dig can be used as a targeting tool to highlight areas subjected to considerable historical exploration which are currently available for acquisition. Dig Targets, shown in Figures 3, 4 and 5, are intended as a

Cundari, R.M., Dorland, G. and Pettigrew T. 2020. DIG: A tool to quantify publicly available geoscience data sets; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.79-82.

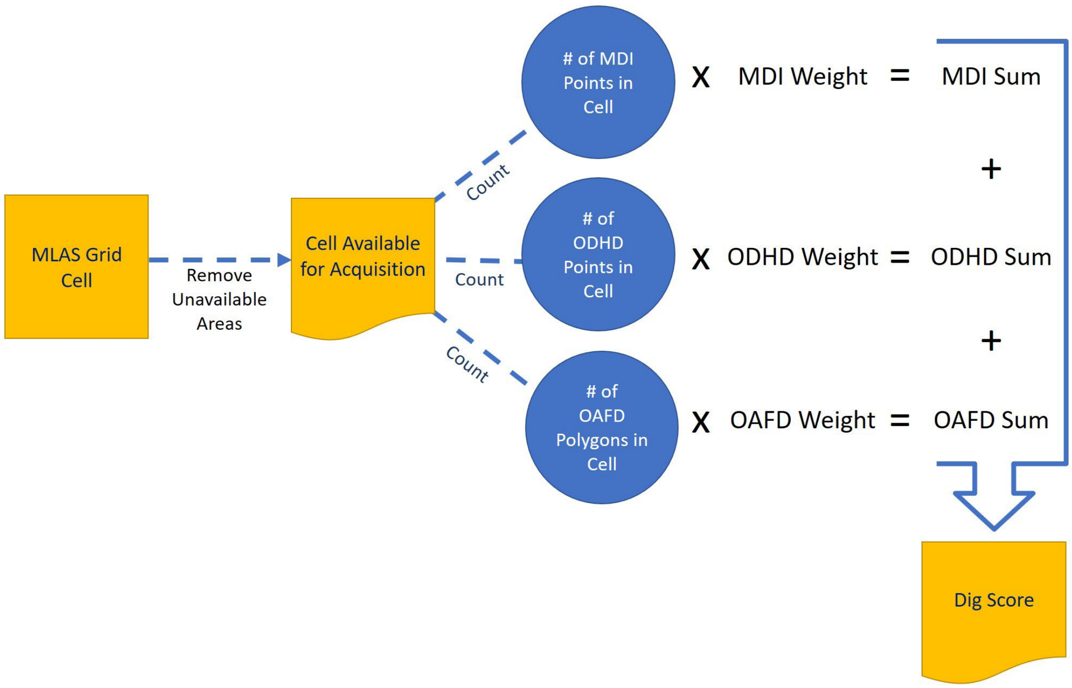

Figure 1. Flowchart showing the calculation process for the Dig Tool.

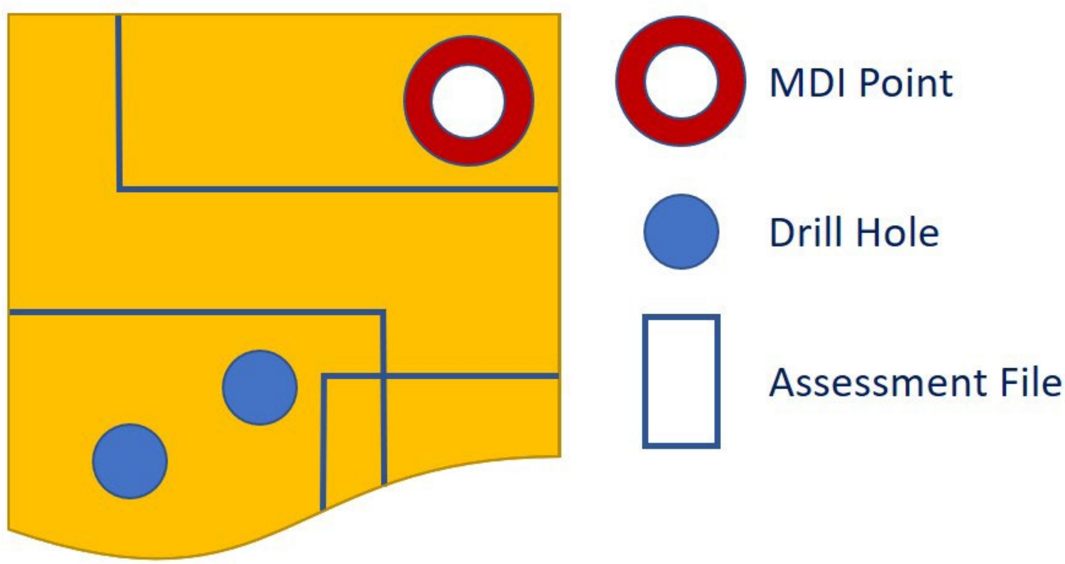

Figure 2. Example of a Dig Score calculation for an open mining claim cell (Feature Count x Dig Weight = Dig Score): Example cell (yellow) intersects 3 Assessment Files (3 x 2 = 6), 2 Drill Holes (2 x 5 = 10), 1 MDI (1 x 10 = 10), Total Dig Score = 26.

first pass approach to help focus the investigation into areas that have previously been deemed worthy of considerable investment and subsequent exploration. Dig also emphasizes the importance of OGS-RGP data sets in targeting areas for mineral exploration. The Dig Tool was developed as a pilot project, using the Thunder Bay North District as a trial area. Figures 4 and 5 show the south and western areas of the Thunder Bay North District, where the highest abundance of quality Dig Targets were generated. At the time of publication, targets generated by the Dig Tool are only available for the Thunder Bay North District. Specific details and supplementary information regarding Dig Targets for the Thunder Bay North District are available from the authors.

Table 1. The input/threshold variables and associated values considered in the Dig Tool.

Input / Threshold	Values
MDI buffer distance	200 m
Buffered MDI point weight	10
Drill hole weight	5
Assessment file weight	2
Percentile threshold for Dig Targets	>85th
Minimum size threshold for Dig Targets	500 ha

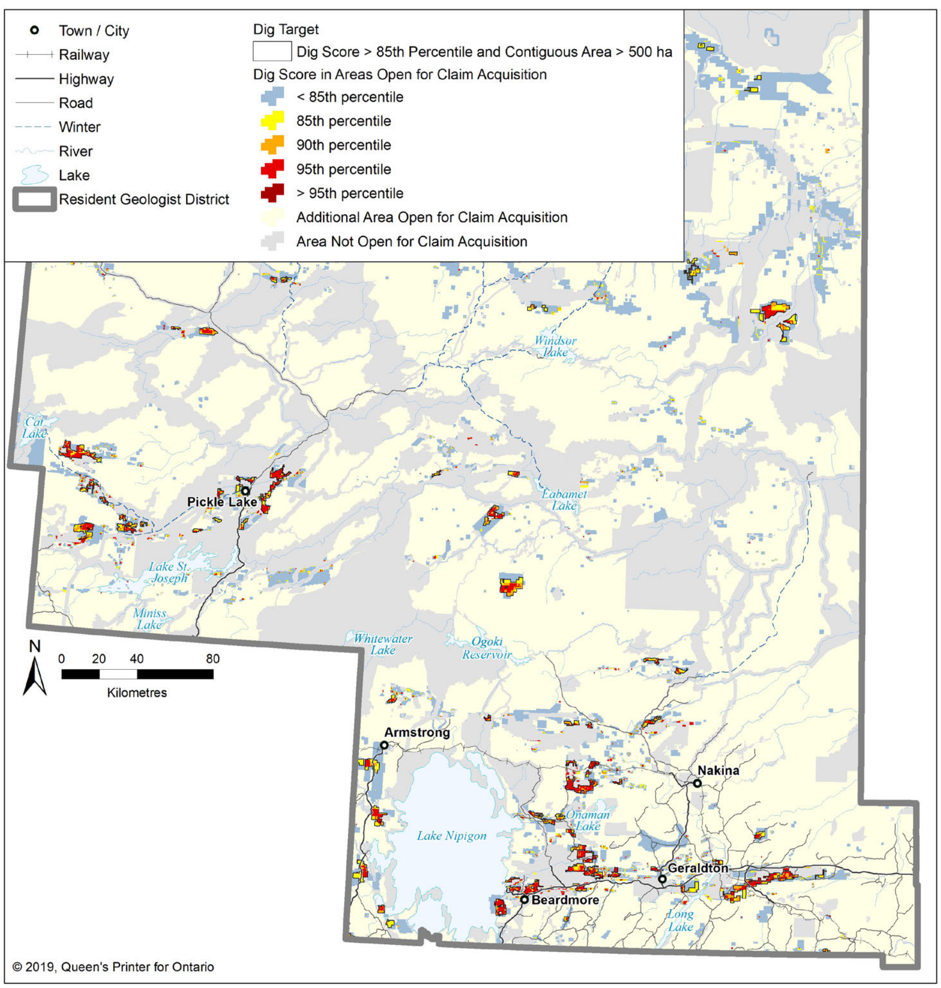

Figure 3. Map showing the results of the Dig Tool for the Thunder Bay North District.

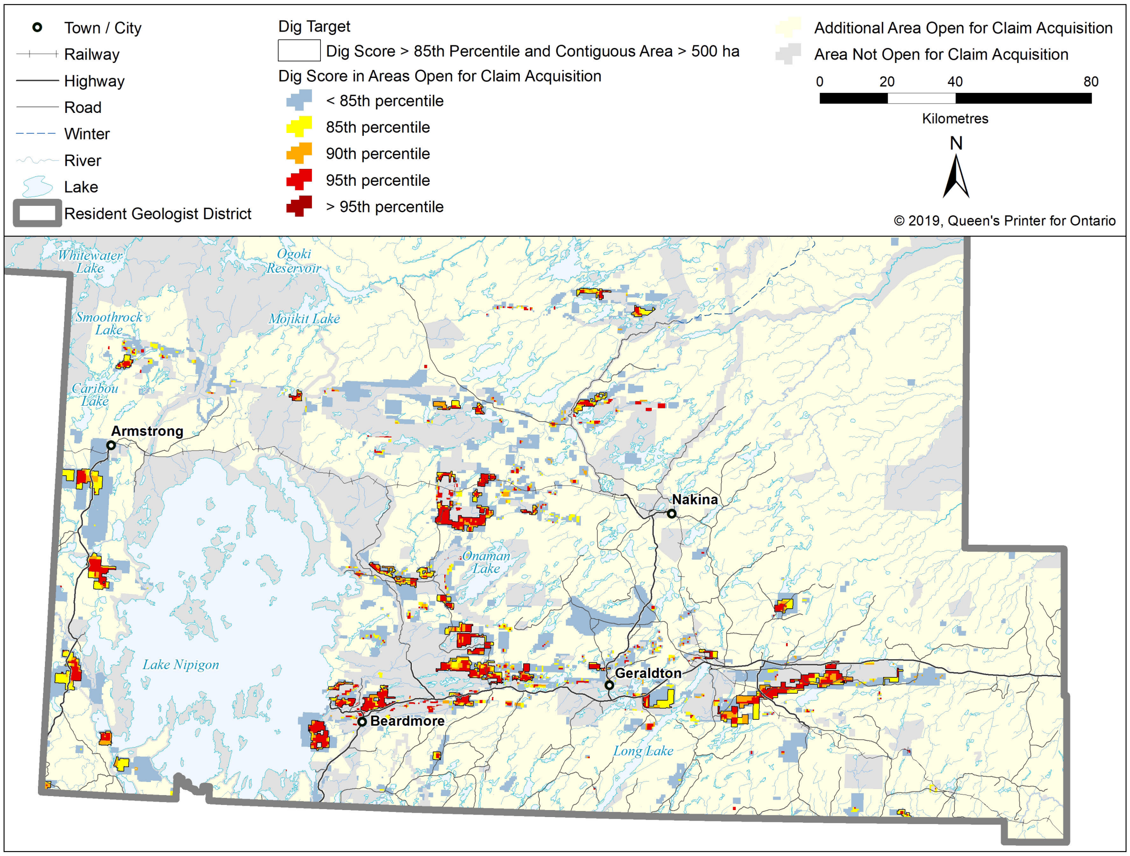

Figure 4. Map showing results of the Dig Tool for the southern portion of the Thunder Bay North District.

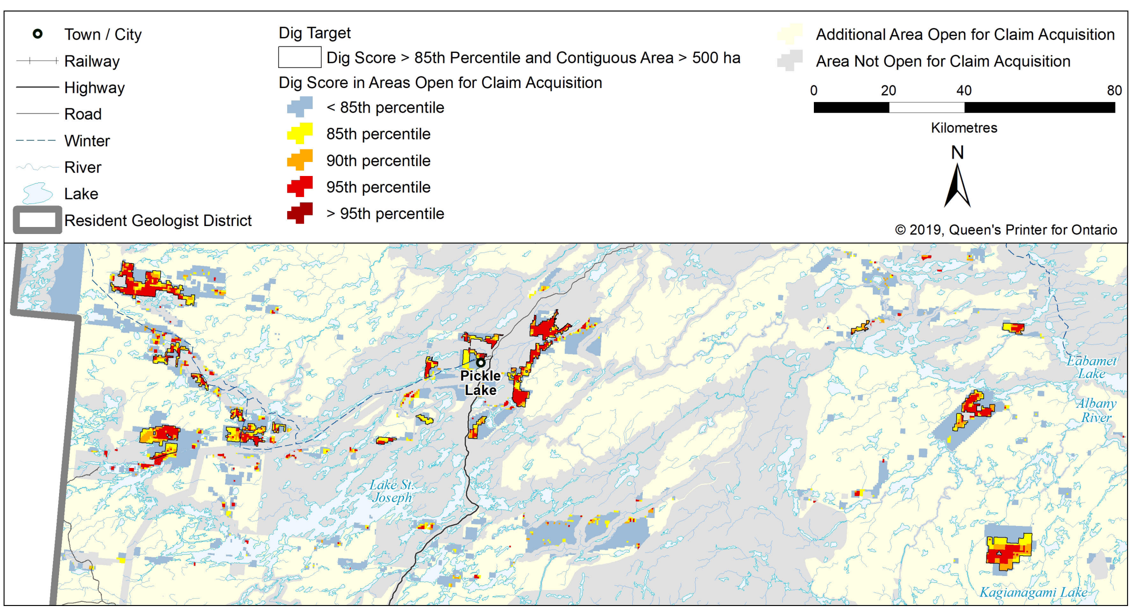

Figure 5. Map showing results of the Dig Tool for the western portion of the Thunder Bay North District.

HIGHLIGHTS

- **Beryl can be found in Be-enriched pegmatite**
- **Chromophore (Cr, V) often responsible for emerald classification of beryl**
- **Explore for emeralds in areas with Be, Cr and V enrichment in pegmatite and adjacent rocks**

Emeralds Can Be Associated with Beryl-Enriched Pegmatite

The Taylor emerald showing situated 8.5 km northeast of Dryden is associated with the Mavis Lake pegmatite field. The Taylor pegmatite, proximal to the peraluminous Ghost Lake batholith occurs in the Wabigoon Subprovince near the boundary of the Winnipeg River Subprovince (Figure 1).

The granitic pegmatites at the Taylor showing intrude chlorite schist—a distinctive altered mafic metavolcanic rock. The pegmatites also intrude and are situated adjacent to an ultramafic body. Beryl, common to pegmatite located in this part of Mavis Lake pegmatite group, is found at the Taylor showing.

Brand and Groat (2009) mention that "the beryl at the Taylor pegmatite are porcelaneous, white to pale green, up to 5 cm long and 1 to 2 cm wide". These beryls predominately occur in the pegmatite but are also found in a zone of chlorite schist. Unique to this showing, up to 10% of these can be classified as emerald (Brand and Groat 2009). The colour of emerald (Photo 1), a green gem variety of beryl, $Be_3Al_2Si_6O_{18}$, is due to trace amounts of chromium (Cr) or vanadium (V) or both replacing aluminum (Al) in the crystal structure (Groat et al. 2008). Brand and Groat (2009) mention that "there is a transparent medium to light green faceted emerald, collected from the Taylor showing, weighing 0.13 carats in the National Gem Collection at the Canadian Museum of Nature in Ottawa".

Brand and Groat (2009) mention that "for beryl to be classified as an emerald is rare because Be [beryllium] and Cr are largely insoluble, and the geological conditions to bring Be into contact with Cr and V are very uncommon". At the Taylor showing, beryllium is most abundant in the pegmatite and this concentration (89 ppm, *see* Table 1) greatly exceeds the crustal abundance of 3.5 to 5 ppm for this type of felsic intrusion (Groat et al. 2008). There is also elevated beryllium found in the altered mafic metavolcanic rocks (see phlogopite and chlorite schist in Table 1). The source of the distinctive green-emerald colour (*see* emerald crystal in Photo 1) is the presence of a chromophore (chromium) in the mineral structure which comes mainly from the altered mafic metavolcanic rocks (*see* phlogopite and chlorite schist in Table 1) and ultramafic rocks (Table 1).

Beryl can be found in beryllium-enriched pegmatite. If the rocks adjacent to these pegmatites are enriched in vanadium and especially chromium, the metasomatism of these rocks by the granitic magmatism can result in emerald-quality crystals.

Contact:

Craig Ravnaas
Tel: 807-468-2819
Email: Craig.Ravnaas@ontario.ca

Ravnaas, C. 2020. Emeralds can be associated with beryl-enriched pegmatite; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.83-86.

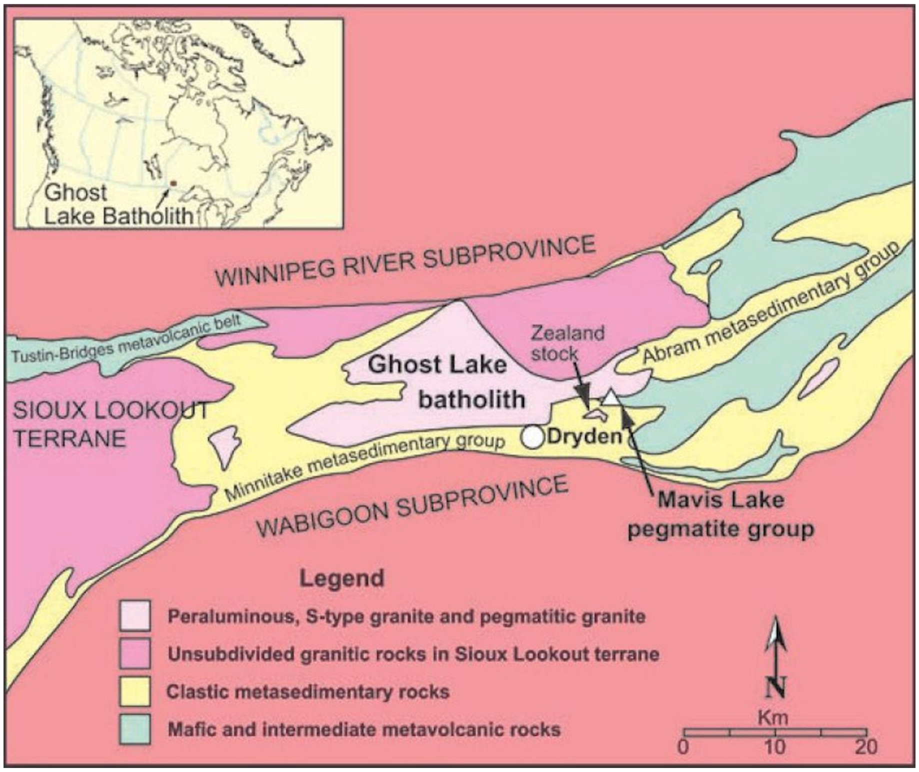

Figure 1. Regional geology showing the relationship of the Mavis Lake pegmatite group and Ghost Lake batholith to the country rock (*after* Breaks and Moore 1992).

Photo 1. Emerald crystal with quartz, feldspar, mica and tourmaline from the Taylor showing (Brand and Groat 2009).

Table 1. Trace element values (ppm) of several rock types collected from the Taylor showing (*modified from* Brand and Groat 2009).

Element	Pegmatite	Phlogopite Schist	Chlorite Schist-1	Chlorite Schist-2	Ultramafic Rock	Metavolcanic Rock-1	Metavolcanic Rock-2
Be	89.00	13.45	17.20	3.12	1.90	2.28	2.40
Cr	90.00	1330.00	1700.00	2610.00	3050.00	40.00	50.00
V	5.00	134.00	178.00	93.00	98.00	451.00	407.00

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HIGHLIGHTS

- **Seven-year, $104 million mineral exploration research and development program**
- **3 transects located in Western Wabigoon Subprovince**
- **Integrated craton-scale, transect, thematic and data analysis research could identify mineral potential areas**

Contact:

Craig Ravnaas
Tel: 807-468-2819
Email: Craig.Ravnaas@ontario.ca

Metal Earth Program

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 2018a).

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 will be conducting research for Metal Earth projects across northern Ontario and Quebec (Figure 1). Three of these transects are located in the Kenora District (Figure 2).

In 2017, transect-scale data collection from seismic reflection surveys was completed along the 3 transects within the Kenora District (*see* Figure 2). In 2018, magnetotelluric (MT) surveys utilizing broadband MT and audio MT techniques were also completed along the 3 transect lines. Magnetotelluric data is often acquired in conjunction with seismic refection surveys to provide additional information on subsurface structure or lithological stratigraphy.

Thematic and data analytical research has been initiated within the area surrounding the 3 transects (*see* Figure 2). Frieman (2018) mentions that "the supracrustal stratigraphy, intrusive history, structural evolution, and metamorphic development are largely under-investigated, and their relationships with economic resource distribution are unknown. This project aims to investigate and integrate these topics to propose a revised Precambrian and metallogenic evolution model of the Western Wabigoon".

Field work at the transects focused mainly on regional lithological contact relationships, geochemical, and geochronological relationships between volcanic rock types. Research Associates Ben Frieman, Gaetan Laundry and Chong Ma are team leaders for the Stormy–Dryden, Rainy River and Sturgeon Transect areas, respectively (Mineral Exploration Research Centre 2019). This field work involved regional lithological sampling, detailed geological mapping and initiation of academic research studies ranging from BSc to PhD degrees.

Field work and research analysis combined with seismic and magnetotelluric survey results will be used by Metal Earth to update the synthesis of the Western Wabigoon Subprovince. This data will be used to develop a new geodynamic model for its formation which will be compared to other mineralized belts in the Superior Province. These concepts, developed during and at the conclusion of the program, could provide valuable information which can be used to determine areas to evaluate for mineral potential

Ravnaas, C. 2020. Metal Earth Program; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.87-89.

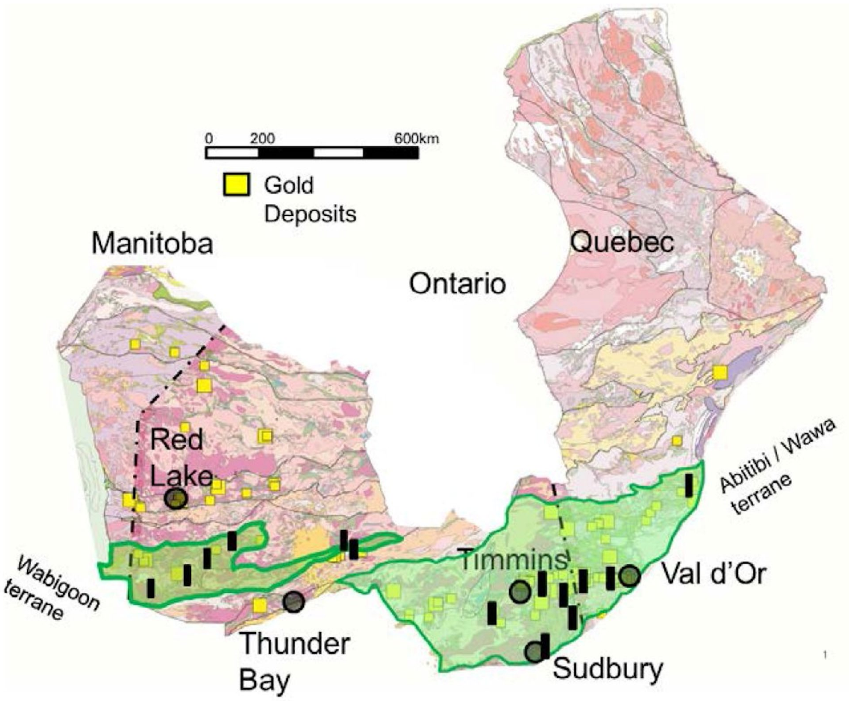

Figure 1. Geological compilation of the Superior Craton showing the Metal Earth transects (black bars), geological terranes (green shading) and selected communities (circles), Mineral Exploration Research Centre 2018b.

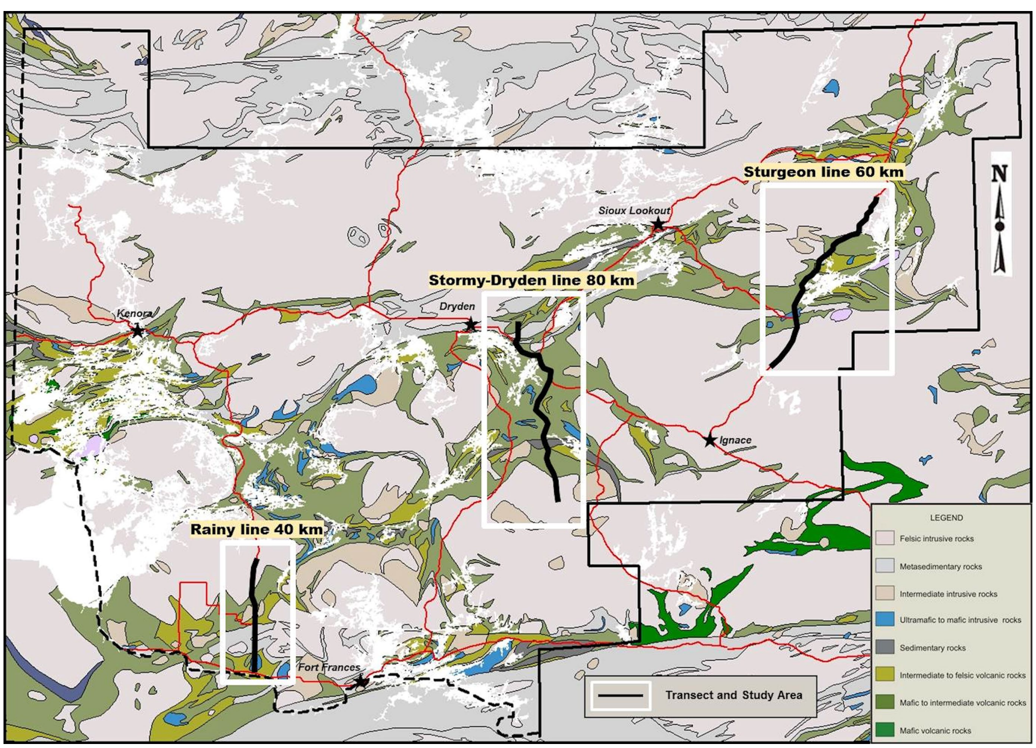

Figure 2. The 3 Wabigoon study transects (white boxes), located in the Kenora District, are outlined on bedrock geology (bedrock geology *from* Ontario Geological Survey 2011).

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HIGHLIGHTS

- **Prospective greenstone belt with little historical exploration**
- **Large mineral potential in open unencumbered ground**
- **Up to 1.36% Cr_2O_3 sample indicated in donated diamond-drill hole log**
- **High density of sulphide mineral occurrences**

Contact:

Bill Paterson
Tel: 807-727-3284
Email: Bill.Paterson@ontario.ca

Samuel Lewis
Tel: 807-727-3272
Email: Samuel.Lewis@ontario.ca

Exploration Potential for Rottenfish R. and Muskrat Dam L. Greenstone Belts

The Muskrat Dam Lake greenstone belt is located within the Sachigo Subprovince approximately 300 km north-northeast of Red Lake in the Red Lake Resident Geologist District. It is a typical Archean greenstone belt comprising metavolcanic and metasedimentary rocks with felsic to ultramafic intrusions and bounded by composite granitic batholiths (Figure 1). Ayres' (1969) fieldwork and report on the Muskrat Dam Lake greenstone belt is the first and only comprehensive study of the Muskrat Dam Lake greenstone belt. Ayres' (1969) interpretation of the Muskrat Dam Lake greenstone belt was drawn from 2 field seasons during which 75% of the area was covered by traverses along major lakes and rivers or by pace and compass traverses in forested areas. Brief follow-up fieldwork and reinterpretation was completed by Thurston, Cortis and Chivers in 1987 focusing on general structural–stratigraphic interpretations (Thurston, Cortis and Chivers 1987).

Only 2 geophysical surveys have been flown over the area. In 1967, the Geological Survey of Canada (GSC) performed the first aeromagnetic survey over the entire belt (Geological Survey of Canada 1967a d). Later in 1980, Gulf Minerals Canada flew another aeromagnetic survey over the central portion of the greenstone belt.

Three assemblages have been mapped in the greenstone belt (Thurston, Osmani and Stone 1991): the 2.9 Ga Nekence assemblage comprising komatiitic and tholeiitic flows overlain by iron formation and quartz arenites, the 2.7 Ga Muskrat Dam assemblage of arc volcanic rocks and the ~2.9 Ga Rottenfish assemblage, also an arc volcanic assemblage. Only 3 age dates have been obtained from the Muskrat Dam Lake greenstone belt (Figure 2A). Two of 2734 Ma come from rhyolites in 2 different stratigraphic positions within Ayres' Upper Metavolcanic Formation, within the Muskrat Dam assemblage and one of 2958 Ma from Ayres' Lower Metasedimentary Formation, near the southern margin of the greenstone belt, in the Nekence assemblage.

Ayres (1969) mapped 3 major structures in the area; the Windigo and Severn River faults affecting the Muskrat Dam Lake belt and the Rottenfish Lake fault (*see* Figure 2A). The Windigo River fault trends roughly north-south through the middle of the belt with the rocks east of it dominated by the upper mafic metavolcanic formation while west of the fault all formations are represented, often with significant thicknesses. Ayres' (1969) work showed the east-west trending Muskrat Dam assemblage to be isoclinally folded and characterized by marked facies changes. The eastern margin of the belt gradually tapers and thins out while the western margin ends abruptly against granitic rocks.

Immediately west and separated by approximately 5 to 8 km of granitic rocks, along the Rottenfish River Shear (Osmani and Stott 1988) is the

Lewis, S. and Paterson, W. 2020. Exploration potential for Rottenfish R. and Muskrat Dam L. greenstone belts; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2019–2020, p.91-96.

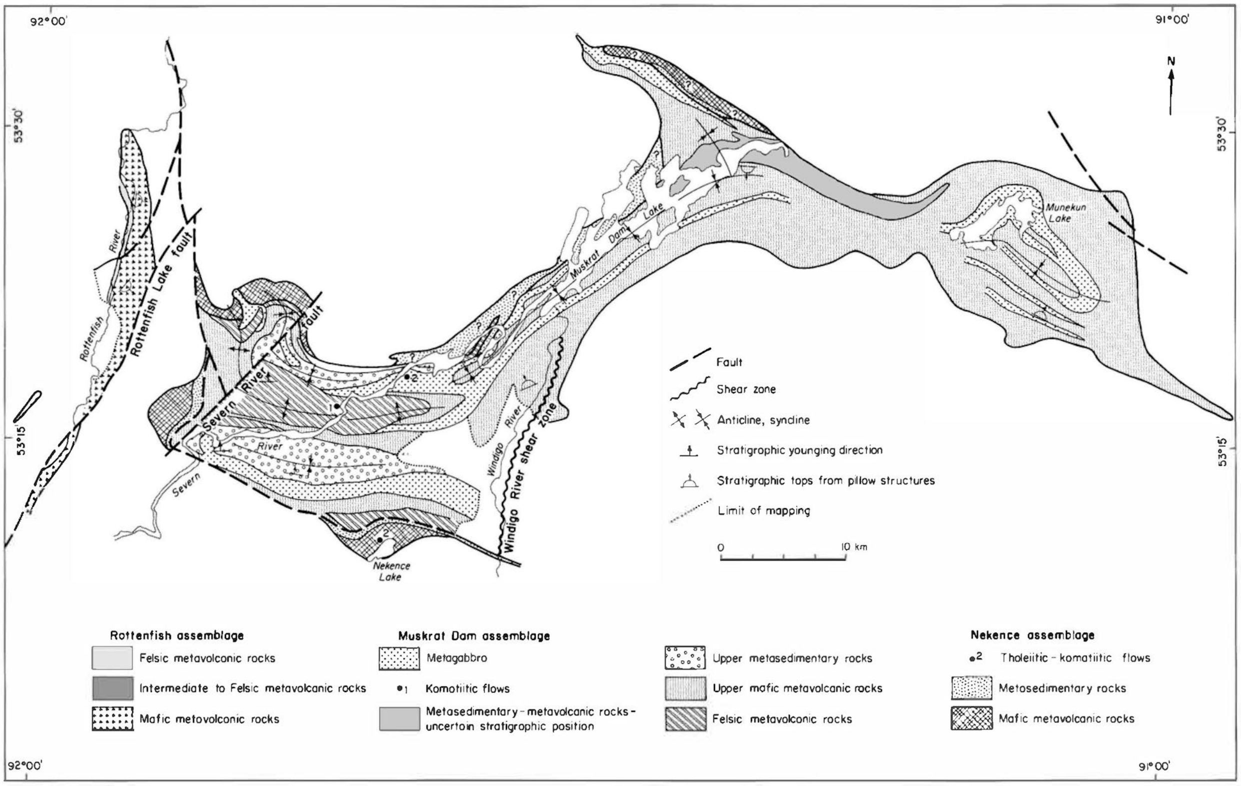

Figure 1. Assemblages of the Muskrat Dam Lake greenstone belt based on mapping carried out by Ayres (1969) and Thurston, Cortis and Chivers (1987).

Rottenfish River greenstone belt (*see* Figure 2A and 2B). This is a narrow north-south trending belt dominated by mafic volcanic and gabbroic rocks with lesser felsic to intermediate volcanic rocks and iron formations. It has been folded into an isoclinal anticline and is thought to be part of the North Sandy Lake assemblage due to its orientation and evidence of a xenolith train linking it to the Sandy Lake greenstone belt (Thurston, Osmani and Stone 1991).

The entire Muskrat Dam Lake greenstone belt has been metamorphosed to greenschist facies in the core through to almandine amphibolite facies with extensive hornblende hornfels around the margins. Gabbros and diorites form several significant (up to 24 km in strike and 2.3 km in thickness) sills in both greenstone belts.

Subsequent investigation by Thurston, Cortis and Chivers (1987) confirmed much of Ayres' (1969) work with some notable new findings. He found that the basal basalts north of Nekence Lake (in the Lower Metavolcanic Formation) included 200 m thick pillowed komatiitic flows and some of the gabbros along the Severn River were also found to be komatiitic flows (*see* Figure 1). He also recorded abundant evidence of a shallow water depositional environment in both the Lower and Upper Metasedimentary Formations, including stromatolites.

Structural deformation in the Muskrat Dam Lake greenstone belt is typically complex (Thurston, Osmani and Stone 1991). Early D_1 thrusting is evidenced by the repetition of the 2734 Ma age dates from differing stratigraphic positions within the Muskrat Dam assemblage and the presence of non-arc komatiitic units in the Muskrat Dam assemblage. Later deformation is seen in the D_2 fold axes within the belt having been broadly warped from the emplacement of the large batholiths surrounding the belt, as are the D_2 fold-parallel shears separating the assemblages (*see* Figure 1).

Given all the evidence that the Nekence assemblage is significantly older and of much different provenance, it is thought to be a sliver of the North Caribou greenstone belt separated from the Muskrat Dam assemblage by an extension of a major shear separating older and younger assemblages in the North Caribou greenstone belt (Thurston, Osmani and Stone 1991).

Within the Superior Province in northwestern Ontario, there are numerous metallogenic associations related to assemblage and rock types and structure. In the Muskrat Dam Lake greenstone belt, what little exploration that has been done has shown there is anomalous gold, copper, nickel, and chromium, to name a few only. Some of the major associations that may be important in the Muskrat Dam Lake greenstone belt can be summarized as below (Thurston, Osmani and Stone 1991).

1. Platformal Rocks
    a. U mineralization in clastic sediments (quartz arenites, conglomerates)
    b. Ni in komatiitic rocks

2. Arc Volcanic Rocks
    a. Cu as disseminated sulphides in altered mafic flows
    b. PGE, Cr in mafic–ultramafic sills

3. Shear Zones
    a. Au in discordant vein systems associated with D_2 shears
    b. Rare metals in pegmatites associated with 2-mica granites in major shear zones

The Muskrat Dam Lake greenstone belt received limited exploration work from 1969 to 1988 and only by a handful of companies. To date, there are only 217 diamond-drill holes and 228 assessment files within the Muskrat Dam Lake greenstone belt—many as single drill hole submittals, documented in the Ontario Drill Hole Database and the Ontario Assessment File Database (Ontario Geological Survey 2019a, 2019b; *see* Figure 2B). There are 35 non-assessment donated exploration files held at the Red Lake Resident Geologist Office. These are also mostly drill hole submissions.

Several prospective mineral exploration targets were identified by Ayres (1969) which suggest that more exploration work is required within the greenstone belt. A high density of sulphide mineral occurrences are found in the eastern part of the Muskrat Dam Lake greenstone belt in rapid lateral and vertical lithology changes where a major syncline is cross folded (*see* Figure 2B). Several thick banded iron formations have been identified in the Rottenfish River belt and along the shore of Munekun Lake appear to contain 20 percent iron over 30 to 100 feet widths and generally correlate with aeromagnetic surveys (Ayres 1969; Geological Survey of Canada 1967a-d; *see* Figure 2B). The Rottenfish Lake fault should be examined in detail because of previously reported occurrences of gold (*see* Figure 2B). Additionally, several muscovite-bearing leucogranites and pegmatites, forming as rare sills, lenses, and dikes in metasedimentary rocks and metavolcanic rocks suggest rare earth element and lithium potential (*see* Figure 2B). Overall, 17 localities containing gold, copper, cobalt, lead, nickel, and zinc potential contained 1 to 10 percent sulphide minerals with 5 localities containing more the 10 percent sulphide minerals (*see* Figure 2B).

Reviewing the past work history of the Muskrat Dam greenstone belt indicates that further examination is required on several open anomalous locations. The high density of sulphide mineral occurrences along the northeastern shores of Muskrat Dam Lake should be followed up with detailed prospecting and geophysics (*see* Figure 2B). Grab samples collected during Ayres' field seasons identified trace amounts of gold, cobalt, copper, lead, nickel and zinc mineralization over several thousand feet in garnetiferous mafic and metavolcanic rocks, felsic to intermediate metavolcanic rocks and metaconglomerates (Ayres 1969). The highly variable mineralized metaconglomerate unit that is exposed over 1500 feet along the north shore of Muskrat Dam Lake and along the western shores of Sandhill Crane Island may be acting as a conduit for sulphide-rich hydrothermal fluids.

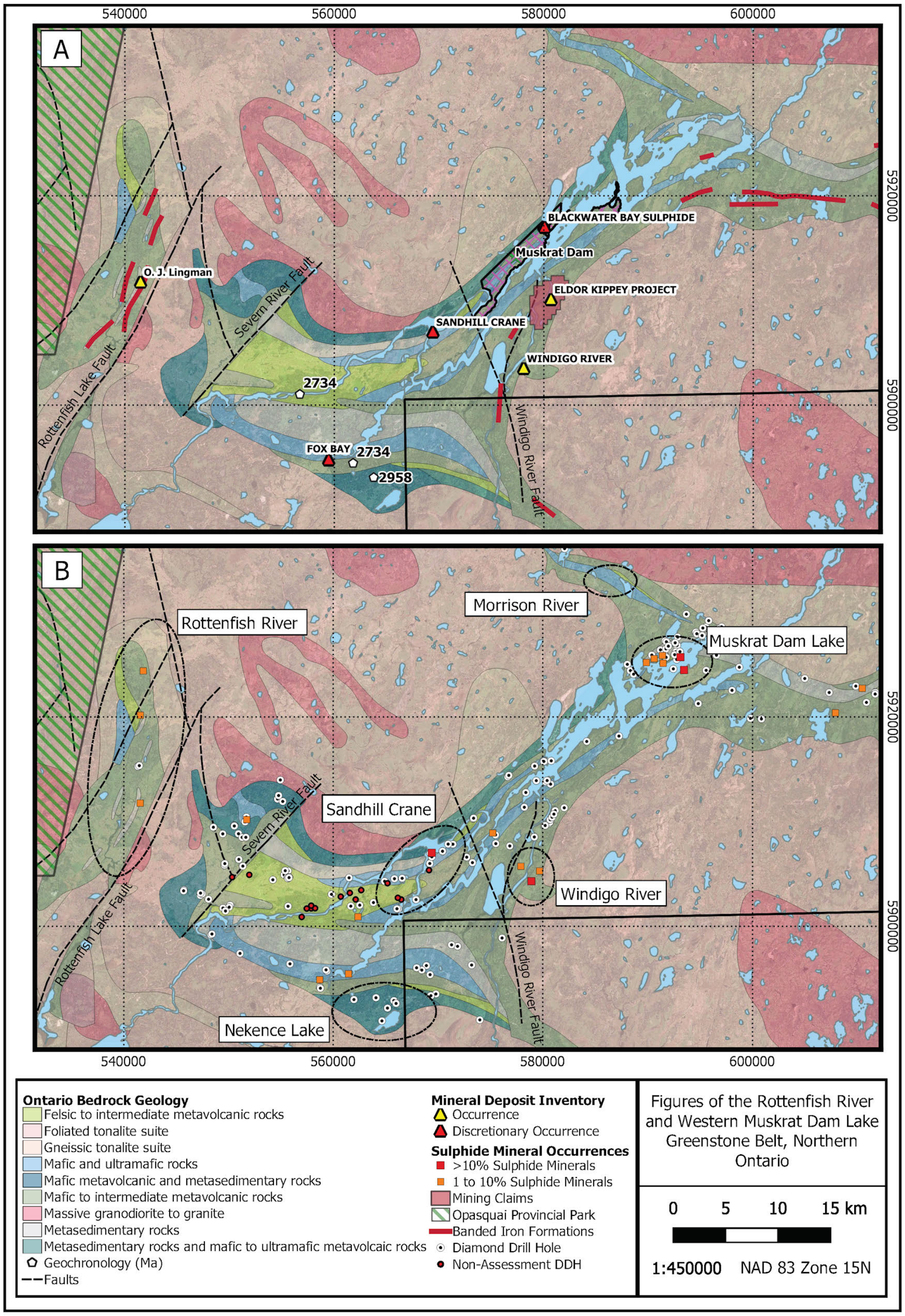

Figure 2. Ayres 1969 geological map showing **A)** OGS Mineral Deposit Inventory occurrence locations and geochronology; and **B)** Ontario Drill Hole Database and non-assessment drill hole locations, sulphide mineral occurrences and target areas (Ayres 1969; Solonyka 1981).

The metaconglomerates exposed at the northwest corner of Sandhill Crane Island for 300 feet have been locally replaced by disseminated to massive pyrrhotite and by concordant lenses of massive pyrite (*see* Figure 2B).

Three grab samples collected by Ayres from the metaconglomerate contained anomalous values of gold, copper, nickel (Ayres 1969). In 1980, Gulf Minerals Canada conducted diamond drilling within this zone and intersected 13 580 ppm Cr_2O_3 (Solonyka 1981). Multiple other drill holes by Gulf Minerals Canada intersected >1000 ppm Cr_2O_3 within their claim area suggesting the potential for chromite mineralization elsewhere within the Muskrat Dam Lake greenstone belt.

The Windigo River occurrence is characterized by pyrite-chalcopyrite mineralization within quartz vein lenses in sheared north-south striking metagabbro sills over several hundred feet (*see* Figure 2B). The metagabbro sills lay adjacent to the Windigo River fault and a broad aeromagnetic anomaly (Ayres 1969; Geological Survey of Canada 1967a-d). A grab sample collected by Ayres from a 6 inch massive pyrite chalcopyrite lens contained 1.22 percent copper and trace amounts of gold (Ayres 1969). Despite Ayres' rapid examination of the Windigo River site, multiple mineralized veins were identified and further detailed prospecting may lead to the discovery of larger zones of mineralization.

The Rottenfish River anomaly is hosted within rusty weathering, felsic metavolcanic rocks, mafic metavolcanic rocks and metagabbro sills containing 1 to 10 percent pyrite, pyrrhotite and trace chalcopyrite mineralization returning anomalous gold, copper, and nickel values (*see* Figure 2B). The Rottenfish River anomaly hosts the thickest and most iron-rich unit identified by Ayres and corresponds well with aeromagnetic data (Ayres 1969; Geological Survey of Canada 1967a-d). The iron formations within the Rottenfish River belt have been metamorphosed to almandine amphibolite facies and are possibly analogous to the mineralization style at the Musselwhite Mine which is primarily hosted in high strain silicate-rich garnetiferous iron formation (Oswald et al. 2015).

Between Morrison River and Muskrat Dam Lake, muscovite-bearing granites and metamorphosed felsic intrusive rocks are sandwiched between felsic and mafic metavolcanic rocks and gabbroic rocks (*see* Figure 2B). The white pegmatite dikes, sills and lenses are typically composed of albite-oligoclase, quartz, muscovite, tourmaline, garnet, magnetite, and molybdenite while the post-gabbroic rocks consist of equigranular, garnetiferous, potassic muscovite leucogranites and pegmatites (Ayres 1969). The mapped outcrop areas of the white pegmatites and muscovite-bearing post-gabbro units share a similar geological setting to Frontier Lithium's Pakeagama property which is also situated near an intersection of 3 differing lithologies, mafic to intermediate metavolcanic rocks, muscovite-bearing granitic rocks, and metasedimentary rocks.

A reconnaissance re-evaluation of a number of northwestern greenstone belts by Thurston, Cortis and Chivers (1987) identified komatiitic pillowed flows north of Nekence Lake in the Nekence assemblage (*see* Figure 2B). The identification of mafic to ultramafic sills indicates the possibility of PGE, and Cr mineralization within the Nekence assemblage in the Muskrat Dam Lake greenstone belt.

The Muskrat Dam Lake greenstone belt provides an excellent opportunity to develop noteworthy exploration properties. Historically underexplored and largely open unencumbered ground, it provides vast potential for new discoveries to occur. Reviewing assessment files, reports and diamond-drill hole data indicates that several deposit types and mineralization styles are possible within the Muskrat Dam Lake greenstone belt. The Windigo River area presents discordant vein systems within metagabbro sills that may host lode gold deposits. Samples collected at Sandhill Crane Island indicate gold, copper, nickel and chromium mineralization and reflects potential PGE and lode gold deposits. The Muskrat Dam Lake area contains the highest density of sulphide mineral occurrences reported by Ayres (1969) and remains an excellent target for lode gold mineralization. The Rottenfish River and other areas around the Muskrat Dam Lake greenstone belt contain almandine-bearing banded iron formation and have the potential to host banded iron-formation–associated gold deposits. Muscovite-bearing granites and intrusive rocks present an opportunity for lithium-bearing and rare earth element deposits near Morrison River.

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Notes

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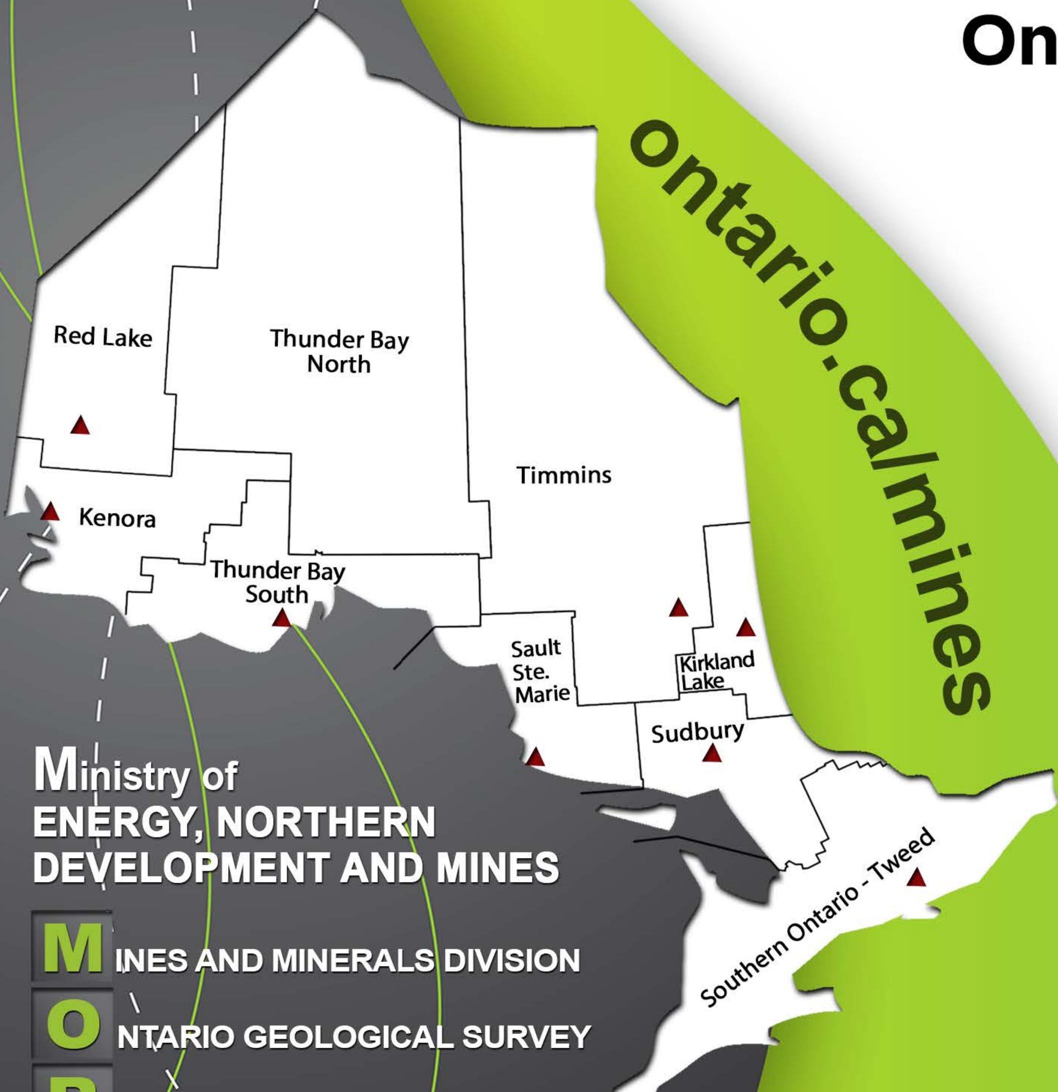

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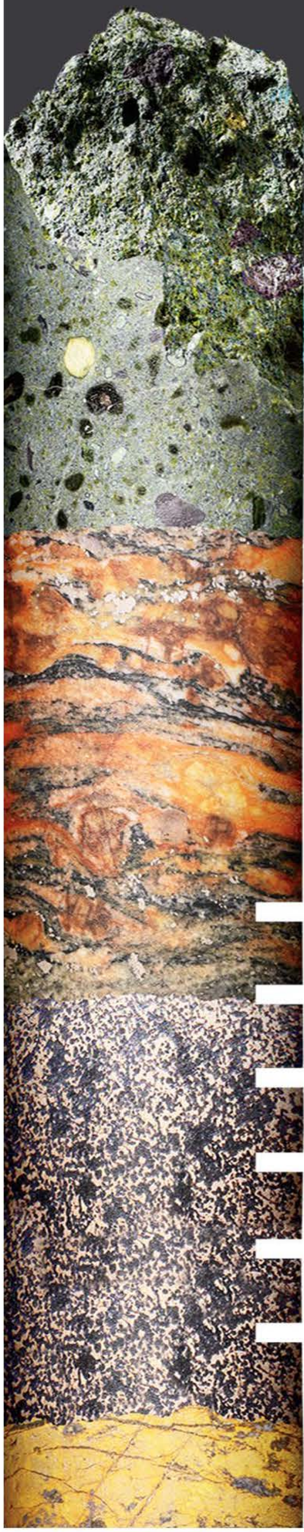

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