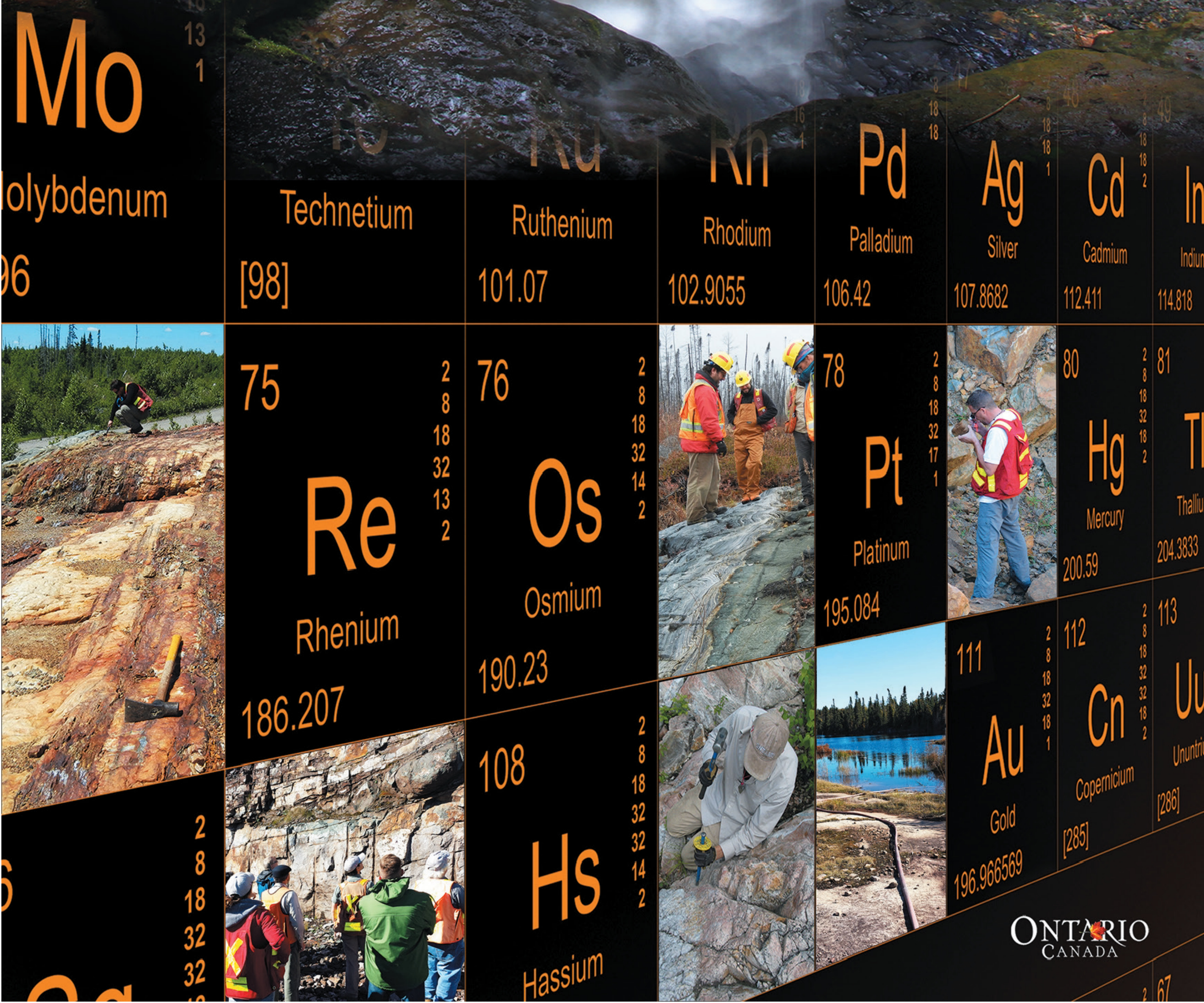
Ontario

RECOMMENDATIONS for Exploration

Ontario Geological Survey **Resident Geologist Program**

Ministry of Northern Development and Mines

2016 - 2017



ONTARIO CANADA

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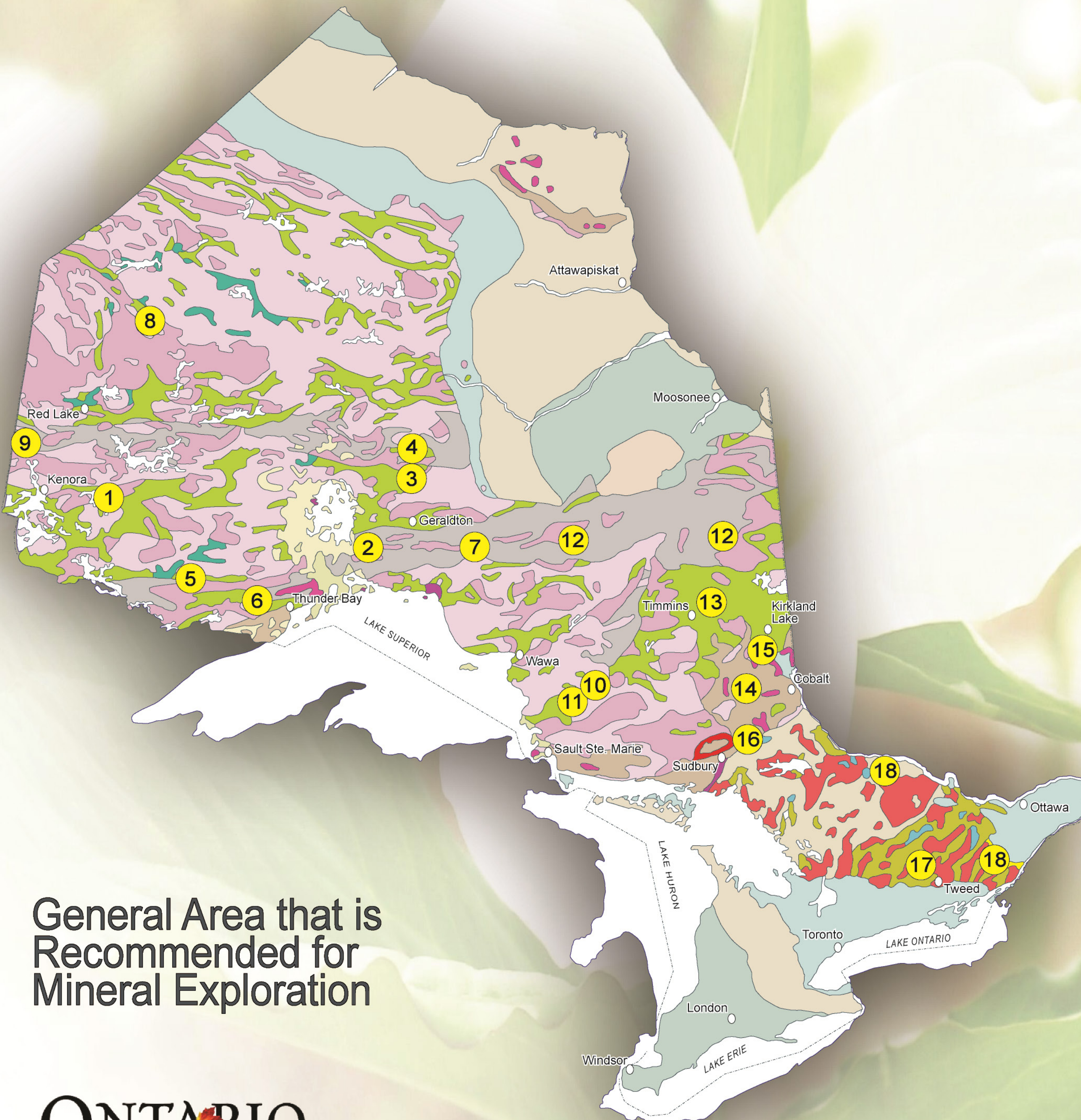

General Area that is Recommended for Mineral Exploration

ONTARIO
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Photo courtesy of Karen Labonte

Ontario Geological Survey
Resident Geologist Program
Recommendations for Exploration 2016–2017

The Ontario Geological Survey is pleased to issue its 2017 Recommendations for Exploration. These recommendations are the product of the Ministry's 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 OGS Earth on the MNDM Mines and Minerals Division Web site (http://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth) to see what else is available.

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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.

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HIGHLIGHTS

- **Pegmatites are known to host a number of economic commodities such as lithium, tantalum, rubidium, cesium and ceramic-grade feldspar and quartz.**
- **Northwestern Ontario, particularly the Kenora District, contains numerous rare-element–bearing granite pegmatite located in a variety of rock types and geological settings.**
- **Recognition of parental granites adjacent to subprovince/terrane boundaries can be critical in the examination of rare-element potential of an area.**

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Rare-Element Pegmatite Potential in the Superior Province and the Kenora District

The Superior Province contains over 200 rare-element mineral occurrences that are hosted by the following: metavolcanic rocks (52%), clastic metasedimentary rocks (23%), peraluminous granite plutons (20%) and tonalite-granodiorite plutons (5%) (Breaks, Selway and Tindle 2005).

Breaks, Selway and Tindle (2003) have proposed there is a linkage between peraluminous, S-type, fertile parent granites and rare-element pegmatites. Recognition of peraluminous granites is critical in the exploration for rare-element pegmatites. Rare-element–bearing (lithium, cesium, rubidium, beryllium, tantalum, niobium, gallium, thalium and germanium) pegmatites derived from a fertile, parental granite pluton are typically distributed over an area of 10 to 20 km^2 within 10 km of the fertile granite. Breaks, Selway and Tindle (2003) provided summaries of the geochemical, mineralogical and textural characteristics of rock types associated with rare-element pegmatites.

Breaks, Selway and Tindle (2005) grouped rare-element occurrences in the Superior Province based on rock type and pegmatite classification. The following is a summary of the geological setting of rare-element occurrences in the Superior Province:

- Peraluminous, S-type and pegmatite granites are typically situated along the boundaries of high-grade (amphibolite-granulite facies), metasedimentary-dominant subprovince boundaries.
- Fertile S-type granites are situated in medium-grade (greenschist-amphibolite facies) parts of the subprovince, such as the Dryden and Separation Rapids pegmatite fields, and are not located adjacent to high-grade metamorphic rocks.
- Rare-element pegmatites ± parental granites can be confined to major regional faults.
- Lithium-bearing rare-element pegmatites, such as the Raleigh Lake occurrences, are located within greenstone belts and are not related to high-grade metamorphic rocks or major fault systems.
- Petalite-type pegmatites are found in the Separation Rapids area while spodumene-type pegmatites are commonly located in the other parts of the Kenora Resident Geologist District.

The diversity of geological settings that are known to host rare-element–bearing pegmatite indicates there is high-potential for additional mineralized zones in various areas of the Superior Province and especially in the Kenora District. A regional approach to identify additional peraluminous felsic intrusions, fertile granites and mineralized pegmatite would include examining the geological settings associated with typical emplacement of rare-metal–enriched, granitic pegmatite systems.

Rare-Element Pegmatite Potential: Superior Province and the Kenora District

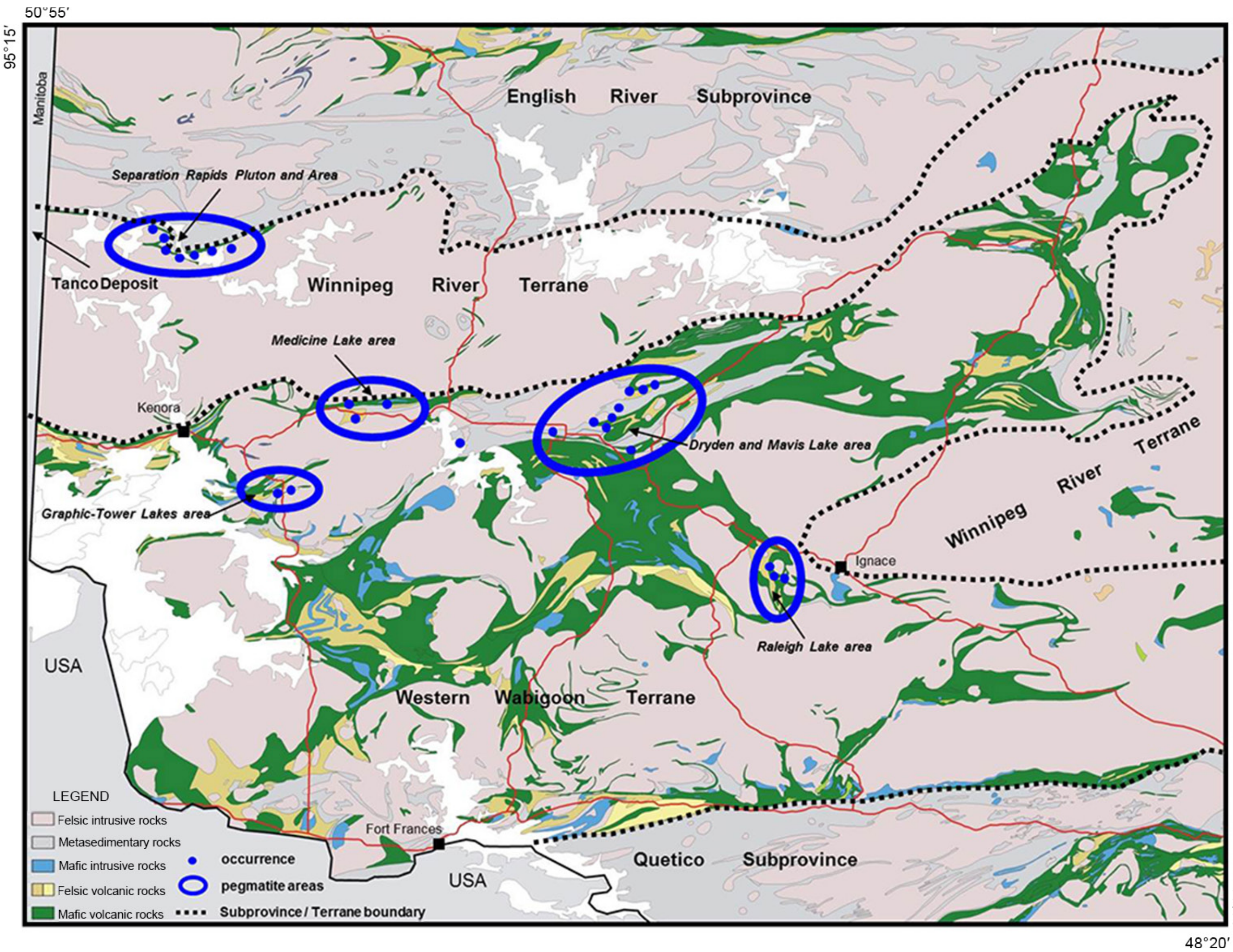

Figure 1. Bedrock geology, showing subprovince and terrane boundaries, pegmatite areas and location of rare-element occurrences in the Kenora Resident Geologist District (*modified from* Ontario Geological Survey (2011) and Stott et al. (2010)).

Granitic pegmatite systems associated with a majority of the known rare-element pegmatite occurrences in the Kenora District are located near the Winnipeg River terrane boundary, adjacent to metasedimentary rocks, and are commonly hosted by supracrustal rocks (Figure 1). Publications that discuss the geological setting, mineralization and assay results of these pegmatite areas in the Kenora District are presented in Table 1.

Unexplored areas situated adjacent to known rare-element occurrences and along the extent of the Winnipeg River terrane boundary are prime locations to identify areas of peraluminous, S-type, fertile parent granites and rare-element–bearing pegmatite (Figure 1). In many cases, the fertile granite is buried; the only surface expression associated with these intrusive rocks is the rare-element pegmatites themselves. Rare-element pegmatites are nonmagnetic and contain insufficient metallic minerals to be conductive. They typically do not contain radioactive minerals and may not have a sufficient specific gravity to allow them to be distinguished from the host rocks utilizing gravity surveys (Galeschuk and Vanstone 2005). Survey techniques typically used in metallic mineral exploration will not be useful in the search for fertile granites and pegmatites.

Rare-Element Pegmatite Potential: Superior Province and the Kenora District

The emplacement of pegmatite is accompanied by the alteration and development of a rare-element–enriched aureole within the adjacent host rocks. Galeschuk and Vanstone (2005) stated: "The best metals with respect to aureole thickness and intensity are Li, Cs, B, Sn, Be and Rb with the latter metal forming smaller, less intense aureoles". This mobility of metals associated with pegmatite emplacement can be a valuable asset when developing exploration programs. Selway, Breaks and Tindle (2005) and Galeschuk and Vanstone (2005) provided summaries of the use of lithogeochemistry as a detection method to define buried pegmatite.

Geological mapping, structural studies, lithogeochemical sampling, testing of B-horizon soil samples utilizing the Enzyme Leach^{SM} analytical technique, and biogeochemistry are some exploration techniques that have been applied to evaluate the rare-element potential of an area. Galeschuk and Vanstone (2005) provided summaries and comparisons of several of these exploration techniques that targeted buried rare-element–bearing pegmatite bodies near the Tanco lithium-cesium-rubidium-tantalum deposit in southeastern Manitoba. Galeschuk and Vanstone (2005, p.163) concluded that the "use of lithogeochemical surveys as a primary exploration tool in the search for buried rare-element pegmatite has resulted in the documentation of number of lithogeochemical anomalies that remain unexplained after drill testing". Based on this study, Galeschuk and Vanstone (2005, p.172) concluded.

> ...Tanco has moved away from lithogeochemistry and is placing increasing emphasis on soil geochemistry and the Enzyme Leach^{SM} method as its primary exploration tool. The geochemistry is used in conjunction with geological and structural mapping in an integrated exploration approach.

Table 1. Known pegmatite fields and groups in the Kenora Resident Geologist District and related references that summarize the rare-element potential of these areas.

Pegmatite Area	Reference
Dryden Pegmatite Field	Breaks (1981, 1989)
Graphic–Tower Lakes Pegmatite	Breaks, Selway and Tindle (2001, 2003)
Gullwing–Tot Lakes Pegmatite Group	Breaks and Janes (1991) Breaks and Kuehner (1984) Breaks and Moore (1992) Breaks, Selway and Tindle (2001, 2003, 2005) Selway, Breaks and Tindle (2005)
Mavis Lake Pegmatite Group	Breaks (1993)
Medicine Lake Pegmatite	Breaks and Janes (1991) Breaks, Selway and Tindle (2001, 2003)
Separation Rapids Pegmatite Group	Breaks and Tindle (1996, 1997, 2001) Breaks, Selway and Tindle (2005) Breaks, Tindle and Smith (1999) Selway, Breaks and Tindle (2005) Tindle, Breaks and Webb (1998) Tindle and Breaks (1998, 2000)
Raleigh Lake Pegmatite	Breaks (1993)
Wabigoon–Winnipeg River Subprovince Boundary Area	Breaks, Selway and Tindle (2001, 2003, 2005) Selway, Breaks and Tindle (2005)
Regional Studies on Pegmatite	Breaks (1981, 1982, 1993, 2005)

Rare-Element Pegmatite Potential: Superior Province and the Kenora District

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Rare-Element Pegmatite Potential: Superior Province and the Kenora District

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HIGHLIGHTS

- **Occurrences of lithium-bearing pegmatites remain open for staking proximal to established exploration targets.**
- **High potential for discovery of new lithium-bearing pegmatites along the contact between the Glacier Lake batholith and Quetico metasedimentary rocks.**

Tantalum and Lithium Potential in the Georgia Lake Pegmatite Field, Quetico Subprovince

Commodity market projections suggest the demand for raw materials used in batteries (especially lithium and graphite) is expected to increase in future years as a result of greater demand for and subsequent production of electric vehicles. Additionally, the demand for ethically sourced tantalum is expected to increase because of uncertainty in the current supply chain and a steady demand for tantalum used in electronics manufacturing (Mackay and Simandl 2015). The looming demand for these critical metals and minerals suggests a greater need for exploration and discovery of new sources. The Georgia Lake pegmatite field, northeast of Nipigon, hosts the largest concentration of rare-metal mineralization in the Superior Province (Breaks, Selway and Tindle 2008).

The Georgia Lake pegmatite field has been subject to considerable lithium exploration since spodumene-bearing pegmatites were first discovered there in 1955. Following the initial discoveries, the Ontario Department of Mines (Pye 1964, 1965) initiated a mapping program in the Georgia Lake area, focussing on the nature, distribution and genesis of the lithium deposits. Exploration for lithium deposits in the Georgia Lake pegmatite field has occurred intermittently since that time and has resulted in the delineation of a number of deposits with resources (Table 1). Potential for significant, undiscovered sources of tantalum- and lithium-bearing pegmatites remains high in this area. Techniques suitable for exploration of lithium and rare-metal–bearing pegmatites were reviewed by Selway, Breaks and Tindle (2006) and include examining the regional zoning of fertile granites and pegmatite dikes, and determining the degree of fractionation of granite and pegmatite bodies. The degree of fractionation of a granitic rock can be evaluated using bulk whole-rock compositions and bulk potassium-feldspar and muscovite compositions as well as identifying the presence of tantalum-bearing minerals. Results of an Ontario Geological Survey study in the area are provided in Breaks, Selway and Tindle (2008); data accompanying this study (Tindle, Breaks and Selway 2008) provide field descriptions, sample locations, whole-rock geochemistry and electron microprobe data, all of which are useful in targeting new areas for tantalum-lithium mineralization.

Widespread S-type, peraluminous granites were generated by the extensive partial melting of clastic metasedimentary rocks in Quetico Subprovince at 2670±2 Ma (Percival and Sullivan 1988). The S-type, peraluminous pegmatitic granites, which locally constitute the Glacier Lake batholith, are widespread over a 40 km by more than 110 km zone in the Quetico Subprovince immediately south and northeast of a medium-grade, clastic metasedimentary belt that forms the northern part of the Quetico Subprovince (Breaks, Selway and Tindle 2008). The Glacier Lake batholith is composed of medium- to coarse-grained granite and pegmatitic granite and is subdivided into southwestern and northeastern parts (Breaks, Selway and Tindle 2008; McCrank, Misiura and Brown 1981).

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Tantalum and Lithium Potential: Georgia Lake Pegmatite Area

Table 1. Summary of identified lithium resources in the Georgia Lake pegmatite field.

Deposit Name / NTS Area	Tonnage-Grade Estimates and/or Dimensions	Reserve References
Aumacho River (Brink) (42E05/SW)	855 475 t @ 1.633% Li_2O	Pye (1965, p.64)
Georgia Lake (Nama Creek Main Zone North, Conway, Line 60, Nama Creek Main Zone Southwest, Harricana) (52H08/NE)	Indicated Resource: 3.19 Mt @ 1.10% Li_2O Inferred Resource: 6.31 Mt @ 1.00% Li_2O (NI 43-101–compliant resources)	Selway et al. (2012, p.18-19)
Jean Lake (42E05/NW)	1.689 Mt @ 1.30% Li_2O	Jean Lake Lithium Mines Ltd., Annual Report (1957)
McVittie (52H08/NE)	261 000 t @ 1.03% Li_2O	Pye (1965, p.89)
MNW (52H/04NE)	40 000 T “high-grade Li”	*Canadian Mines Handbook* 2002–2003, p.190
Vegan–Newkirk (42E05/SW)	750 000 t @ 1.38% Li_2O	*The Northern Miner*, March 22, 1956

Fractionation of residual pegmatitic granite melts produced several fertile, peraluminous granite bodies and associated rare-metal–bearing pegmatites. Fertile granitic bodies are located along the contact zone between the Glacier Lake batholith and clastic metasedimentary rocks in the northeastern part of the batholith (Barbara Lake stock) and the southwestern part of the batholith (MNW stock and Pine Portage pegmatitic granite; Breaks, Selway and Tindle 2008). These areas have been proven to host rare-metal–mineralized pegmatites and have the potential to host new occurrences and resources. The areas listed below, and shown in Figure 1, represent recommended exploration targets for rare-metal–bearing pegmatites (cf. Breaks, Selway and Tindle 2008):

1. Contact zone between the northeastern part of Glacier Lake batholith and Quetico clastic metasedimentary rocks:
   - a) Gathering Lake area
   - b) Parks Lake area
   - c) Barbara Lake stock
2. Contact zone between the southwestern part of the Glacier Lake batholith and Quetico clastic metasedimentary rocks:
   - a) Cosgrave Lake–Hanson Lake area
3. Quetico Subprovince clastic metasedimentary rocks:
   - a) Brink and Southwest complex-type, spodumene-subtype pegmatites
   - b) McVittie and Foster albite-spodumene pegmatites
   - c) MNW stock, especially area around the MNW complex-type, petalite-subtype pegmatite

Tantalum and Lithium Potential: Georgia Lake Pegmatite Area

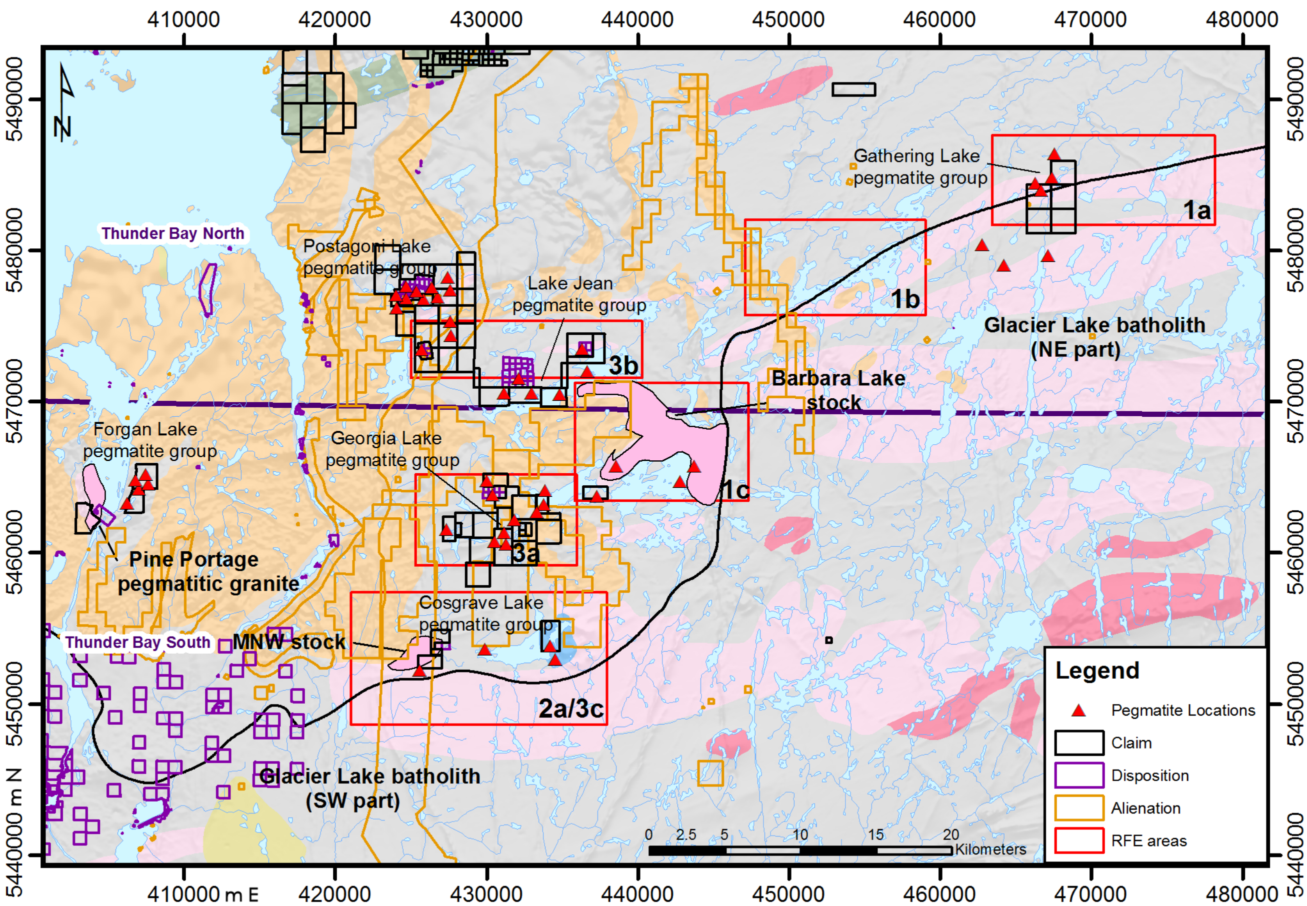

Figure 1. Geological map (underlain with shaded residual total magnetic field (darker grey shading)) showing the distribution of pegmatites in the Georgia Lake pegmatite field and "Recommendations for Exploration" (RFE) areas. UTM co-ordinates in North American Datum 1983 (NAD83), Zone 16; Claim units as of October 4, 2016; Regional geology *from* Ontario Geological Survey (2011); selected granitic intrusion outlines *from* Breaks, Selway and Tindle (2008) and McCrank, Misiura and Brown (1981). Geophysical data *from* Ontario Geological Survey (2015a, 2015b, 2015c). Numbers refer to recommended exploration targets mentioned in the text.

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Tantalum and Lithium Potential: Georgia Lake Pegmatite Area

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HIGHLIGHTS

- **Fertile parental granites and lithium-rich pegmatites have been identified along the Wabigoon–English River Subprovince north of Nakina.**
- **This greenfields area has seen very little historical exploration for lithium-rich pegmatites.**

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Lithium- and Rare-Metal–Bearing Pegmatite Potential Along the Wabigoon–English River Subprovince Boundary, Nakina Area

Increasing demand for electric cars and mobile devices has driven a recent increase in demand for raw materials used in lithium-ion batteries (i.e., lithium, cobalt, graphite and nickel). Demand for lithium is forecasted to continue to increase in the coming years as current lithium production is not expected to satisfy world demand. Since the 1950s, the Superior Province has been subject to considerable exploration for lithium and rare-metal–bearing pegmatites and remains an extremely high-potential area for "hard rock" lithium resources. Over the past 18 months, Ontario has seen a considerable increase in staking and exploration for lithium-bearing pegmatites, with efforts largely focussed on already established lithium- and rare-metal–bearing districts, projects and occurrences. Little effort has been directed towards grassroots areas with the proper geological setting to host lithium and rare-metal deposits (i.e., fertile parental granite rocks). Significant opportunity remains in many untested areas for the discovery of lithium- and rare-metal–bearing pegmatites. Here, we highlight 3 such areas north of Nakina.

A fertile granite is the parental granite to a rare-element pegmatite dike, the identification of which can drastically reduce the target area when exploring for prospective pegmatite bodies (Selway, Breaks and Tindle 2006). Fertile, peraluminous pegmatitic granites have been documented along the Wabigoon–English River Subprovince boundary north of Nakina (Breaks, Selway and Tindle 2006). The fertile granites are hosted in clastic metasedimentary rocks (metawacke) along the subprovince boundary zone proximal to the Onaman–Tashota greenstone belt to the south. Barren granitic rocks are present to the north of the fertile granites, further away from the subprovince boundary zone and are hosted in migmatites and tonalites. It should be noted that several lithium-bearing pegmatites occur along the Wabigoon–English River boundary to the west, including the Seymour Lake, Crescent Lake and Falcon Lake Pegmatite groups (Breaks, Selway and Tindle 2003). Fertile, peraluminous granitic rocks were noted in the following 3 locations in the Nakina area, which correspond to red boxes in Figure 1 (cf. Breaks, Selway and Tindle 2006):

1. Abamasagi Lake Road near the junction with the Anaconda Road
2. Northwestern shoreline of Superb Lake
3. Maun Lake Road near Maytham and Queenston lakes

Outcrops exposed near the junction of Abamasagi Lake Road and the Anaconda Road revealed fertile peraluminous granite units, indicated by elevated levels of tantalum (63 ppm Ta) from bulk compositions of green muscovite (sample 02-FWB-054-02; Breaks, Selway and Tindle 2006). A small, white pegmatite dike was located on the west side of the Anaconda Road. Blocky potassium feldspar from the dike centre returned

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elevated rubidium (2418 ppm Rb) and cesium (147 ppm Cs) and low K/Rb (44) and K/Cs (727) ratios that represent the most evolved compositions found in the Abamasagi Lake Road area (*see* Tindle, Selway and Breaks 2006, Table 5). These compositions were noted to be comparable to fertile granite-pegmatite systems elsewhere, as at Separation Rapids pegmatite field, north of Kenora (Breaks and Tindle 2002).

A 30 m wide, garnet-muscovite potassic pegmatite dike is exposed on the northwestern shoreline of Superb Lake (Breaks, Selway and Tindle 2006). Samples from the Superb Lake pegmatite returned lithium values of 2246 ppm and 2688 ppm (samples 02-JBS-63-22 and 02-JBS-63-23, respectively; Tindle, Selway and Breaks 2006). Although this occurrence is currently staked at the time of publication, it highlights the presence of lithium-rich, rare-element pegmatite bodies in this drastically under-explored region.

The Maytham–Queenston lakes pegmatitic granite pluton comprises an elliptical, 10 by 13 km body of peraluminous, massive, undeformed granites with abundant coarse muscovite, pink to lilac garnets and small enclaves of metasedimentary rocks (Stott and Parker 1997; Breaks, Selway and Tindle 2006). Several characteristics of a peraluminous, fertile granite were observed in the Maytham–Queenston lakes pluton, including radiating fans of green plumose muscovite-quartz intergrowths; graphic blocky potassium feldspar-quartz; local graphic tourmaline-quartz and garnet-green muscovite aplite layers (Breaks, Selway and Tindle 2006). Breaks, Selway and Tindle (2006) also note that the Maytham–Queenston lakes pluton bears resemblance to fertile pegmatitic granites observed in the Allison Lake batholith and in the Onion Lake area, suggesting this unit could represent the parent body to considerable, undiscovered lithium- and rare-metal–bearing pegmatite dikes.

The preliminary work carried out by Breaks, Selway and Tindle (2006) highlighted the presence of fertile parental granitic rocks and lithium-rich pegmatites, giving strong evidence to suggest that all 3 areas described above may host substantial lithium- and rare-metal–bearing pegmatites. The areas listed above have not been subject to

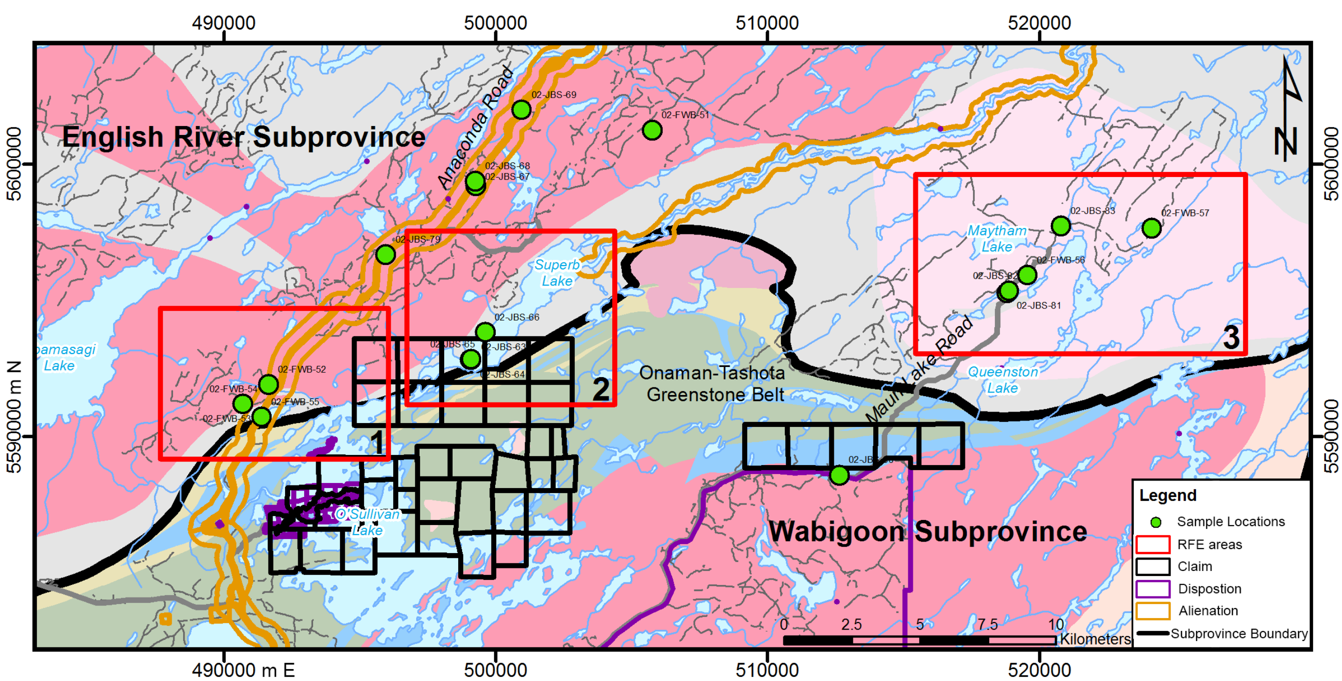

Figure 1. Geological map showing location of fertile granites along the Wabigoon–English River boundary and “Recommendations for Exploration” (RFE) areas (red boxes). UTM co-ordinates in North American Datum 83 (NAD83), Zone 16; claim units as of October 4, 2016; regional geology *from* Ontario Geological Survey (2011); sample locations *from* Tindle, Selway and Breaks (2006); subprovince boundary location *from* Stott (2011).

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significant exploration for such pegmatites. All 3 areas remain untested, with a high-potential to host new lithium and rare-metal occurrences and resources. Exploration in these areas is warranted, following up on the samples described in Breaks, Selway and Tindle (2006) and focussing on the discovery of more fractionated, pegmatitic phases. Techniques suitable for exploration of lithium and rare-metal–bearing pegmatites were reviewed by Selway, Breaks and Tindle (2006), which include examining the regional zoning of fertile granites and pegmatite dikes, and determining the degree of fractionation of granite and pegmatite bodies. The degree of fractionation of a granitic rock can be evaluated using bulk whole-rock compositions and bulk potassium-feldspar and muscovite compositions as well as identifying the presence of tantalum-bearing minerals.

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HIGHLIGHTS

- **Several zinc-rich VMS occurrences have been identified in the Melchett Lake greenstone belt which all remain open for staking.**
- **Widespread VMS-related alteration recognized within a dominantly felsic metavolcanic package.**

Volcanogenic Massive Sulphide-Hosted Base and Precious Metal Potential in the Melchett Lake Greenstone Belt

The Melchett Lake greenstone belt (MLGB) hosts a number of gold and base metal occurrences, some of which suggest a volcanogenic massive sulphide (VMS) environment (Table 1). The Melchett Lake banded iron formation was the focus of iron exploration in the 1960s and hosts 2 iron resources: Skibi Lake (335 000 000 tons of 26.2% acid-soluble Fe) and Stewart Lake (49 500 000 tons grading 30% Fe; Ontario Geological Survey 2016). The MLGB is approximately 8 by 40 km in size, and consists largely of felsic metavolcanic rocks, namely east-trending, amphibolite-facies lithological units (Figure 1; Bond and Foster 1981a, 1981b; Devaney 1999). It is flanked to the south by the Melchett Lake banded iron formation, which extends for over 60 km. The MLGB is located approximately 65 km north-northwest of Nakina and can be accessed by the Anaconda Road, which extends north from Nakina to the southwestern corner of the MLGB. The remainder of the belt can be accessed by boat on Melchett Lake and Nass Lake or by float-plane or helicopter.

The Ontario Geological Survey (OGS) released an aeromagnetic survey in the Melchett Lake area, north of Nakina, in 2010 (Figure 2; OGS 2010). A detailed interpretation of these aeromagnetic data was completed by Stott and Rainsford (2010). The survey area largely straddles high-grade, gneissic, metasedimentary and granitoid rocks of the English River basin between the Neoarchean Uchi domain (including the Fort Hope greenstone belt) to the north and the Winnipeg River (Caribou Lake greenstone belt) and Marmion terranes (Marshall Lake and O'Sullivan Lake greenstone belts) to the south. The MLBG occurs in the midst of this high-grade gneissic terrane.

Exploration for VMS deposits in the MLGB has occurred sporadically following the discovery of zinc mineralization at the Nakina Mine prospect (Nakina 1) in 1959. The area, which hosts the Nakina 1 and Relf zones, was described by Wahl (1985) as a lenticular felsic metavolcanic sequence, approximately 15 km in strike length and upwards of 1500 m thick, which appears to thin at the eastern and western ends. Mineralization was interpreted to occur in paleotopographic depressions as a result of fumarolic activity during a volcanic hiatus, depositing polymetallic massive sulphides in 2 currently recognized areas (Nakina 1 and Relf; Wahl 1985). Alteration, characterized by sodium depletion and iron + magnesium enrichment, were noted in areas proximal to the Nakina 1 and Relf zones, as well as in northeastern portion of the MLGB around Colpitts Lake (Wahl 1985; Devaney 1999). The Nakina 2 zone was recognized by Ottone (1987) as a gold target and lies stratigraphically above the Nakina 1 target, possibly representing a later-stage, gold-rich mineralizing event related to VMS deposition.

The potential for discovery of economic zinc-lead-silver-gold–bearing VMS deposits in the Melchett Lake greenstone belt is high. A compilation of all historical work on the property is recommended to provide a

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comprehensive framework of rock types, structures and alteration systems controlling mineralization within the belt. Locating and sampling all occurrences, historical trenches and drill collars is recommended following compilation. Considerable attention should be paid to the alteration system noted by Devaney (1999) and the structures controlling currently recognized mineralized zones. Geophysical methods suitable for VMS exploration (e.g., high-resolution magnetometer, electromagnetic and borehole techniques) should aid in identifying and prioritizing drilling targets. Assessment files for all work conducted on the property are available on GeologyOntario (http://www.geologyontario.mndm.gov.on.ca/), through the OGSEarth Assessment Files application (http://www.mndmf.gov.on.ca/en/mines-and-minerals/applications/ogsearth) or in the Resident Geologist's files in the Thunder Bay Regional office. Ontario Geological Survey products covering the Melchett Lake area include bedrock geological maps (Table 2), airborne geophysical surveys and mineral deposit inventory points, which provide an excellent framework for the area's mineral potential.

Table 1. Summary of occurrences/prospects in the Melchett Lake greenstone belt (excluding iron occurrences and deposits; MDI data *from* OGS 2016). Universal Transverse Mercator (UTM) co-ordinates in North American Datum 83 (NAD83), Zone 16.

Occurrence/Prospect and Location	Mineral Deposit Inventory (MDI) Number	Assay Highlights	Description of Occurrence
Nakina Mines Prospect (Nakina 1 Zone) (499534E, 5622152N)	*MDI42L14SE00005*	14.85% Zn, 0.13% Cu, 0.92 oz/ton Ag and 0.30 oz/ton Au (assay from trench; Nakina Mines Ltd., 1968) 8.25% Zn, 1.08% Pb, 0.76 oz/ton Ag and 0.20 oz/ton Au (Hole N-4, Nakina Mines Ltd., 1968)	Polymetallic pyrite-sphalerite-chalcopyrite-galena mineralization occurs within felsic to intermediate metavolcanic schists within abundant pyrite, sericite and chloritic alteration.
Lun-Kerr Occurrence (Relf Zone) (503908E, 5622130N)	*MDI42L15SW00003*	19.1% Zn, 0.40% Cu, 2.2% Pb and 16.4 oz/ton Ag (assay from trench, Shawmine Explorations Ltd., 1964)	Polymetallic pyrite-sphalerite-chalcopyrite-galena mineralization occurs within muscovite-sericite schists and quartzo-feldspathic mica schists
Aldor Exploration Gold Occurrence (512492E, 5616455N)	*MDI42L10NW00007*	0.52 oz/ton over 25 cm	Sample from quartz vein in a quartz gabbro dike (later interpreted to be a mafic metavolcanic unit)
Campbell Occurrence (506406E, 5618999N; location approximate)	n/a	1.8% Zn, 1.0% Cu and 0.06 oz/ton Au (assay from grab sample)	Disseminated copper, zinc, gold mineralization from pyritic quartz-sericite schist (altered felsic pyroclastic rocks)
Molly Lake Occurrence (508192E, 5617632N; location approximate)	n/a	1.5 % Zn and 0.17 oz/ton Au	Mineralization consists of massive pyrrhotite in a 3 m thick amphibolite schist layer

N.B., oz/ton – ounces per ton.

Table 2. Summary of relevant Ontario Geological survey map products available for the Melchett Lake greenstone belt.

Map No.	Map name	Authors	Year	Scale
P.2392	Precambrian geology of the Melchett Lake area, west part, District of Thunder Bay	W.D. Bond and J.R. Foster	1981	1:15 840
P.2393	Precambrian geology of the Melchett Lake area, east part, District of Thunder Bay	W.D. Bond and J.R. Foster	1981	1:15 840
OFM234	Precambrian geology, Colpitts–Bury lakes area, west part	J.R. Devaney and S.M. Nacha	1994	1:20 000
P.565	Operation Fort Hope, Makokibatan–Melchett lakes sheet, districts of Kenora (Patricia Portion), Cochrane and Thunder Bay	P.C. Thurston and M.W. Carter	1969	1:126 720
P.275-REV	Compilation Series, Ogoki Lake sheet, Thunder Bay and Cochrane districts	G.M. Stott, C.D. McConnell and J.K. Mason	1984	1:126 720

VMS-Hosted Base and Precious Metals: Melchett Lake Greenstone Belt

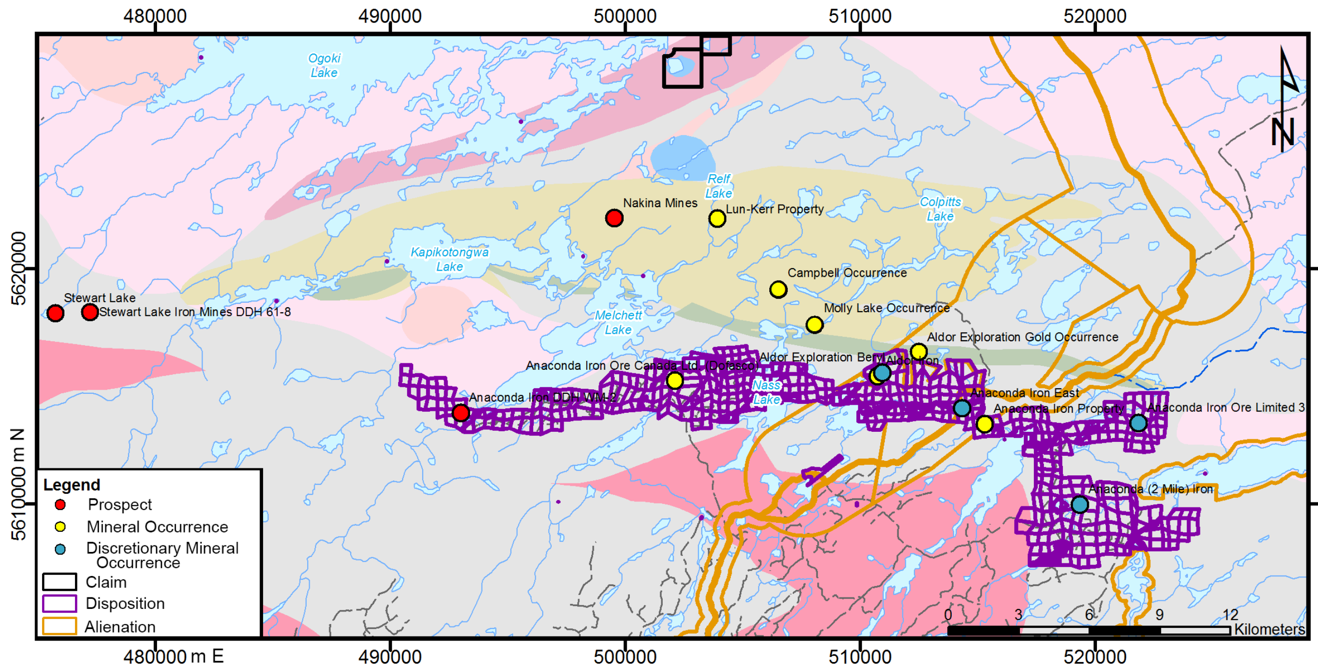

Figure 1. Geological map showing Mineral Deposit Inventory points in the Melchett Lake greenstone belt (beige and olive green). UTM co-ordinates in NAD83, Zone 16; claim units as of October 4, 2016; regional geology *from* Ontario Geological Survey (2011).

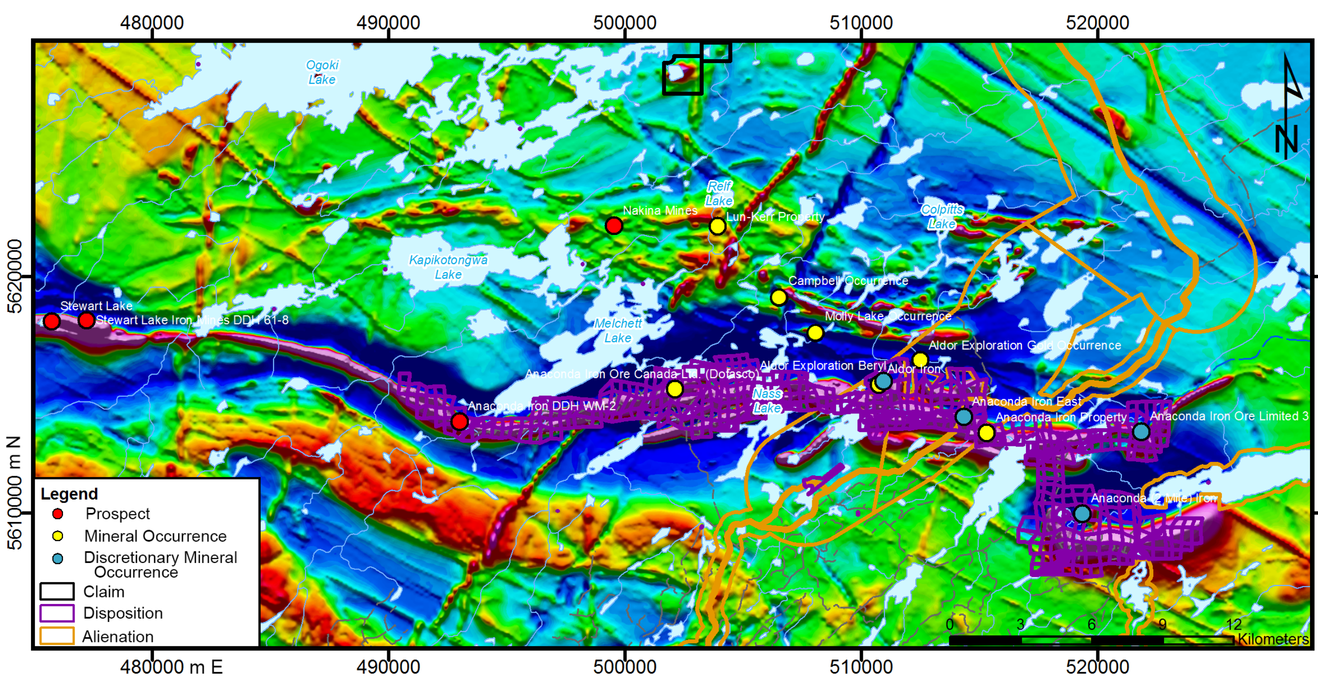

Figure 2. Total residual magnetic field map showing Mineral Deposit Inventory points in the Melchett Lake greenstone belt. UTM co-ordinates in NAD83, Zone 16; claim units as of October 4, 2016; geophysical data *from* Ontario Geological Survey (2010).

VMS-Hosted Base and Precious Metals: Melchett Lake Greenstone Belt

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5

Iron, Copper, Cobalt and Nickel Potential near Atikokan

HIGHLIGHTS

- **Mafic-ultramafic Atikokan River Intrusions have potential to host iron-copper-cobalt-nickel mineralization.**
- **Demand for cobalt is expected to rise dramatically.**

The Commodity Research Unit (CRU) anticipates a 68% increase in cobalt consumption between 2015 and 2025. CRU foresees the cobalt market falling into a 3000 tonne deficit this year, following 7 years of overcapacity and oversupply. Prices are projected to increase in 2017 as global demand for refined cobalt exceeds the 100 000 ton mark and supply tightens (Spencer 2016). Cobalt is used in batteries for electric vehicles, which is the driver for the market increase.

The Atikokan River Intrusions (ARI) are a series of linear, east-northeast–trending, dike-like ultramafic to mafic intrusions prospective for iron-copper-cobalt-nickel (Fe-Cu-Co-Ni) deposits (MacTavish 1999). These intrusions occur in the Sapawe Lake area, east of Atikokan and approximately 200 km west of Thunder Bay. The dominant regional geological feature is the boundary between the volcano-plutonic Wabigoon Subprovince and the younger metasedimentary sequences of the Quetico Subprovince. This boundary is locally delineated by the transcurrent Quetico Fault Zone, a major east-trending structural feature that is characterized by intense and steeply dipping foliations and deformation. This fault zone is, in some places, up to 1 km or more in width (Purdon 1989). The ARI are, in some places, up to 100 m wide, 1100 m long, and occur along a 25 to 30 km long section of the Quetico Fault Zone (MacTavish 1999). They form a series of distinct, semicontinuous, magnetic "high" anomalies as shown in red and purple on the following airborne magnetic map (Figure 1). Stone (2008) mapped the ARI in the Sapawe Lake area as hornblende gabbro, pyroxene-hornblende gabbro, melagabbro, and fine- to medium-grained, massive diorite.

The iron-copper-cobalt-nickel-prospective ARI are distinct from the nearby Quetico mafic–ultramafic intrusions that are known for copper-nickel and platinum group elements (PGE) mineralization. The Quetico intrusions were recommended for copper-nickel-PGE exploration last year by the Resident Geologist Program, Thunder Bay South District, in the Report of Activities 2015 (Puumala et al. 2016).

The ARI have previously been explored by numerous companies and examined by the Ontario Geological Survey (MacTavish 1999). The most recent exploration work was carried out for MetalCorp Ltd. on the Staines Intrusion (MacTavish 2006). A summary of historic exploration highlights is provided in Table 1.

MacTavish (1999) described the ARI as iron-copper- and commonly cobalt-rich syntectonic bodies, and characterized mineralized zones as:

> …sulphide-rich, massive to semi-massive zones, lenses, and pods of magnetite, usually surrounded by diffuse, disseminated, occasionally net-textured, sulphide/magnetite halos. The associated sulphides are often Cu- and Co-rich and primarily comprise pyrite, pyrrhotite, and chalcopyrite. Sulphide content within the group of intrusions apparently increases to the west and semi-massive to massive sulphide

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Iron, Copper, Cobalt and Nickel: Atikokan Area

> zones begin to dominate over the oxide-rich zones. Deformation commonly remobilises the sulphides (particularly chalcopyrite) and sometimes magnetite into stringers, veins, and semi-massive pods. Supergene weathering of sulphides commonly forms delicate, fibrous aggregates of gypsum and melanterite.

The 2 largest intrusions, known as Iron Mountain and Staines, are both currently available for option. The Iron Mountain intrusion is located under the eastern portion of Sapawe Lake and extends approximately 4 km further east on the Atikokan Iron Mine property of K. Bjorkman. The Staines Intrusion is located under the western portion of Sapawe Lake and extends 1.5 km further west on the Staines (formely Sabawi) property held by G. Staines and F. Broomhead (Figure 1).

D. Campbell of the Resident Geologist Program visited the Staines and Atikokan Iron Mine properties on August 23 and 24, 2016. Brief summaries of the exploration histories for each property are provided below along with descriptions of the mineralization that was observed on surface during the site visits.

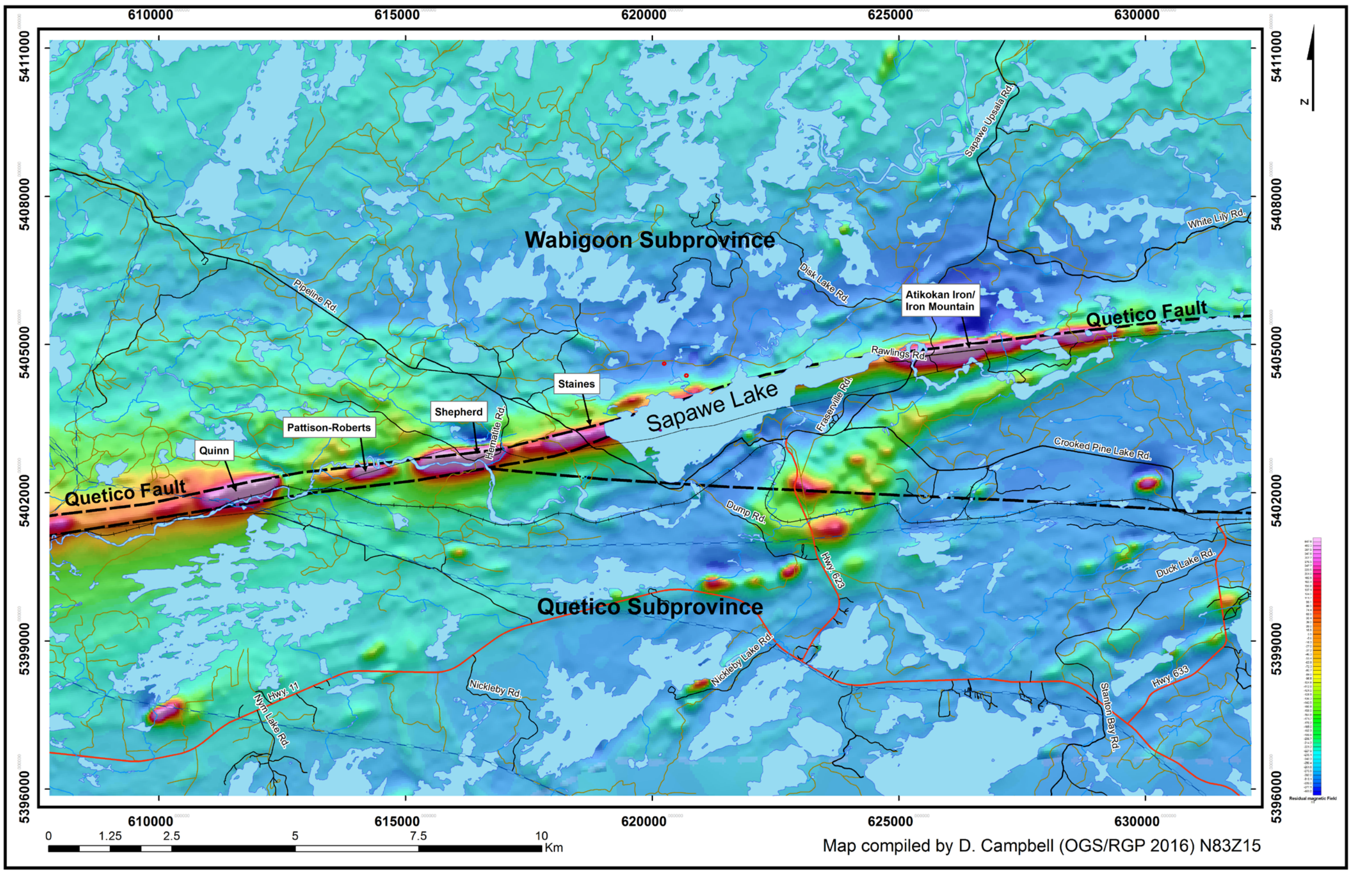

Figure 1. Map of the Sapawe Lake area illustrating "high" magnetic signature of the Atikokan River Intrusions (OGS 2003). Universal Transverse Mercator (UTM) co-ordinates in North American Datum 1983 (NAD83), Zone 15.

Staines (Formely Sabawi) Property

The Staines Intrusion is poorly exposed, as it is located under Sapawe Lake and covered by overburden on the western portion of the property. No mafic to ultramafic intrusive rocks were observed during the recent Resident Geologist Program site visit. The Staines Intrusion was first explored by Steep Rock Iron Mines in 1940. This

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program consisted of 5 diamond-drill holes that returned assays of up to 40% Fe and 0.8% Cu over 18.3 to 24.4 m (MacTavish 2005). Additional diamond drilling occurred on the property between 1969–80 and during 2005–06. Highlights of these exploration programs are provided below in Table 1.

Atikokan Iron Mine Property (Iron Mountain Intrusion)

The Iron Mountain intrusion has been explored intermittently since the late 1800s and was developed as an iron mine in the early 1900s. Between 1887 and 1901, the property was worked by various individuals and companies, with exploration consisting of trenching, stripping, 6 diamond-drill holes and excavation of a 284 foot tunnel through the hill. In 1905, Atikokan Iron Company Limited took over the development of the property and then commenced mining operations. Development consisted of construction of a mining plant and a 3 mile spur line to the Canadian National Railway main line. Mining operations included the excavation of 5 tunnels and drifting on both sides, an open cut, and 3 shafts sunk to depths of 147 feet, 150 feet and 127 feet. Mining was carried out intermittently from 1907 until termination in 1913 (Grabowski 1975). The mine produced 82 264 tonnes of ore grading 59.8% iron (Shklanka 1968). Highlights of more recent exploration on the Iron Mountain intrusion on the Atikokan Iron Mine property are tabulated below in Table 1.

The surface expression of the Iron Mountain intrusion consists of a large east-northeast–trending ridge that is well-exposed; however, rust and supergene weathering (Photo 1b) masks the bedrock, making identification of rock types and structures difficult. During the recent Resident Geologist Program site visit, 11 samples were collected from mineralized rocks that were either i) semimassive to massive sulphides (pyrite, pyrrhotite, chalcopyrite)(Photo 1a); ii) magnetite-rich zones and/or stringers ± pyrrhotite or iii) chlorite and/or carbonate-altered rocks with disseminated sulphides (*assays are pending*). Oxide and sulphide mineralization in the area indicates potential for a large tonnage deposit, with iron and low-grade copper and cobalt.

Systematic diamond-drilling and geophysical programs are recommended to fully evaluate the potential for iron-copper-cobalt-nickel mineralization, keeping in mind Grabowski's (1975) observations that "cobalt is concentrated in pyrite while nickel is concentrated in the pyrrhotite". Infrastructure in the Sapawe Lake area is excellent with a network of all-weather roads, rail and power, allowing easy access for exploration.

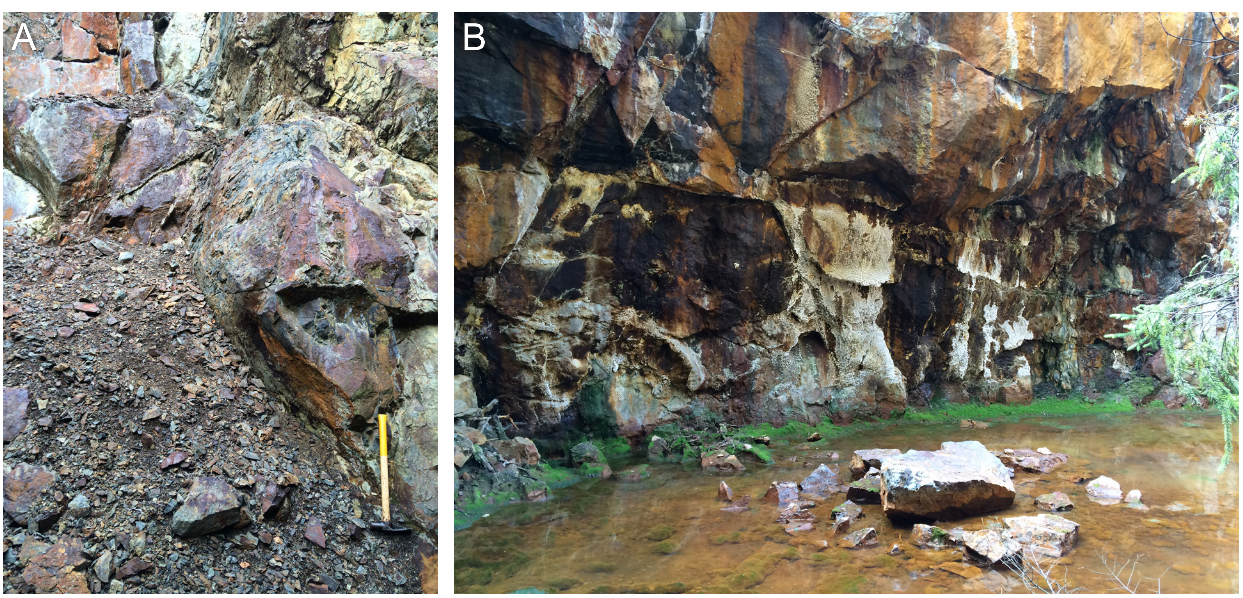

Photo 1. Atikokan Iron Mine property: a) massive to semimassive sulphide zones (rock hammer for scale); b) supergene weathering of sulphides (rock wall 6 m high in photo).

Iron, Copper, Cobalt and Nickel: Atikokan Area

Table 1. Atikokan River Intrusions with associated claim information, assay highlights and references.

Name	Owner/ Claim Info	Highlights	Reference
Staines/Sabawi Lake Property Staines Intrusion	G. Staines and F. Broomhead Patents; E103, E104 Leases; FF3505, F3507-09, K202184-85 Claims; 4283701-42837002	2005 to 2006: MetalCorp Limited completed 2 DDHs; • 2005: DDH02; from 129.6 to 133.6 m. returned 0.8648% Cu over 3.74 m • 2006: DDH03; from 255.90 m to 257.20 m returned 1.05% Cu, 0.0453% Co, 0.0106% Zn, 0.0227% Ni over 1.9 m	MacTavish (2005)
		• 2006: DDH03; from 260.00 to 271.05 m returned 0.2655% Cu, 0.0291% Co, 0.0152% Zn, 0.0546% Ni over 11.05 m	MacTavish (2006)
		1979: Sherritt Gordon Mines Limited: completed 4 DDHs; • DDHSA-1 returned 0.62% Cu, 0.098% Co over 39.2 ft • DDHSA-2b returned 0.49% Cu, 0.11% Co over 46 ft	Scime (1979)
		1970, 1972: main sulphide zone outlined to be 1155 m long x 76 m wide. Drill hole results returned 32.7% soluble Fe, 0.23% Cu, 0.71 lbs/ton Co over ~ 25 m (*The Northern Miner*, Oct. 26, 1972, p.1; *The Northern Mine*r, Jan. 8, 1970, p.1 and 16)	Schnieders (1985)
Atikokan Iron Mine / Iron Mountain Intrusion	K. Bjorkman Patents; E10, E11, E12	1955: Steep Rock Iron Mines Ltd. took 65 samples yielding 0.32% Cu and trace Ni 1959: Tonnage estimated at 4 033 770 long tons grading 50.29% Fe and 1.87% S 1962: Paulpic Gold Mines Ltd. and JV Monteagle Exploration Ltd. completed 10 DDH. Assays included 39.8 to 64.3% Fe, 0.34 to 0.89% Cu and 14.3 to 25.1% S. Appreciable, but unreported, amounts of cobalt were encountered within all of the drill holes.	MacTavish (1999)
		1972: The Atikokan Iron Mine and 3 additional properties to the west have been indicated, by previous work, to contain 24 000 000 tons to a depth of 91 m of a minimum 35% Fe, 0.40% Cu, with Ni and Co indications (*The Northern Miner*, Oct. 26, 1972, p.1 and 17)	Schnieders (1985)
		1975: Grabowski's sampling results: • 5 samples of pyrite contained an average trace element concentration of 0.19% Co, 0.23% Cu, 0.13% Ni, 0.03% Zn • 5 samples of pyrrhotite contained an average trace element concentration of 0.08% Co, 0.30% Cu, 0.17% Ni, 0.02% Zn • 9 samples of magnetite contained an average trace element concentration of 0.16% Co, 0.017% Cu, 0.016% Ni, 0.018% Zn	Grabowski (1975)
Shepherd Intrusion	N/A Patents; R400, R401, R402	1953: Ontario Department of Mines estimated 1 500 000 tons of ore (750 000 tons open pitable) at 58 to 59% Fe and 2 to 3% S 1959: An E.H. Mulligan report estimated 2 623 000 long tons grading 53% Fe and 2.72% S	MacTavish (1999)
Pattison-Roberts Intrusion	N/A Patents; R405, R404, X212	1940: The intrusion was examined by Steep Rock Iron Mines Ltd., who estimated 8 000 000 tons grading 59.03% Fe, 0.023% P, 3.38% SiO_2 and 20.4% S 1953: Ontario Department of Mines estimated 6 000 000 tons (1 500 000 tons open pitable) grading of 56 to 57% Fe, 20% S, 0.44% Cu and 0.10% Ni	MacTavish (1999)
Quinn Intrusion	N/A Patents; X138, X139, X140	940: Steep Rock Iron Mines Ltd. estimated a resource of 1 823 000 tons of pyrrhotite-rich material averaging 55.73% Fe, 0.037% P, 6.67% SiO_2 and 20.38% S 1970 to 1971: Hanna Mining Co. completed exploration over a large property that included the Quinn property. Hanna completed 5 DDH with assay results ranging from 17.26 to 67.56% Fe, 0.20 to 23.82% S, and up to 0.75% Cu, 0.15% Ni, 0.14% Co, 8.61% SiO_2, 0.134% P and 0.90% TiO_2	MacTavish (1999)
Garland Intrusion	N/A E111, E112	1985: Resident Geologist Program reported 4 samples that returned assays of up to 1280 ppm Cu, 138 ppm Ni and 206 ppm Co	MacTavish (1999)

Abbreviations: DDH – diamond-drill hole; N/A – not available.

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Gold Potential in the Matawin Gold Belt near Shabaqua

HIGHLIGHTS

- **The Matawin Gold Belt has favourable geology for high-grade gold mineralization.**
- **Prospective ground is available for staking immediately west of Shabaqua and several other properties are available for option throughout the Matawin Gold Belt.**

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Shabaqua is located near the northern margins of the Shebandowan greenstone belt (*see* Figure 1), in the eastern portion of a gold-prospective area known as the Matawin Gold Belt (Lavigne and Scott 1994). Since the 1980s, gold exploration has been recommended for a number of specific areas within the Matawin Gold Belt (e.g., Schnieders and Dutka 1985; Lavigne and Scott 1994, 1995, 1996a, 1996b; Schnieders, Scott and Smyk 1998; Schnieders et al. 1999, 2003). In the time since these recommendations were made, a number of new gold showings have been found less than 4 km southwest of Shabaqua. These discoveries provide further confirmation of the area's gold potential and were recently added to the Ontario Geological Survey's Mineral Deposit Inventory (MDI) database.

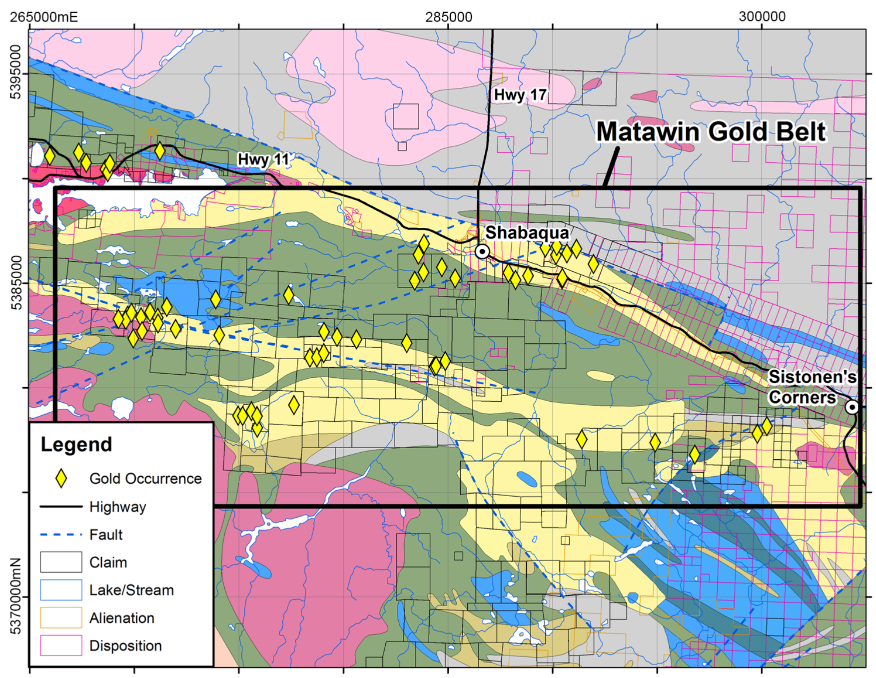

Figure 1. Geological map of the Shabaqua area illustrating the location of the Matawin Gold Belt and the distribution of documented gold occurrences (geology *from* Ontario Geological Survey 2011). Map grid is provided in Universal Transverse Mercator (UTM) North American Datum 1983 (NAD83), Zone 16 co-ordinates. Mining claim status as of October 31, 2016.

Exploration Criteria for the Matawin Gold Belt

Schnieders, Scott and Smyk (1998) described the following exploration criteria for the Matawin Gold Belt.

Gold Potential: Matawin Gold Belt

Important lithologies for gold mineralization include:

- Timiskaming-aged [Shebandowan assemblage] rocks (~2680-2695 Ma), including metasedimentary rocks (arkose, wacke, conglomerate, oxide-facies iron formation); alkalic metavolcanic rocks (tuff, breccia); and intrusive rocks (syenite, lamprophyre, quartz porphyry and feldspar porphyry, granodiorite and diorite);
- Keewatin [Greenwater assemblage] metavolcanic and intrusive rocks (felsic to mafic), and Keewatin metasedimentary rocks and iron formation.

Important structural components include:

- Large-scale structures, faults, and fault-bounded basins;
- Subsidiary structures, sub-basins, flexures and fault intersections, and related, structurally controlled, intrusions (syenite, lamprophyre, granodiorite, diorite);
- Conjugate and extensional structures;
- 040° to 060°-, and 100° to 120°-trending structures; and flat sets of quartz veins, sheeted veins and stockworks.

Gold mineralization is associated with:

- quartz veins, sheeted veins, en échelon veins, stockwork zones and vein breccias;
- stocks, dikes and sills of felsic to mafic composition, commonly of alkalic affinity; and structurally controlled, hydrothermal breccia zones;
- quartz-veined, sulphidized zones in oxide iron formation;
- silica-flooded, hydrothermally altered zones; and
- iron carbonate- and pyrite-rich (commonly disseminated) zones typically associated with structures, shear zones and permeable zones.

Associated alteration and accessory minerals include:

- Iron carbonate, silica, potassium feldspar, sericite, hematite, chlorite and calcite; and
- Pyrite, arsenopyrite, tourmaline and green mica.

The following, more specific, exploration criteria for the Shabaqua–Dawson Road Lots area were provided by Schnieders et al. (2003):

> Exploration in the Shabaqua Corners - Dawson Road Lots area (e.g. the Gold Cache, Dawson Road Lots, Bylund, Matawin, Goldie and Schultz occurrences) should concentrate on the unconformable, locally fault-bounded contact between the Timiskaming [Shebandowan assemblage] rocks and the older, Keewatin [Greenwater assemblage] metavolcanic rocks to the south. Ultramafic intrusive and extrusive rocks should be thoroughly explored and diamond-drilled. Deep-penetrating, induced polarization surveys should be considered to target auriferous, disseminated sulphide zones. Carbonatized, sulphidized and green mica-bearing rocks should be targeted. Numerous splay structures strike 040° to 060° and host gold-mineralized rocks. The 110°-trending, Timiskaming-Keewatin [Shebandowan-Greenwater] unconformity/fault zone is also considered a key exploration target.

Gold Potential West of Shabaqua

During the late 1990s and early 2000s, exploration efforts in the area west of Shabaqua in Blackwell and Laurie townships resulted in the discovery of a number of new gold occurrences (Morgan and Rees 1997; Bottrill 2003; Parker 2003) that are known as the Creek, Wedge and South zones (*see* Figure 2). All of these zones were drill-tested during a 17-hole (2689.62 m) diamond-drilling program that was carried out by RJK Explorations during 2003 on a claim group known as the Wedge property. Although several intersections of anomalous gold mineralization were documented, including 5.89 g/t Au over 3.03 m in drill hole W-03-01 (Bottrill 2003; Parker 2003), no additional work was done to follow-up on these discoveries and the claims were allowed to lapse.

Gold Potential: Matawin Gold Belt

The area was re-staked in October 2016. Other nearby showings include the historic Kaspar and Quartz Float occurrences (also shown on Figure 2).

Renewed gold exploration is recommended for the area west of Shabaqua that surrounds all of these occurrences. A large area of prospective ground north and west of the Wedge property (including the Quartz Float occurrence) was open for staking as of October 31, 2016. A brief description of the Wedge property occurrences and the Quartz Float occurrence are provided below along with discussion of each area's exploration potential.

Wedge Property Occurrences

The Wedge Zone was visited by Resident Geologist Program staff during a September 2016 site visit. The surface expression of the occurrence was noted to be a zone of strong iron carbonate alteration that appears to parallel the contact between amphibole-phyric intermediate metavolcanic rocks to the south, and a more competent felsic metavolcanic unit to the north. The alteration zone strikes 110° and dips 70° to the south. It contains abundant quartz-carbonate stringers, minor fine-grained disseminated sulphides (pyrite + arsenopyrite) and possibly green mica. A similar style of mineralization has been described in the vicinity of the Kaspar occurrence, 1.3 km to the west-northwest, approximately along strike with the Wedge Zone (Morgan and Rees 1997). As a result, it has been suggested that these occurrences may represent portions of the same mineralized horizon (Parker 2003).

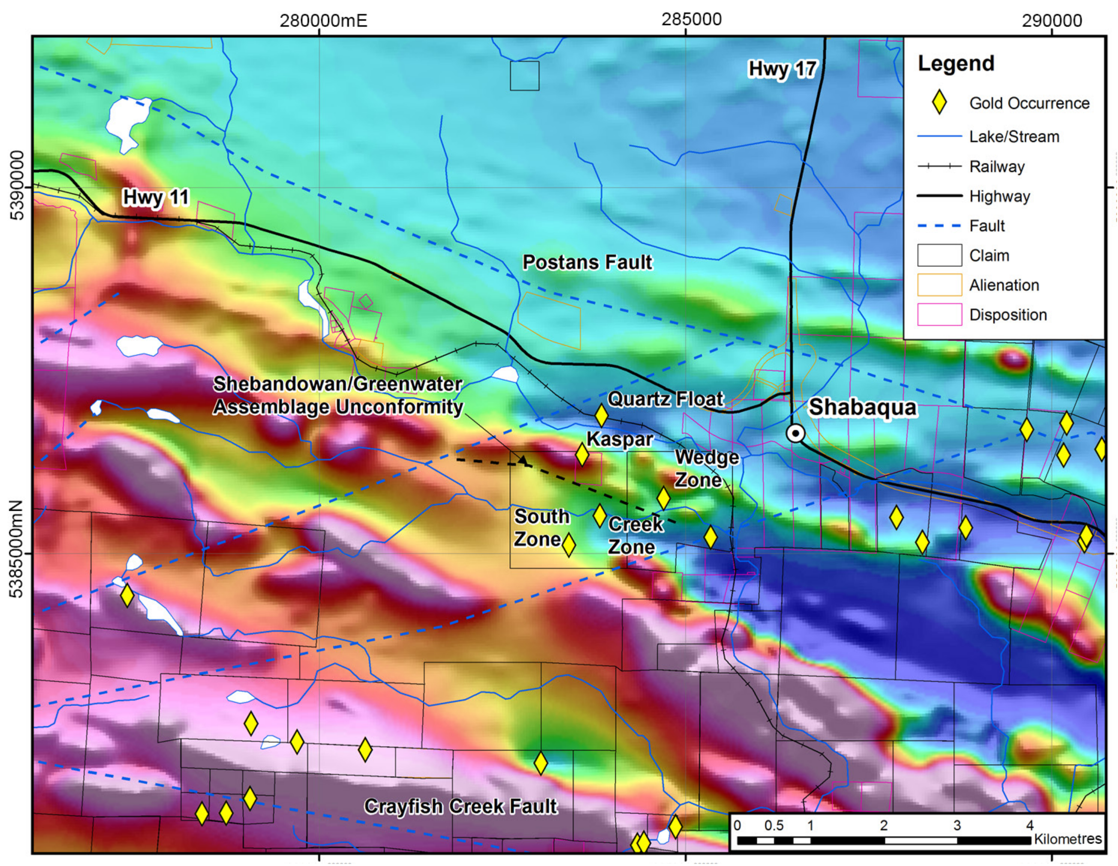

Figure 2. Total residual magnetic field map of the Shabaqua area highlighting gold occurrences referenced in text. Geophysical data *from* Ontario Geological Survey (2003). Map grid is provided in UTM NAD83, Zone 16 co-ordinates. Mining claim status as of October 31, 2016.

Gold Potential: Matawin Gold Belt

The Creek Zone is located approximately 800 m southwest of the Wedge Zone. Gold mineralization in this zone is hosted by debris flow and pyrite-rich, graphitic mudstone horizons, and is associated with quartz and calcite veins/stringers that contain minor arsenopyrite, chalcopyrite and sphalerite.

The South Zone, located 650 m southwest of the Creek Zone, is hosted in altered metavolcanic rocks and graphitic mudstone containing 5 to 7% quartz stringers and/or veins and up to 3% pyrite + arsenopyrite. The style of mineralization observed at the South Zone is similar to that found at the Wedge Zone (Parker 2003).

In evaluating the gold potential of the area where the Wedge, Creek and South zone discoveries have been made, it is important to note that it provides examples of all of the key exploration criteria for the Shabaqua area that were outlined previously by Schnieders et al. (2003). Examples are listed below.

- All of these occurrences are located in close proximity to the prospective 110°-striking Greenwater–Shebandowan assemblage unconformity (*see* Figure 2). In fact, the Wedge Zone is located immediately to the north of the interpreted unconformity and is hosted in rocks (hornblende-phyric metavolcanic rocks) that can be correlated to the Shebandowan assemblage (Corfu and Stott 1998). The Creek Zone is immediately to the south of the unconformity, and is hosted in rocks (graphitic mudstone) that can be correlated to the Greenwater assemblage (Lodge, Ratcliffe and Walker 2014).
- The occurrences are located between 2 approximately 060°-striking splay faults. The geophysical expressions of these faults can be seen clearly on the residual total field magnetic map of Figure 2.
- Carbonatized, sulphidized and green mica-bearing rocks have been described in association with the mineralized zones.

Further exploration is recommended in proximity to the 110°-striking Greenwater–Shebandowan unconformity, which extends onto unstaked ground to the west of the Wedge property. Geophysical data also suggest the presence of additional 060°-striking splay faults in this area (*see* Figure 2).

Quartz Float Occurrence

The outcrop area surrounding the Quartz Float gold occurrence was visited by Resident Geologist Program staff in September 2016 in an effort to collect information that could lead to determining a potential bedrock source for this mineralization. The Quartz Float occurrence (*see* Figure 2) was discovered along the Canadian National Railway tracks by Noranda in 1988. Grab samples of this float material returned up to 27 g/t Au (Thomson 1988), but no bedrock source could be located. Since that time, it has been suggested that the float is most likely to have originated from an adjacent outcrop (Larouche 1994). This outcrop consists of fissile interbedded siltstone and mudstone striking 065° and dipping 75° to the south. Foliation in the siltstone is oblique to bedding and has a strike of 075° with a southerly dip of 75°. Some of these steep-dipping, fissile rocks have collapsed to a near-horizontal attitude, covering and obscuring a significant portion of the original exposure.

During the examination of some loose, tumbled-over material located immediately above a large piece of quartz float, a narrow (10 cm) felsic dike was observed. This dike was crosscut by a 3 cm wide white quartz vein that was similar in appearance to the float. As a result, it appears most likely that the gold-bearing float was sourced locally. Features that make the Quartz Float occurrence area prospective for gold include the presence of highly deformed (i.e., fissile) metasedimentary rocks, along with quartz veining that is associated with a more competent lithology (i.e., felsic intrusion) that occurs within the deformation zone. Exploration for additional gold-bearing veins in this area should focus on the identification of altered and/or mineralized shear zones in the metasedimentary rocks, and on the identification of intrusions (e.g., porphyry dikes) with the potential to host stockwork vein systems.

Numerous Ontario Geological Survey geological, geochemical and geophysical maps, reports and data sets are available for the Shabaqua area to assist in the identification of gold exploration targets. This information

Gold Potential: Matawin Gold Belt

can be obtained online through the OGSEarth and/or GeologyOntario applications on the Ministry of Northern Development and Mines website, or by contacting the Thunder Bay South Resident Geologist District Office.

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HIGHLIGHTS

- **High-grade metamorphic rocks north of Manitouwadge are favourable hosts for flake graphite.**
- **New discoveries made during 2015 indicate the potential for flake graphite deposits with considerable strike length and width.**

Graphite in the Quetico Subprovince North of Manitouwadge

The high-grade metamorphic rocks of the Quetico Subprovince north of Manitouwadge have long been known to host occurrences of flake graphite (e.g., Coates 1966, 1968). However, no concerted flake graphite exploration efforts had been carried out in the area until recently. As noted below, the success of this recent exploration suggests that the metasedimentary migmatites north of Manitouwadge are an excellent flake graphite exploration target.

The earliest reports of graphite in the area north of Manitouwadge were provided by Coates (1966, 1968), who noted its presence in association with a number of small sulphide occurrences. In 1992, flake graphite was discovered approximately 28 km north of Manitouwadge along the Thomas Lake Road. The graphite at this location occurs in an east-trending sequence of granulite-facies paragneiss and biotite migmatite (Hinz and Landry 1994). A second flake graphite occurrence was documented 25 km farther north, near Taradale, by McKay (1994). McKay (1994) also noted that graphitic, sulphide-bearing shear zones are relatively common in the migmatitic paragneisses north of Manitouwadge.

Very little follow-up exploration was done in the vicinity of Thomas Lake until 2012, when Rare Earth Metals Inc. staked the occurrence and a number of nearby electromagnetic conductors (Rare Earth Metals Inc., news release, February 24, 2012). Recently, Ardiden Inc., the current owner of the property, discovered several new zones of flake graphite that are associated with these conductors. Recent diamond drilling also indicated that these graphitic horizons have the potential for considerable strike length and width (Ardiden Limited, news releases, April 14, 2015 and January 5, 2016).

Figure 1 shows the locations of known graphite occurrences in the area north of Manitouwadge. Most of these showings are located within 10 km of the southern Quetico Subprovince boundary. The one exception is the Taradale occurrence (open for staking at the time of writing), located near the centre of the subprovince.

Further exploration for graphitic shear zones is warranted in the areas shown on Figure 1 where paragneiss-hosted sulphide showings have been documented. Exploration is also warranted in areas located along strike of the known graphite occurrences. Because graphite is an excellent conductor, airborne electromagnetic (AEM) survey data should be reviewed where available (e.g., the area south of the yellow line on Figure 1 has been flown) to identify conductive horizons for follow-up prospecting. Prospecting along the numerous logging roads that traverse the region north of the existing AEM survey coverage may also prove fruitful, as bedrock exposure is extensive in most areas and graphite-bearing rocks typically have a distinctive rusty weathered appearance (Coates 1966, 1968).

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Graphite: Quetico Subprovince

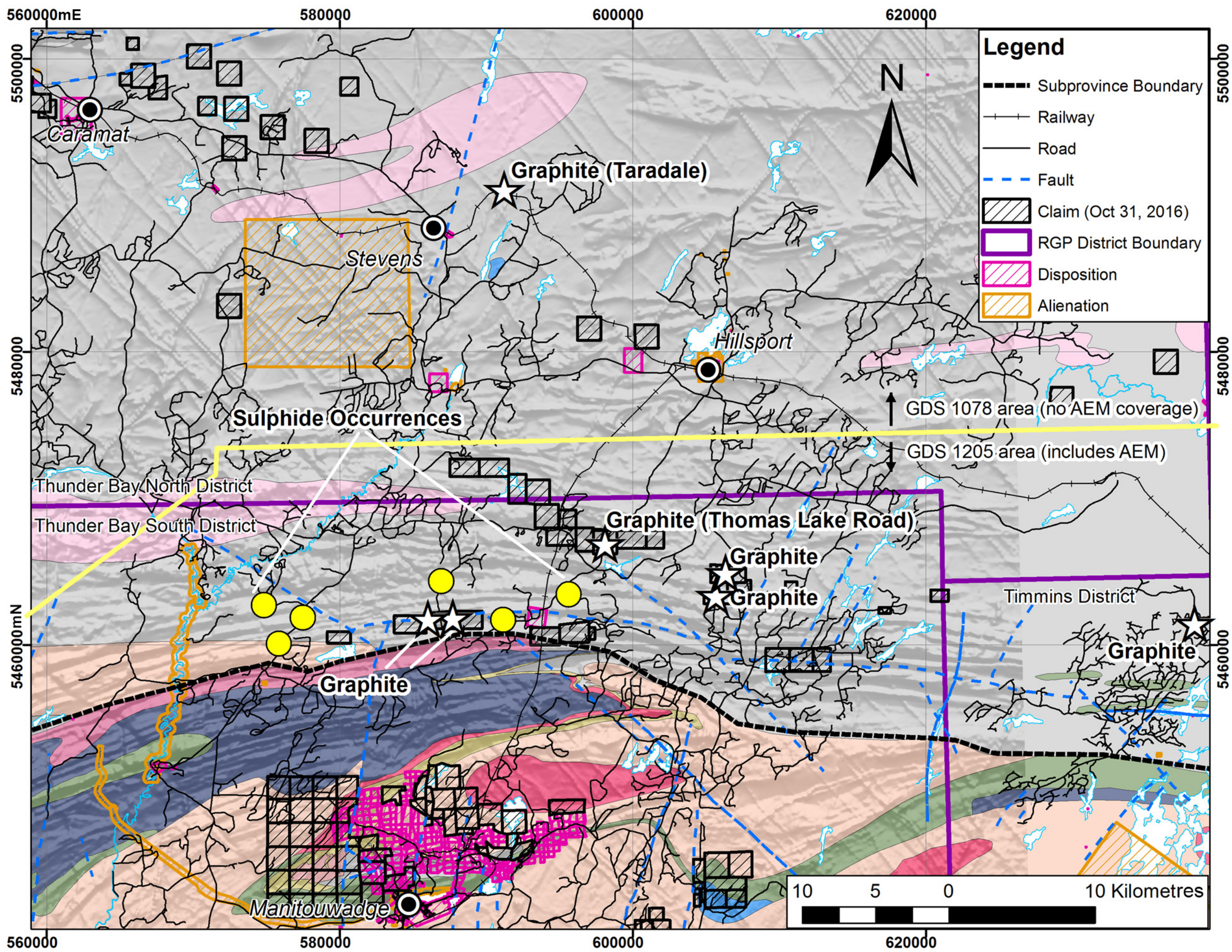

Figure 1. Geological map (with shaded residual total magnetic field underlay) illustrating graphite (white stars) and paragniess-hosted sulphide occurrences (yellow circles) in the Quetico Subprovince north of Manitouwadge. Geology *from* Ontario Geological Survey (2011), geophysics *from* Ontario Geological Survey (2002 and 2015a, 2015b).

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Graphite: Quetico Subprovince

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HIGHLIGHTS

- **Numerous VMS-associated sulphide showings and aluminosilicate alteration surround the Shrimp Lake pluton.**
- **The pluton hosts a copper-nickel–bearing pod of massive sulphides, perhaps indicating more than one type of ore-forming process was active.**
- **This is an area that has seen limited historic exploration activity and is currently open for staking.**

The Enigmatic Shrimp Lake Pluton: Volcanic Massive Sulphide or a Copper-Nickel Deposit?

The Shrimp Lake pluton (SLP), 165 km north of Red Lake, intrudes an underexplored prospective volcanic terrane hosting volcanogenic massive sulphide (VMS) mineralization. The pluton itself is host to an, as yet unexplained, occurrence of copper-nickel–bearing massive sulphide.

The Shrimp Lake pluton is located in the southeastern corner of the North Spirit Lake greenstone belt, in the Hewitt assemblage (2.743 to 2.731 Ga: Corfu and Wood 1986), an interpreted arc sequence (Thurston, Osmani and Stone 1991). The SLP is part of a series of synvolcanic plutons that range in composition from trondhjemite to quartz diorite (Figure 1) and are interpreted to be approximately coeval with the Hewitt assemblage (Buse et al. 2007). Henderson (2008) determined that the SLP ranges from granodiorite to tonalite.

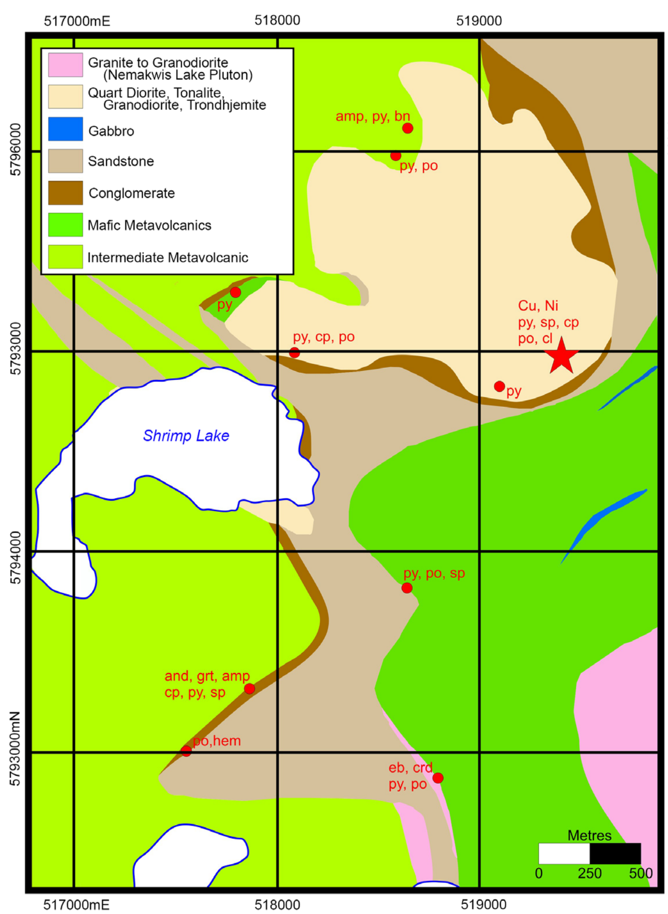

Figure 1. Simplified geology of the Shrimp Lake pluton (*modified from* Buse et al. 2008). The red star denotes the location of the Shrimp Lake massive sulphide occurrence. Alteration abbreviations: amp-amphibole, and-andalusite, cl-chlorite, crd-cordierite, ep-epidote, grt-garnet. Mineralization abbreviations: bn-bornite, cp-chalcopyrite, Cu-copper, Ni-nickel, po-pyrrhotite, py-pyrite, sp-sphalerite. Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83) in Zone 15.

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Shrimp Lake Pluton: VMS or Copper-Nickel Deposit?

The overall metamorphic grade of the belt ranges from mid to upper greenschist facies, with localized areas of low to middle amphibolite facies (Buse et al. 2008); the metasedimentary rocks contain porphyroblasts of garnet, andalusite and cordierite (Parker 1998). Within the southernmost portion of the greenstone belt (hosting the SLP) the alteration is represented by aluminosilicate minerals such as cordierite and andalusite (Buse et al. 2007), similar to the anthophyllite-cordierite-garnet alteration Parker (1998) had noted in the intermediate rocks north of the SLP. This alteration assemblage is typically associated with VMS deposits hosted in late Neoarchean rocks of the Superior Province (Parker 1998).

Metavolcanic rocks at Shrimp Lake consist of pillowed, massive and coarse-grained mafic metavolcanic flows overlain by intermediate to felsic lapilli tuff, tuff breccia and feldspar crystal tuff interlayered with fine-grained arkosic wackes, arenites and mudstones (Parker 1998). The supracrustal rocks are intruded by the interpreted synvolcanic feldspar-porphyritic Shrimp Lake pluton, which hosts disseminated pyrrhotite, pyrite and chalcopyrite (Wood 1988). Buse et al. (2007) states: “The synvolcanic intrusions have ages of 2731±2 Ma for the Bijou Point intrusion and 2743±2 Ma for the intrusion north of Hewitt Lake, indicating a coeval relationship between the Hewitt assemblage and the synvolcanic plutons within the greenstone belt.” As well, a sample taken within the trondhjemitic phase of the SLP had an age of 2732.6±0.8 Ma: this crystallization age falls within the interpreted age of the Hewitt assemblage, *circa* 2714–2744 Ma (Buse et al. 2008).

The porphyry is epidotized and hosts disseminated pyrrhotite, pyrite and chalcopyrite (Parker 1998). The porphyry is enclosed in a clastic apron of sulphide-bearing, poorly sorted, clast- to matrix-supported conglomerate (Parker 1998), with a strike length of at least 7 km (Wood 1988). The conglomerate contains abundant disseminated pyrrhotite, pyrite and minor chalcopyrite in both matrix and clasts (Wood 1988). Wood (1988) interpreted the conglomerate as a debris flow or lahar that may have slumped off the side of a volcano in a deep-water, subaqueous environment.

Buse et al.’s (2007) mapping identified new pyrrhotite, pyrite + chalcopyrite occurrences. The mineralization was typically manifested as disseminated sulphides in intermediate metavolcanic rocks and iron formation of the Makataiamik assemblage, with some occurrences hosted in the Hewitt assemblage.

A new occurrence of massive pyrrhotite, pyrite and chalcopyrite was discovered by Buse et al. (2007) in the SLP. Buse et al. (2007) stated that: “The massive sulphide zone is approximately 10 by 10 m in size and is surrounded by altered host rock with disseminated pyrrhotite, pyrite and chalcopyrite.” OGS sample 07AH141-3 (MDI000000000749), taken from within a 5 by 5 m area of massive sulphide comprising pyrite, sphalerite, chalcopyrite and pyrrhotite, returned 1128 ppm Cu and 583 ppm Ni (Buse et al. 2008). The nickel values could be derived from mafic to ultramafic xenoliths within the SLP, as Wood (1988) noted: “The porphyry contains inclusions of black carbonate and ultramafic rock at its southwestern contact.”

The geochemistry of OGS sample 07AH141-3 (Préfontaine and Buse 2009) raises the question of whether or not the mineralization is hosted within a mafic xenolith (OGS 2014). Similar mineralization at the Zenith deposit was demonstrated, by Corporation Falconbridge Copper, to be a rafted or dislodged portion of the main volcanic-hosted Winston Lake deposit. The sulphide and associated host rock xenoliths were dislodged and transported by a multiphase intrusive gabbro (OGS 2007).

Canstar Resources Inc. drilled in the vicinity of the new Shrimp Lake occurrence in 2007. Although no assays were included in the assessment report, Canstar reported that they had intersected the volcanic-metasedimentary sequence, as well as felsic intrusive rocks, massive sulphides and sulphidic, possibly silicified zones (Palmer 2008). The observed sulphide mineralization belonged to 1 of 3 dominant settings:

1) quartz vein-hosted arsenopyrite-pyrite-tourmaline (e.g., DDHs SL07-1, -2);
2) massive pyrite-pyrrhotite + minor sphalerite-galena-chalcopyrite (e.g., DDHs SL07-4, -9); or
3) bands or stringers of massive pyrrhotite ± pyrite in metavolcanic rocks (e.g., DDHs TL07-1, SL07-5, -6, -8) or quartz-rich, possibly exhalative, horizons (e.g., DDH SL07-7).

Shrimp Lake Pluton: VMS or Copper-Nickel Deposit?

Despite the apparent VMS-associated alteration and sulphide mineralization, the nature of the relationship between the metavolcanic host rocks and the SLP and its massive sulphide occurrence remains enigmatic. The OGS, through its Resident Geologist Program, plans to map in detail and resample the massive sulphide pod and its altered host rocks within the SLP to determine whether it has typical VMS affinity, or whether the copper-nickel sulphides may be of magmatic provenance. In both cases, major oxide and trace element chemistry may give a clue as to unaltered host protolith (i.e., felsic to intermediate extrusive volcanic rocks, or mafic to ultramafic intrusive rocks). The relatively high Ni values in the OGS sample 07AH141-3 (389 ppm) in bulk chemistry is anomalously high for VMS-associated sulphide deposits. Studies of individual sulphide minerals (pyrrhotite, pyrite) from VMS orebodies in the Rouyn-Noranda District of Quebec (Sharman et al. 2015), show Ni values 3 orders of magnitude lower (in a range from below detection limit to a high of 957 ppb Ni) than the bulk chemistry results from the SLP.

The Shrimp Lake pluton and surrounding area remain open for staking at the time of publication. The explorationist has opportunity to focus on the extensive VMS-associated mineralization and alteration in the volcanic assemblage, as well as the possibility of magmatic copper-nickel sulphide mineralization within the Shrimp Lake pluton.

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Cobalt-Copper-Nickel-Chromium-Platinum Group Element Potential in the English River Subprovince

HIGHLIGHTS

- **High potential for the discovery of more cobalt-copper-nickel-PGE deposits in the English River Subprovince.**
- **Recent high-resolution airborne magnetic gradiometer survey increases the likelihood of discovery of previously unknown mafic-ultramafic intrusions in the English River and Winnipeg River subprovinces.**

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Historical production of cobalt, copper, nickel and platinum group elements came from 3 deposits—Norpax, Gordon Lake and Werner Lake Cobalt—in the English River Subprovince, in the Werner–Rex lakes area of northwestern Ontario (Figure 1). Underexplored cobalt-copper-nickel-chromium-PGE occurrences are known for at least 40 km along strike of the Werner–Rex lakes fault. The following summary is taken from Parker's (1998) evaluation of the mineral potential of the area.

Mineralization is hosted in numerous mafic intrusive pods associated with the extensive Werner–Rex lakes fault system. The host ultramafic to mafic rocks were part of a syntectonic stratiform intrusion that was deformed after emplacement. The present pods of mafic intrusive rocks are tectonic fragments of this stratiform intrusive body or bodies. They occur as isolated lenses, discontinuous chains, layers and podiform bodies. The pods at the Gordon Lake Mine are 180 x 45 x 180 m (Scoates (1972) in Parker (1998)), and are the largest found to date in the Werner–Rex lakes area (Parker 1998).

Mineralization is associated with 3 deposit-model types:

1. magmatic mineral deposits: disseminated and remobilized nickel-copper sulphide, chromium and PGE mineralization (e.g., Norpax and Gordon Lake deposits);
2. cobalt-copper skarnoid mineral deposits (e.g., Werner Lake cobalt deposit); and
3. remobilized sulphide mineralization in migmatite, pegmatite and gneissic mineral deposits (e.g., Rex–Lower Fortune occurrences).

Historical, non-NI43-101-compliant mineral resources include:

- Norpax deposit: 1 million tonnes grading 1.2% Ni and 0.5% Cu (Parker 1998);
- Gordon Lake deposit: 170 420 tonnes grading 0.85% Ni and 0.25% Cu (Parker 1998);
- Werner Lake Cobalt deposit: Proven 140 031 000 tonnes grading 0.47% Co, Probable 40 829 000 tonnes grading 0.25% Co and Indicated 51 456 000 tonnes grading 0.13% Co (Global Energy Metals Corporation, Management Discussions and Analysis, October 28, 2016).

Cobalt-Copper-Nickel-Chromium-PGE Potential: English River Subprovince

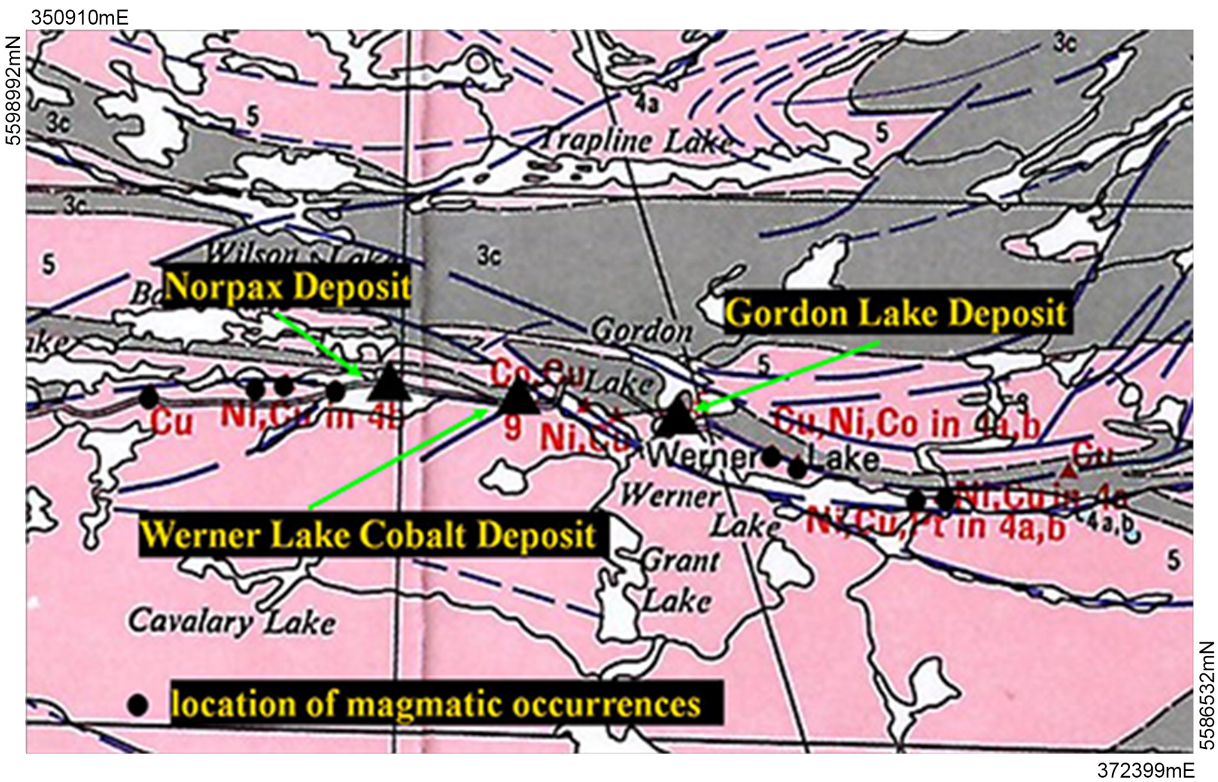

Figure 1. Geological map showing metasedimentary assemblages (in grey) and granitoids (in pink) within the English River Subprovince, as well as the location of magmatic occurrences and 3 historical deposits (Norpax, Gordon Lake and Werner Lake Cobalt) in the Werner–Rex lakes area, along the Werner–Rex lakes fault. *Modified from* Ontario Geological Survey (2011).

Additional, as yet unrecognized, mafic intrusive bodies may be present as tectonic fragments within the underexplored Werner–Rex lakes fault system. Ultramafic to mafic bodies distributed throughout the English River Subprovince are associated with metasedimentary assemblages and spatially associated with large regional fault systems. Mafic intrusive bodies within the Winnipeg River Subprovince, situated south of the English River Subprovince (Figure 2), should also be examined for magmatic cobalt-copper-nickel-chromium-PGE mineralization similar to that within the Werner–Rex lakes area.

In 2016, the Ontario Geological Survey completed an airborne magnetic gradiometer and gamma-ray spectrometer geophysical survey of the Ear Falls area, which covered 31 035 km^2 (*see* Figure 2). The survey (200 m flight-line spacing) was designed to cover the western portions of the Winnipeg River and English River subprovinces, extending from the Manitoba–Ontario provincial border to the Sioux Lookout–Savant Lake area. The results of the western portion of the survey are planned to be released in the spring of 2017; the eastern portion will follow in late spring or summer 2017. Areas of high magnetic response east of the known mafic and ultramafic intrusions of the Werner–Rex lakes area should provide immediate targets for ground follow-up.

Historical work has shown that the discovery of mafic-ultramafic rocks in the migmatites of the English River Subprovince is likely. Mafic-ultramafic intrusions have been discovered up to 10 km north of the Werner–Rex lakes area. Diamond drilling in 1959 by Anglo Barrington Mines Ltd. intersected up to 64 m of gabbro, amphibolitized ultramafic rock and peridotite (AFRI# 52L06NE0018). Numerous pods and lenses of hornblendite, amphibolite and biotite-hornblende schists have been mapped along other regional faults in the western portion of the English River Subprovince (Carlson 1958).

Cobalt-Copper-Nickel-Chromium-PGE Potential: English River Subprovince

Regional surficial sediment sampling conducted by Morris (1996) covered the area between the Werner–Rex lakes area and Separation Rapids. Anomalous concentrations of chromite (chrome-spinel) and hercynite (iron-spinel) were found in heavy mineral separates. These minerals are believed to indicate the presence of pods of ultramafic rocks (Parker 1998).

Research by the explorationist prior to the release of the airborne survey should start by consulting the results of the most recent mapping of the immediate Werner–Rex lakes area by Parker (1998) and Beakhouse (1997). Mafic-ultramafic rocks were encountered during reconnaissance mapping in 1974 and 1975 by the Ontario Geological Survey (formerly, Ontario Division of Mines). Operation Kenora–Sydney Lake and Operation Kenora–Ear Falls produced a series of 12, 1:63 360 scale maps covering approximately the western three-quarters of the 2016 airborne geophysical survey (*see* references of Breaks and many others, 1975 and 1976, in "References"). The earlier work by Carlson (1958) should also be consulted.

Specific locations of previous diamond drilling and other assessment work affords good, on the ground starting points within the current 31 035 km^2 survey area. Files may be searched online using the OGSEarth application on the Ministry of Northern Development and Mines website (http://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth), but for completeness, hardcopy files in the Resident Geologist District offices in Kenora and Red Lake should also be consulted. Except for the immediate areas of the past-producing mines, most of the area is open for staking.

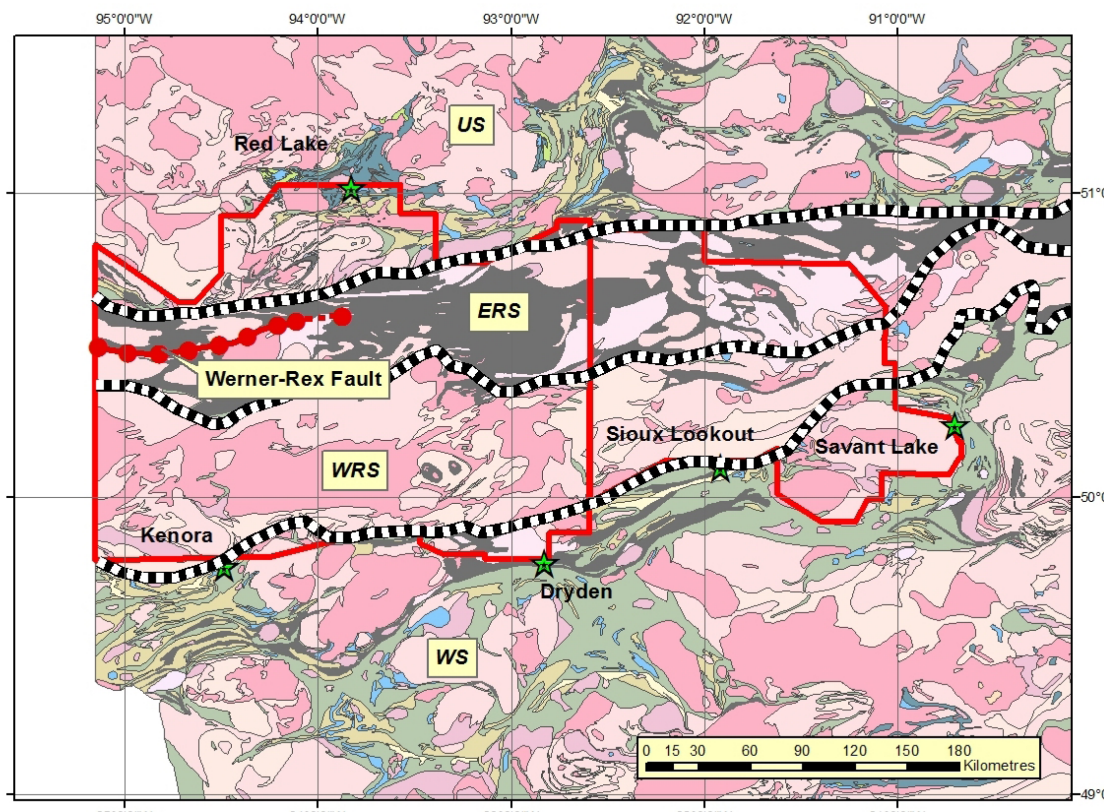

Figure 2. Western and eastern extent of the Ontario Geological Survey's 2016 Ear Falls airborne magnetic gradiometer and gamma-ray spectrometer geophysical survey, northwestern Ontario, outlined in red. Abbreviations: ERS, English River Subprovince; US, Uchi Subprovince; WS, Wabigoon Subprovince; WRS, Winnipeg River Subprovince (bedrock geology *modified from* Ontario Geological Survey 2011). Subprovincial boundaries are shown in heavy, hatched lines.

Cobalt-Copper-Nickel-Chromium-PGE Potential: English River Subprovince

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HIGHLIGHTS

- **A regional lake sediment geochemical survey revealed significant anomalies in zinc, cadmium and copper in the Percy Lake area. This metal association is typical of Archean VMS deposits and points to the prospectivity of the underlying rocks.**
- **Historically, there was little understanding of the bedrock geology of the area in large part because of poor road access and outcrop exposure. In the last few years, forestry operations have opened up new roads, providing new opportunities for prospectors to investigate the area.**

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A Possible Volcanogenic Massive Sulphide-Target in the Batchawana Greenstone Belt, Percy Lake Area?

The Percy Lake area, located in Moggy Township, has demonstrated that there are significant base metal anomalies identified in the northeast portion of the Batchawana greenstone belt (BGB) (Figure 1). This portion of the BGB is made up of the Dismal Lake assemblage (2700 to 2720 Ma), which consists predominantly of a calc-alkalic mafic to felsic metavolcanic sequence with intercalated metasedimentary rocks and associated syntectonic to late tectonic intrusions of diorite, tonalite and granodiorite of the Ramsey Gneiss Domain (*circa* 2668 to 2677 Ma: Corfu and Grunsky 1987). Historically, there was little understanding of the bedrock geology of the area, in large part because of poor road access and outcrop exposure. In the last few years, forestry operations have opened up new roads to the area, providing an opportunity for prospectors to investigate these base metal occurrences. Unfortunately, no volcanogenic massive sulphide deposits have been delineated to date.

Wilson (1983) identified a regional-scale, east-northeast–trending syncline west of the Percy Lake area. On a site visit to the area in 2015, staff of the Sault Ste. Marie District Geologist office, Resident Geologist Program, observed small-scale folding in the Percy Lake area, ranging from centimeter-scale crenulation cleavage to larger folds with amplitudes of a few metres. These small-scale features, as well as boudinaged structures, may be related to the larger syncline to the west.

A drilling program completed by Vault Minerals Inc. on the Percy Lake property in 2006, intersected numerous quartz-calcite-feldspar fracture veins containing sphalerite, chalcopyrite and galena (Lengyel 2006). These fracture veins may reflect a structural control related to the intrusion of the surrounding synvolcanic rocks. Earlier, Avalon Ventures Ltd. reported that contorted and brecciated, siliceous, graphitic iron formation in the Percy Lake area hosts finely disseminated to semimassive pyrite and pyrrhotite (Bain 1996).

Strong base metal lake sediment geochemical anomalies are associated with the Dismal Lake assemblage, particularly within the Percy Lake area. A regional lake sediment geochemical survey completed by the Ontario Geological Survey (Hamilton, Forescue and Hardy 1995) revealed significant anomalies in zinc, cadmium and copper in the Percy Lake area. This metal association is typical of Archean volcanogenic massive sulphide (VMS) deposits and points to the prospectivity of the underlying rocks. Mineral exploration in the Percy Lake area has been limited: the 2 exploration programs completed in 1995 and 2006 by Avalon Ventures and Vault Minerals, respectively, make reference to anomalous values of copper, zinc, cadmium, as well as lead; grab samples collected by Avalon Ventures Inc. in 1995 returned values of up to 2.86% Cu, 11.04% Zn, 1.98% Pb and 33.7 g/t Ag (Bain 1996). In 2006, Vault Minerals Inc., following-up on the work completed by Avalon Ventures Ltd., completed the first and only diamond-drilling program in the area. The drilling intersected several exhalite-bearing horizons containing zinc, lead,

VMS Potential: Batachawana Greenstone Belt

copper and cadmium. The adjacent host rocks display variable chlorite, biotite, sericite and silica alteration that is consistent with a VMS setting (Lengyel 2006).

The Percy Lake area has received limited bedrock mapping and mineral exploration by the OGS and industry, respectively. The significant zinc, cadmium and copper anomalies found by Hamilton, Fortescue and Hardy (1995) suggest the underlying stratigraphy is favourable for the location of Archean volcanogenic massive sulphide deposits. The following are recommendations that could assist in further exploration within the area.

1. Conduct further geological mapping and an extensive lithogeochemical survey. Geological mapping should focus on developing a better understanding of the strong structural deformation observed on many of the outcrops during the 2015 field visit by staff of the Sault Ste. Marie District Geologist office.
2. Conduct further lake and stream sediment geochemical surveys, especially in the Percy Creek, Tool Creek and Cow River watersheds, which may help point towards the source of the zinc, copper and cadmium anomalies discovered by Hamilton, Forescue and Hardy (1995).

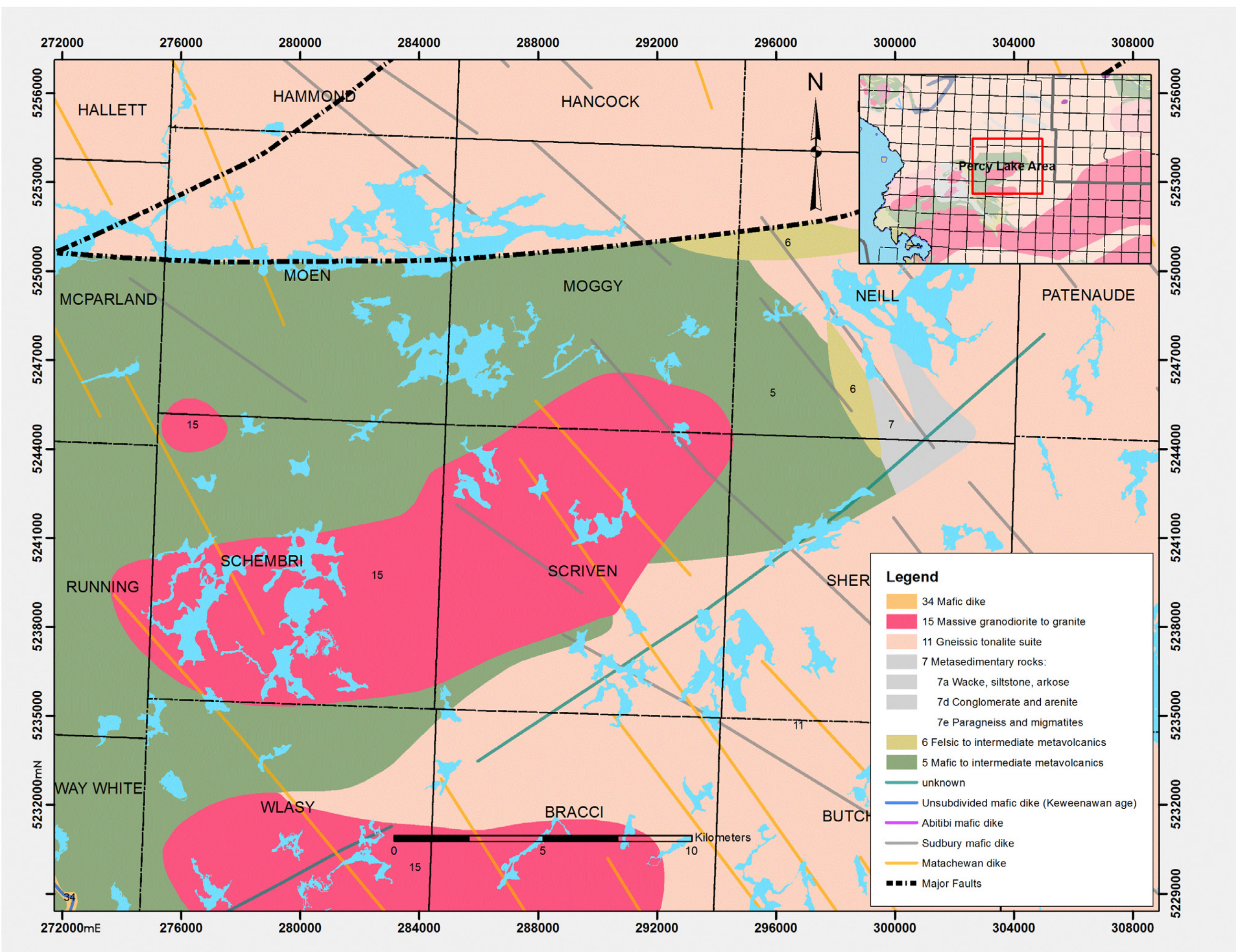

Figure 1. Location of the Percy Lake area in the Dismal assemblage (felsic to mafic metavolcanic rocks) of the Batchawana greenstone belt (geology *from* Giblin, Leahy and Robertson 1979). Universal Transverse Mercator (UTM) co-ordinates provided in North American Datum 1983 (NAD83), zones 16 and 17.

VMS Potential: Batachawana Greenstone Belt

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Gold Potential in the Troy Lake Area

HIGHLIGHTS

- **Structural deformation, alteration and mineralization in the Troy Lake area are consistent with an orogenic-lode gold model.**
- **The Troy Lake stock and the close proximity to the gold mineralization indicate that the stock might have been the heat source that initiated auriferous fluid migration along existing and/or synorogenic extensional structures.**

The Troy Lake area is centred on Moen Township at the northeastern end of the Batchawana greenstone belt (Figure 1). This portion of the belt is underexplored, but work completed in the early 2000s identified 3 gold showings, indicating the area is favourable for gold exploration. These include the Troy, Road and East showings, located in UTM Zone 17, at 276755E 5245927N; 278278E 5247403N; 279458E 5247395N, respectively.

The area is underlain by Archean-age mafic, intermediate and felsic metavolcanic rocks. The Troy Lake stock is a quartz-feldspar intrusive (quartz diorite to tonalite) that intrudes metavolcanic rocks located at the east end of Troy Lake (Wilson 1983; *see* Figure 1). A series of northwest-trending, steeply dipping diabase dikes occurs throughout the area and intrudes all rock types.

A regional-scale, east-northeast–trending syncline was identified in the middle part of the township (Wilson 1983). The Montreal–Cow River fault is located north of the syncline and strikes east-northeast across the northern part of the Troy Lake area. A second northeast-trending fault lies parallel to the Montreal–Cow River fault, crossing the southern part of the area (*see* Figure 1).

Mapping, sampling, a geochemical survey and diamond drilling, completed by Edgewater Exploration Ltd. in 2009, identified a number of brittle-ductile shear zones with weak to intense structural deformation. The shear zones occur in all rock types except the northwest-trending diabase dikes. A significant east to north-east–trending, steeply dipping shear zone (the Troy Lake shear zone), occurs along the northern contact of the Troy Lake stock with the metavolcanic rocks (Figure 2). The structure was traced for more than 1000 m with reported widths from 30 to 150 m (Perk 2009).

The Troy Lake gold showing is hosted by intermediate to felsic metavolcanic rocks of the Batchawana greenstone belt, in close proximity to the Troy Lake stock. The showing contains a series of quartz-carbonate veins that are hosted in the shear zone. Alteration and mineralization occurring in and around the quartz-carbonate veins consist predominantly of chlorite, carbonate and sericite, as well as pyrite and trace amounts of chalcopyrite and pyrrhotite. The mineralization is related to the Troy Lake shear zone (Perk 2009) (*see* Figure 2). Grab samples collected from the showing assayed up to 4.909 g/t gold (Cullen 2002). Channel and grab sampling in 2003 indicate a moderate to strongly anomalous gold trend, with values in excess of 0.5 g/t gold.

The Road showing consists of a series of quartz-carbonate veins that are hosted in shear zones traversing intermediate to felsic metavolcanic rocks. Wallrock alteration consists predominantly of chlorite, carbonate and sericite, as well as of pyrite and trace amounts of chalcopyrite and pyrrhotite in and in close proximity to the quartz-carbonate veins. Grab samples of veins and wallrock assayed up to 5.677 g/t gold (Cullen 2002). Channel and grab sampling that was followed up by Troon Ventures Ltd. in 2003 (Visage 2003) returned gold values greater than 0.1g/t gold across the Road showing, with samples assaying as high as 3.445 g/t gold.

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Gold: Batchawana Greenstone Belt

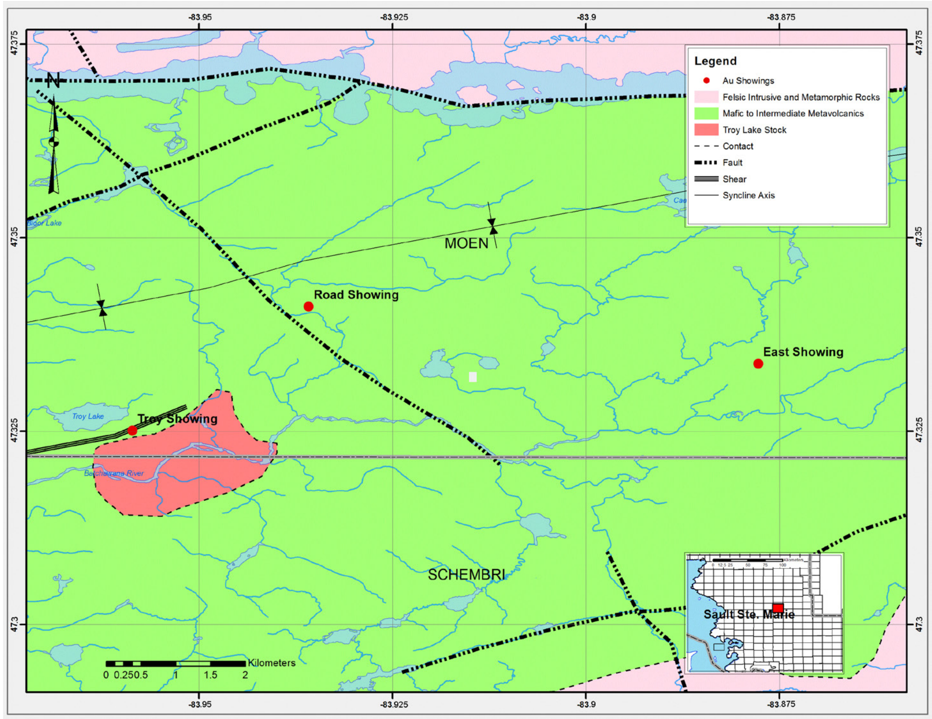

Figure 1. Troy Lake area showing the locations of the Troy, Road and East gold showings in the northeast part of the Batchawana greenstone belt. Geology *from* Giblin, Leahy and Robertson (1979) and Visage (2003).

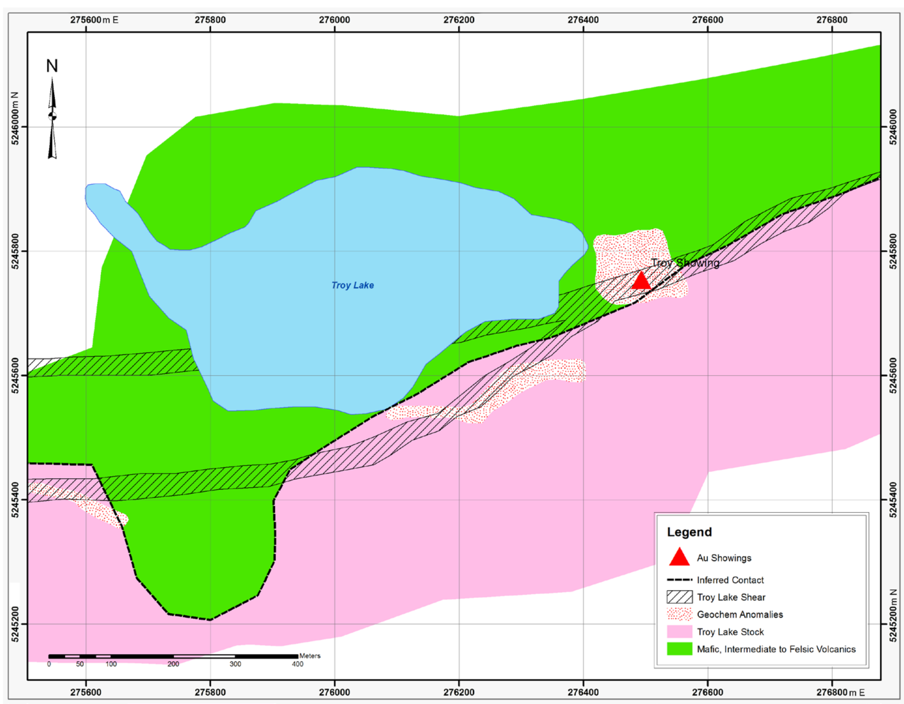

Figure 2. Map of the immediate area surrounding Troy Lake, showing the location of the Troy Lake gold showing (red diamond) and east-west–trending Troy Lake shear zone, as well as the 3 gold anomalies in overburden occurring along the Troy Lake shear zone. (*From* Perk 2009).

Gold: Batchawana Greenstone Belt

The East showing consists of quartz veins containing pyrite. Limited channel and chip sampling completed on the quartz veins produced anomalous gold values, including a 1.8 m sample averaging 1.072 g/t gold (including 1 m assaying 1.358 g/t gold) (Visage 2003).

A soil geochemistry survey identified 3 gold anomalies along the Troy Lake shear zone (*see* Figure 2), one at the Troy Lake showing, and the other two west of the showing (Perk 2009).

Conclusions and Recommendations

Exploration work completed in the Troy Lake area defined structural deformation, alteration and mineralization that are consistent with an orogenic-lode gold model. The Troy Lake stock and the close proximity to the gold mineralization (particularly to the Troy Lake showing), indicate that the stock might have been the heat source that initiated auriferous fluid migration along existing and/or synorogenic extensional structures.

Existing data indicates that the environment for gold emplacement is open in all directions. At the time of writing there were no unpatented mining claims recorded in the area. Further investigation is required to gain a better understanding of the controls on gold mineralization deposition and to determine the extent of gold mineralization.

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HIGHLIGHTS

- **Favourable geology for lithium-bearing pegmatites in the eastern Quetico Subprovince and Opatica domain.**
- **The Lowther pegmatite and the Case pegmatite are both lithium-bearing and located in these subprovinces.**
- **The potential for more lithium-bearing pegmatites is present in these underexplored areas.**

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Evolved White Pegmatites in the Eastern Quetico Subprovince and Opatica Domain

The world is seeing a push for technologies that will decrease the release of carbon dioxide in the atmosphere in order to mitigate climate change. Among those technologies is the replacement of internal combustion engines by electrical engines, powered by lithium-ion batteries. This is one of the reasons why analysts project the market price of lithium to increase in the near future and why Ontario is witnessing an increase in the number of prospectors and companies searching for lithium deposits.

Worldwide, lithium is exploited from 2 sources: brine deposits and hard-rock deposits. In Ontario, the potential is for hard-rock deposits, specifically, lithium-bearing pegmatitic intrusive rocks (dikes and sills). Lithium-bearing pegmatite bodies form through fractionation of highly evolved magmas and generally radiate from a parent granitic intrusion (Breaks and Tindle 1997). These fertile granites are generally small in comparison to the large batholiths found in the Superior Province. They are also silicic (quartz rich) and peraluminous. This favours the crystallisation of aluminum-rich variations of minerals like garnet, tourmaline and muscovite (Breaks and Tindle 1997). Late-stage melts of these granites intrude the country rocks as pegmatites. These late-stage pegmatites may be rich in rare elements such as lithium, rubidium, cesium and tantalum. It is believed the source material for the magma that crystalize as peraluminous granites and associated pegmatites is sedimentary. Areas of migmatitic metasedimentary rock are considered favoured for locating peraluminous granites and rare-element pegmatites.

The eastern Quetico Subprovince and the Opatica domain are made of migmatitic paragneiss, granitic and tonalitic orthogneiss, minor mafic gneiss of volcanic origin and abundant biotite granite and peraluminous, palingenetic intrusions (Card and Sanford 1989). Breaks, Selway and Tindle (2006) showed that the Quetico and the Opatica host various fertile granites and pegmatites. This is portrayed, as an example, by the following 2 occurrences: the Lowther pegmatite and the Case pegmatite.

The Lowther pegmatite is located in Lowther Township, situated 20 km south of the town of Hearst, in the Quetico Subprovince (Figure 1; MDI42G05NE00004, Ontario Geological Survey 2016a). The pegmatite, discovered in the late 1930s, is a lens-shaped body 3.7 to 11 m in width over a minimum length of 110 m, striking at 110° (Breaks, Selway and Tindle 2006). It is contained in a north-pinching parent mass of garnet-biotite pegmatitic leucogranite. The lens is zoned into various units: sodic pegmatite wall zone, aplite zone, spodumene zone, cleavelandite-rich zone with local coarse-grained beryl, lepidolite-clevelandite pod and quartz-rich core with green muscovite and minor spessartine and black tourmaline (Breaks, Selway and Tindle 2006). Bulk whole rock composition samples of the various units returned assays to up to 1.8% Li (Breaks, Selway and Tindle 2006).

Pegmatites: Eastern Quetico Subprovince and Opatica Domain

Other pegmatitic rocks have been encountered in the Hearst area, as pictured on Figure 1. These occurrences have a habit of popping out of the landscape as areas of elevated relief, as defined in Breaks, Selway and Tindle (2006). Another area includes the Pivabiska Lake area in Hanlan Township, where a diamond-drill hole reportedly intersected a beryl-bearing pegmatite (MDI42G13SE00001, Ontario Geological Survey 2016a).

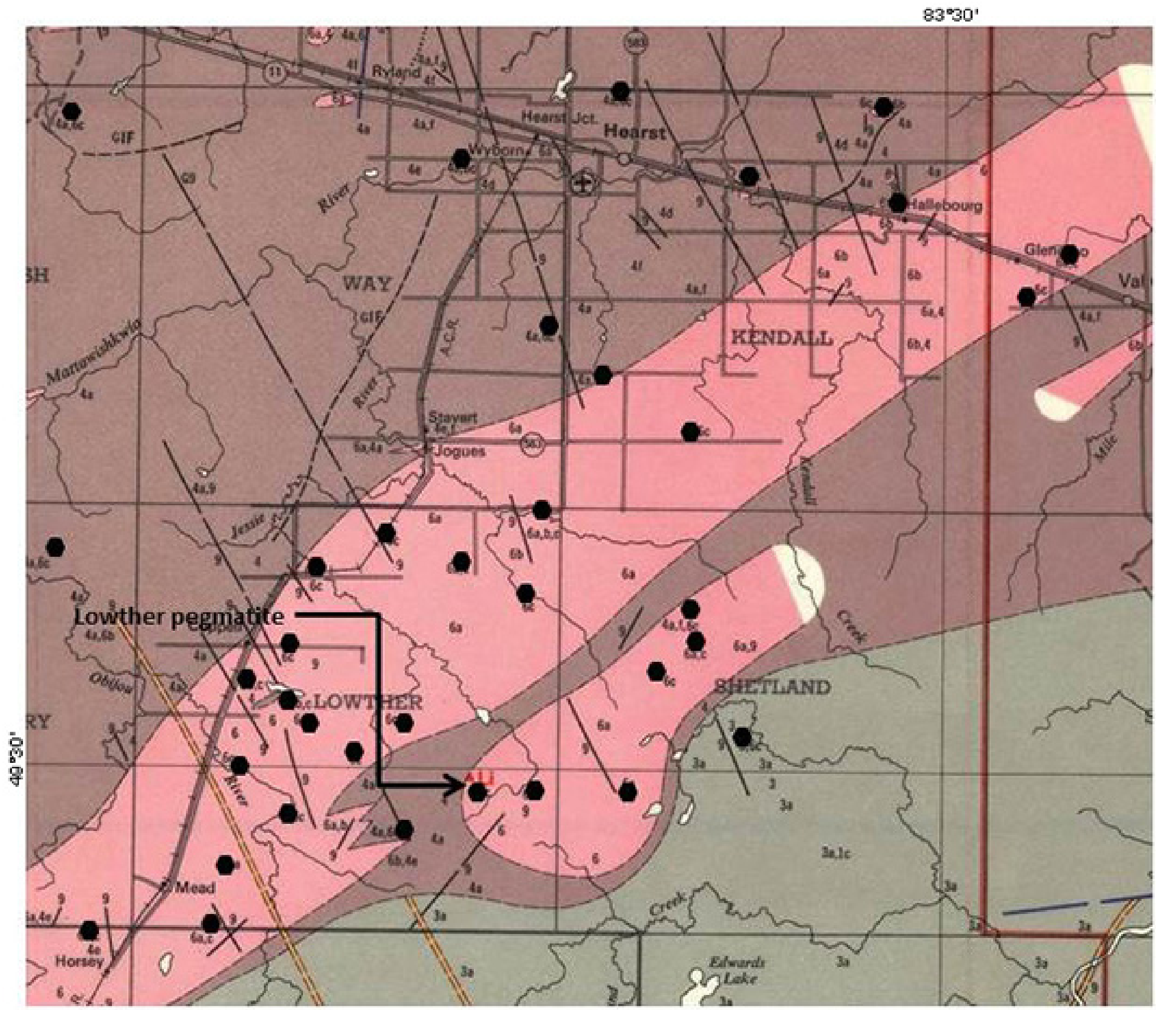

Figure 1. Location of Lowther pegmatite in Lowther Township. The black hexagons represent areas where pegmatitic rocks were recorded by the OGS. *Modified from* OGS Map 2166 (Bennett et al. 1969).

The Case pegmatite is located in Steele Township, situated 80 km east of the town of Cochrane, in the Opatica domain (Figure 2). The 3 pegmatitic dikes, discovered by S.B. Lumbers while mapping for the Ontario Department of Mines, run parallel and strike obliquely to the contact between the Case batholith and Scapa metasedimentary rocks. Each dike is complexly zoned (MDI32E04SW00016, MDI32E04SW00018, MDI32E04SW00020, Ontario Geological Survey 2016a; Breaks, Selway and Tindle 2006). The Central and North dikes are similar in mineralogy and zonation, while the South dike does not hold any spodumene (Breaks, Selway and Tindle 2002). Grab samples taken from all 3 dikes returned an average grade of 0.28% Li in the North dike, 0.75% in the Central dike and 0.06% in the South dike (Burns 1991). The dikes were thoroughly investigated by Breaks, Selway and Tindle (2006). The investigation revealed that the dikes were representing a south to north fractionation trend for more evolved pegmatites to the north into the Case batholith. It was highly recommended for further exploration.

Pegmatites: Eastern Quetico Subprovince and Opatica Domain

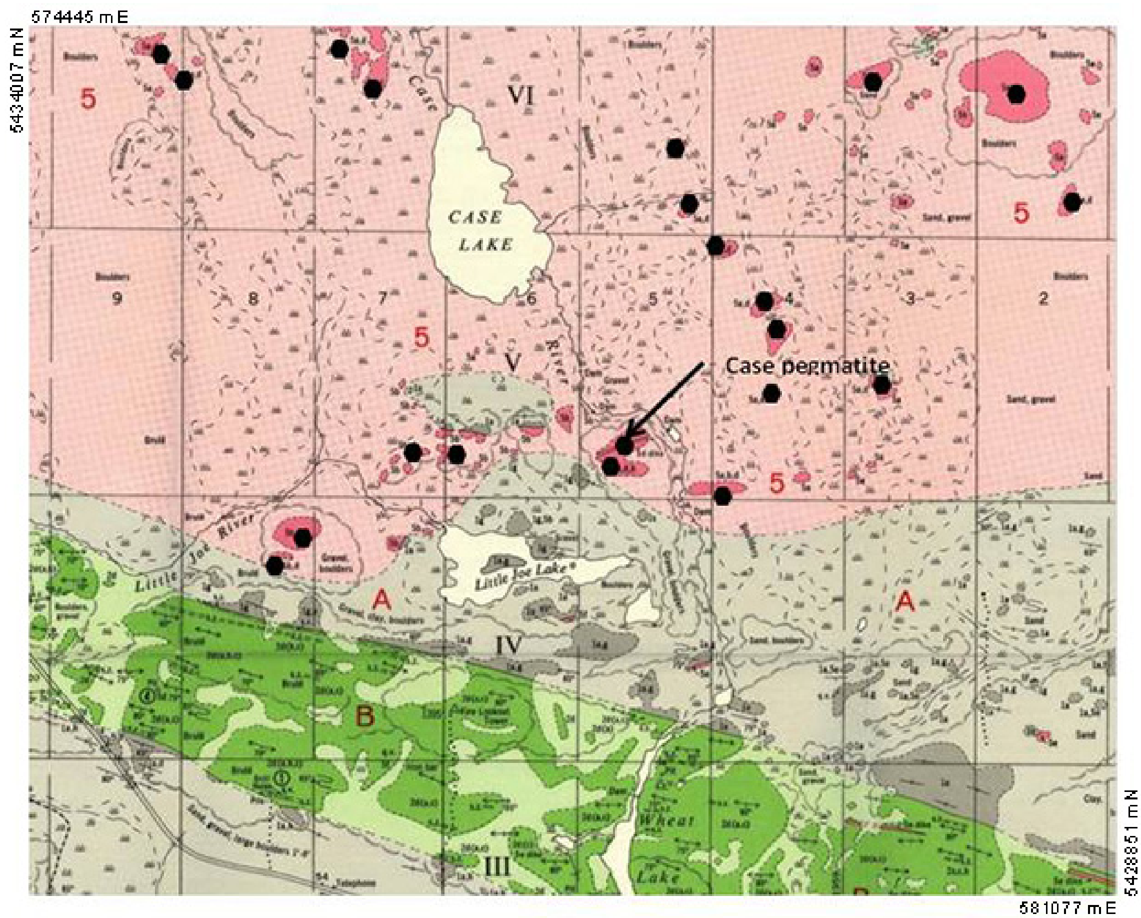

Figure 2. Case pegmatite. The black hexagons represent areas where pegmatitic rocks were recorded by the OGS. *Modified from* OGS Map 2018 (Lumbers 1962). Universal Transverse Mercator (UTM) co-ordinates, in North American Datum 1927 (NAD27), Zone 17, are approximate.

The underexplored Opatica domain also hosts pegmatitic rocks in other locations. Pegmatites were observed at the entrance of the town of Strickland (MDI42H05SW00001, Ontario Geological Survey 2016a), north of Cochrane near the mouth of Dora Creek, on the Abitibi River (MDI42H02NW00001, Ontario Geological Survey 2016a), and near the bridge on the Little Abitibi River on the road to Detour Mine (537216E 5465492N, Figure 3 and Photo 1). The latter is just outside the perimeter outline of the Case batholith. The area was covered recently by an OGS airborne geophysical survey (Ontario Geological Survey 2016b).

In the future, more sources of lithium will be required in order to power up the new green technologies. Among possible sources, hard-rock deposits are known to occur in areas where metasedimentary rocks were melted down and re-injected as evolved pegmatite dikes and sills associated with peraluminous granites. Both the eastern Quetico Subprovince and Opatica domain are known to host such evolved pegmatites as demonstrated by the Case pegmatite in the Opatica domain and the Lowther pegmatite in the eastern Quetico Subprovince. Outcrops of pegmatitic rock are numerous in both the eastern Quetico Subprovince and the Opatica domain. The presence of some of the indicator aluminum-rich minerals, such as garnet, tourmaline and muscovite, found in granite or pegmatite suggest the area be thoroughly prospected for exposures enriched in lithium, tantalum, cesium or rubidium. These areas are underexplored and worthy of prospecting. The majority of the land covered in this recommendation is available for staking.

Pegmatites: Eastern Quetico Subprovince and Opatica Domain

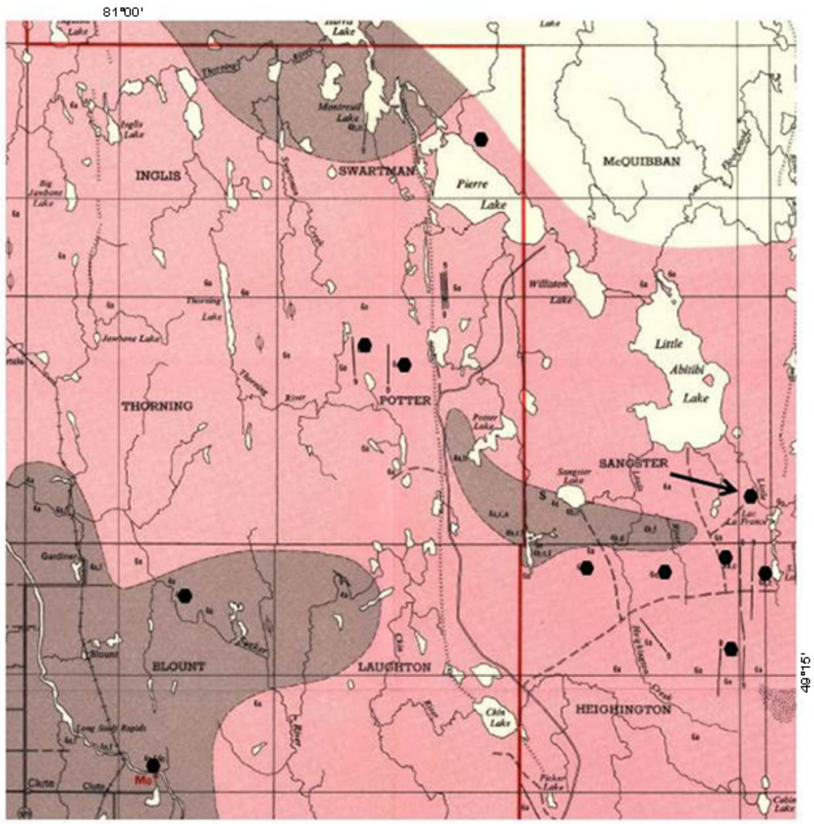

Figure 3. Area northeast of Cochrane. The black hexagons represent areas where pegmatitic rocks were recorded by the OGS. The white pegmatite of Photo 1 is just south of Little Abitibi Lake, in Sangster Township (arrow). *Modified from* OGS Map 2161 (Bennett, Brown and George 1968).

Photo 1. Sangster Township white pegmatite. Digital camera casing for scale.

Pegmatites: Eastern Quetico Subprovince and Opatica Domain

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Porcupine Area Volcanogenic Massive Sulphide Exploration Opportunities

HIGHLIGHTS

- **A gold-rich VMS deposit in Porcupine camp contains >7.0 g/t Au and is hosted by Blake River-age rocks.**
- **Blake River rocks are prospective because they host the giant gold-rich Horne and Bousquet #2 VMS deposits.**
- **The Terminus VMS prospect contains ~1 g/t Au, that accounts for 16% of its metal value.**
- **Gold-bearing clasts in Pamour Mine conglomerate might originate from a gold-rich VMS deposit comparable to the Agnico Eagle deposit in Quebec.**

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Summary

Volcanogenic massive sulphide (VMS) deposits and prospects found in the Porcupine Mining Camp range from the gold-poor to gold-rich copper-zinc variety and also include a lead-zinc-silver prospect. Gold-bearing sulphide clasts in the Pamour conglomerate indicate that an auriferous pyrite VMS deposit might also exist south of the Pamour Mine. The real and possible variation in VMS deposit types present in the Porcupine Camp has important implications for exploration models and strategies, as well as deposit economics.

VMS Types in the Porcupine Area

A ternary plot of the Cu+Zn+Pb (%), Ag (ppm) and Au (ppm) content in VMS-type deposits or prospects helps to identify 3 different types of VMS mineralization that might exist in the Porcupine area (Figure 1). The chemical composition for 9 of 11 VMS deposits and prospects (Table 1) plot in the gold-poor VMS field near the Cu+Zn+Pb to Ag axis (*see* Figure 1). The gold-poor copper-zinc VMS deposits that have been mined contain less than 0.5 g/t Au and include the Canadian Jamieson, Jameland, Kam Kotia, Kidd Creek and Potter deposits. The Chance, Halfmoon, Terminus and Tillex prospects all plot with the gold-poor VMS deposits even though Chance is copper-poor and Terminus contains ~1 g/t of Au.

Two of three zones sampled in the Genex deposit plot in the gold-rich part of the ternary diagram because they have higher gold contents than the other VMS deposits plotted on Figure 1 (Calhoun 2001). Comparable gold-rich VMS deposits include the giant Horne and Bousquet #2 deposits in the Quebec portion of the Abitibi greenstone belt (Galley et al. 2005).

A third type of VMS deposit might exist in the Porcupine area, as indicated by gold-bearing pyrite clasts found in the Pamour conglomerate (Figures 1 and 2). Eight pyrite clasts collected by the author returned gold assays ranging from 3 to 8 g/t (unpublished results). Pyrite clasts with comparable gold assays were found in an outcrop near the junction of Municipal Road 67 and Highway 101 (Matt Gray, personal communication, 1995), 15 km east of the Pamour Mine.

VMS Deposits: Porcupine Area

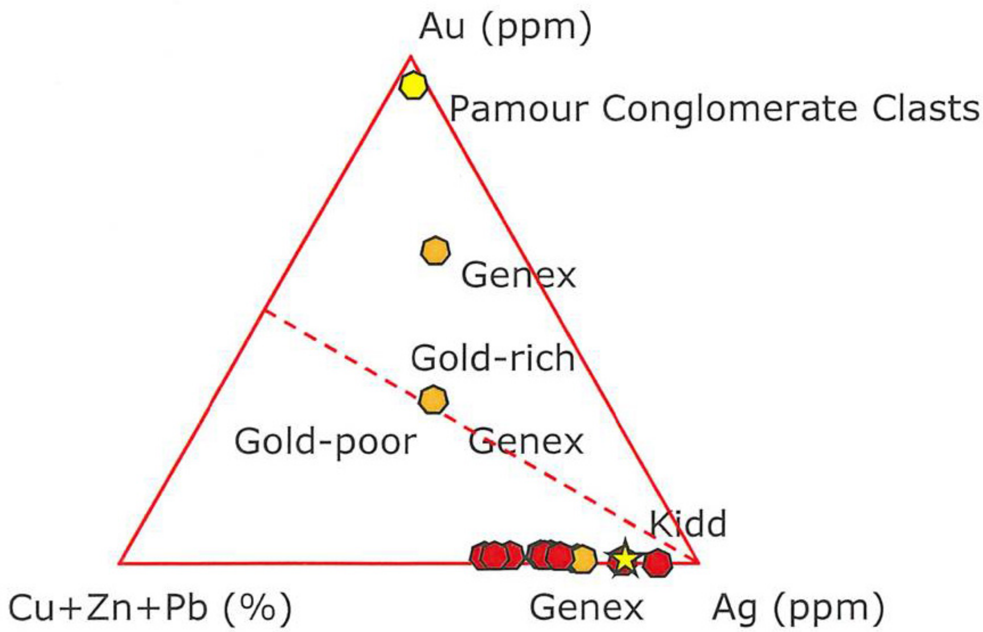

Figure 1. Ternary plot of Cu+Zn+Pb, Ag and Au content in Porcupine area VMS deposits or prospects. Red hexagons indicate the Canadian Jameson, Jameland, Kam Kotia and Potter deposits and Chance, Halfmoon, Terminus and Tillex prospects. The Kidd Creek deposit is indicated by a yellow star, Genex deposit by orange hexagons and pyrite clasts in Pamour conglomerate by a yellow hexagon. (*After* Galley et al. 2005.)

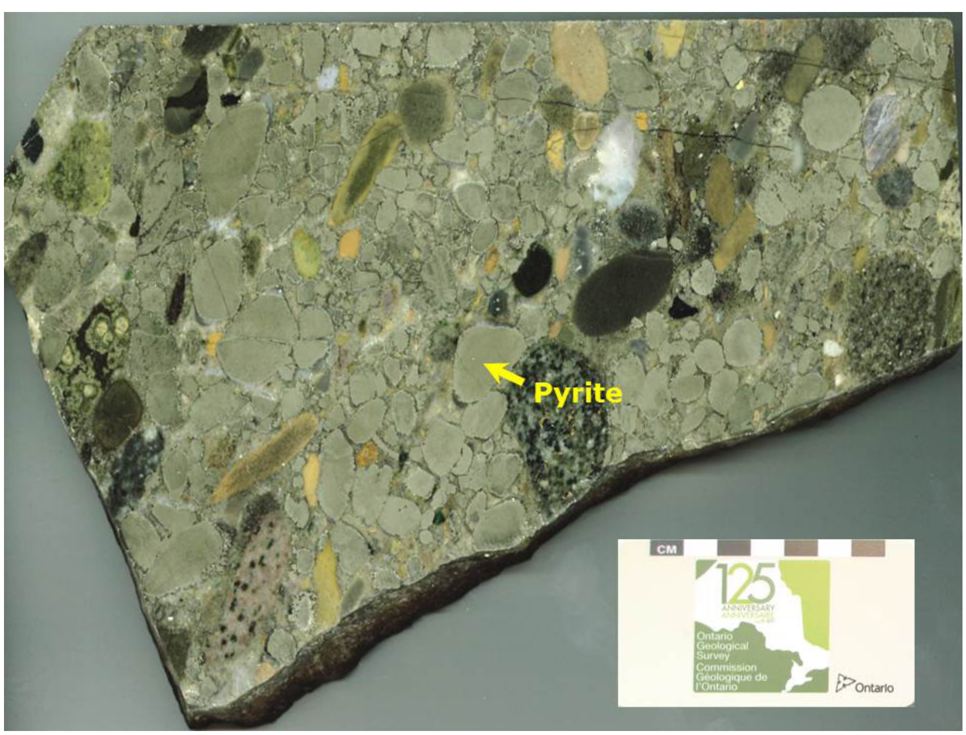

Figure 2. Pamour conglomerate ore (20 cm long slab) with approximately 50% pyrite clasts.

VMS Deposits: Porcupine Area

Table 1. Elemental composition of Porcupine area VMS deposits.

Deposit / Prospect	Cu (%)	Zn (%)	Pb (%)	Au (g/t)	Ag (g/t)
Kidd	2.3	6.19	0.23	0.1	75
Chance	0	12	4	0	223
Chance - Disc DDH	0	14.7	1.96	0	114.3
Kam Kotia	1.12	1.22	0	0.05	3.9
Half Moon	19.03	0.90	0.57	0.763	44.3
Jameland	0.99	0.88	0	0.05	3.5
Canadian Jamieson	2.44	4.22	0	0.3	27
Genex	1.39	0.453	0.023	7.54	2.8
Genex	2.12	4.64	0.07	7.22	8.8
Genex	4.42	18.41	0	0.89	61.6
Terminus	1.21	7.27	0	0.98	26.21
Tillex	1.5	0	0	0	10.9
Potter - 1967–70	1.50	0.43	0.00	0.08	5.31
Potter - 250 lb	3.65	1.04	0.00	0.23	18.66
Potter - 28 Ton	15.22	4.15	0.00	1.40	64.38
Pamour	0.00	0.00	0.00	4.75	0.25

Sources of information:

Kidd	*- Calloway and Gemmel - pers. comm, April/Nov 2016*
Chance	*- Energy, Mines and Resources Canada (1989)*
Chance	*- Disc DDH - Atkinson 1977, telegram to Paul Lindberg*
Kam Kotia	*- Franklin and Thorpe (1982), p.14-18*
Half Moon	*- Prospectors Alliance (1998)*
Jameland	*- Franklin and Thorpe (1982), p.14-18*
Canadian Jamieson	*- MDI File MDI42A12SE00009*
Genex	*- Calhoun (2001)*
Terminus	*- Falconbridge Ltd. (1990)*
Tillex	*- Metals Creek Resources - average of TX11 holes 1 to 8 inclusive (Tillex Fact Sheet, under "Projects | Tillex - ON" at www.metalscreek.com)*
Potter - 1967–70	*- Bath (1990)*
Potter - 250	*- Bath (1990)*
Potter - 28 Ton	*- Bath (1990)*
Pamour	*- van Hees, unpublished data*

Generalized Porcupine VMS Model

Porcupine VMS deposits contain copper, zinc and lead (in decreasing order of abundance) as well as silver and gold. Copper and zinc are found proximal and distal, respectively, to the hydrothermal vents that formed these deposits (Franklin and Thorpe 1982). They are also zoned vertically, with copper and zinc found near the base and top, respectively. A copper stringer zone underlies the vent area and has a sodium depletion zone in the footwall rock alteration halo. The deposit is usually overlain by graphitic and/or chert exhalite sedimentary layers.

The gold-poor Kidd Creek VMS deposit is associated with F3 type rhyolites (Lesher et al. 1986) and was dated between 2710 and 2717±2 Ma (Bleeker and Parrish 1996). The gold-rich Genex deposit differs from the Kidd Creek and other gold-poor VMS deposits in the Porcupine area because it is hosted by Blake River-age rocks dated at 2698.6±2 Ma (Finamore et al. 2008). This rock unit also hosts the Horne and Bousquet #2 gold-rich deposits in the Quebec portion of the Abitibi greenstone belt (Dubé et al. 2005).

VMS Deposits: Porcupine Area

Deposit Economics

A majority of the Porcupine area VMS deposits contain 0.5 g/t Au or less (*see* Table 1) and are classified as low-gold type (*see* Figure 1). The low gold content accounts for 5% or less of metal value in these deposits (*see* Table 2). The Terminus zone differs from the other low-gold type deposits because it contains approximately 1.0 g/t Au, accounting for 15% of the total metal value. Two of three zones in the Genex deposit plot in the gold-rich field because they contain more than 7.0 g/t Au, accounting for more than 50% of the metal value (*see* Figure 1 and Table 2).

Pyrite clasts separated from the Pamour conglomerate contained 3 to 8 g/t Au, have a Au:Ag ratio of 95:5, and plot near the Au apex of the ternary VMS diagram (*see* Figure 1). The gold content accounts for 99.9% of the total metal value. If such a VMS source is found it should be easy to exploit.

Table 2. Metal value (in CDN $) per tonne of mineralization in Porcupine area VMS deposits.

Deposit	Cu	Zn	Pb	Au	Ag	Total	Au/Total
Kidd	$135	$179	$6	$5	$57	**$382**	**1.4%**
Chance	$0	$347	$100	$0	$171	**$617**	**0.0%**
Chance - Disc DDH	$0	$425	$49	$0	$88	**$561**	**0.0%**
Kam Kotia	$66	$35	$0	$3	$3	**$107**	**2.6%**
Half Moon	$1,116	$26	$14	$42	$34	**$1,231**	**3.4%**
Jameland	$58	$25	$0	$3	$3	**$89**	**3.1%**
Canadian Jamieson	$143	$122	$0	$16	$21	**$302**	**5.4%**
Genex	$81	$13	$1	$414	$2	**$511**	**81.0%**
Genex	$124	$134	$2	$396	$7	**$663**	**59.7%**
Genex	$259	$532	$0	$49	$47	**$888**	**5.5%**
Terminus	$71	$210	$0	$54	$20	**$355**	**15.1%**
Tillex	$88	$0	$0	$0	$8	**$96**	**0.0%**
Potter - 1967-70	$88	$12	$0	$4	$4	**$109**	**4.0%**
Potter - 250 lb	$214	$30	$0	$13	$14	**$271**	**4.7%**
Potter - 28 Ton	$892	$120	$0	$77	$49	**$1,138**	**6.7%**
Pamour	$0	$0	$0	$261	$0	**$261**	**99.9%**

Sources of information as per Table 1.

Metal prices (CAN$), October 28, 2016:

Cu - $2.93/lb *US$: CDN$ Exchange rate 1.3385*
Zn - $1.45/lb
Pb - $1.24/lb
Au - $54.87/g
Ag - $0.77/g

Exploration Strategy

Gold-bearing pyrite clasts in the Pamour conglomerate support the hypothesis that the clasts might have originated from a gold-rich VMS source, comparable to the Agnico Eagle Mine near Joutel, Quebec (Barnett et al. 1982). The absence of quartz veins in outcrop hosting gold-bearing clasts near the junction of Municipal Road 67 and Highway 101 are interpreted to indicate that the gold-bearing clasts were derived from a pyrite VMS source rather than being enriched by gold-bearing hydrothermal fluids. Conglomeratic VMS deposits, like those in Buchans, Newfoundland, also support a VMS source for the clasts. The VMS source might be located just south of the Pamour Mine and Porcupine Destor Fault because the brittle nature of pyrite precludes a long transport distance.

VMS Deposits: Porcupine Area

The gold-rich Genex copper-zinc VMS deposit (and possibly the Terminus Zone) is hosted by Upper Blake River-age rocks (2698.6±2 Ma: Finamore et al. 2008), which are approximately 10 million years younger than those that host the Kidd Creek deposit (2710 to 2717 Ma). These same rocks also host the gold-rich giant Horne and Bousquet #2 VMS deposits in Quebec (Dubé et al. 2005). Exploring these younger rocks using lithogeochemical and gravity geophysical techniques might prove more fruitful than previous exploration efforts. The lithogeochemical approach would ensure that exploration efforts are focused on the proper stratigraphic unit.

The gravity geophysical technique will recognize geophysical anomalies associated with increased density of the earth caused by large concentrations of sulphide minerals such as pyrite, sphalerite, chalcopyrite and galena (Figure 3). The technique is especially helpful at recognizing sphalerite-rich VMS deposits, such as the Chance prospect, that do not respond to many other geophysical techniques. Electromagnetic geophysical anomalies associated with the numerous graphitic argillite horizons found in the Abitibi greenstone belt can be eliminated because their low density will not produce a gravity anomaly (*see* Figure 3). The recent development of the airborne gravity technique also makes it much more affordable.

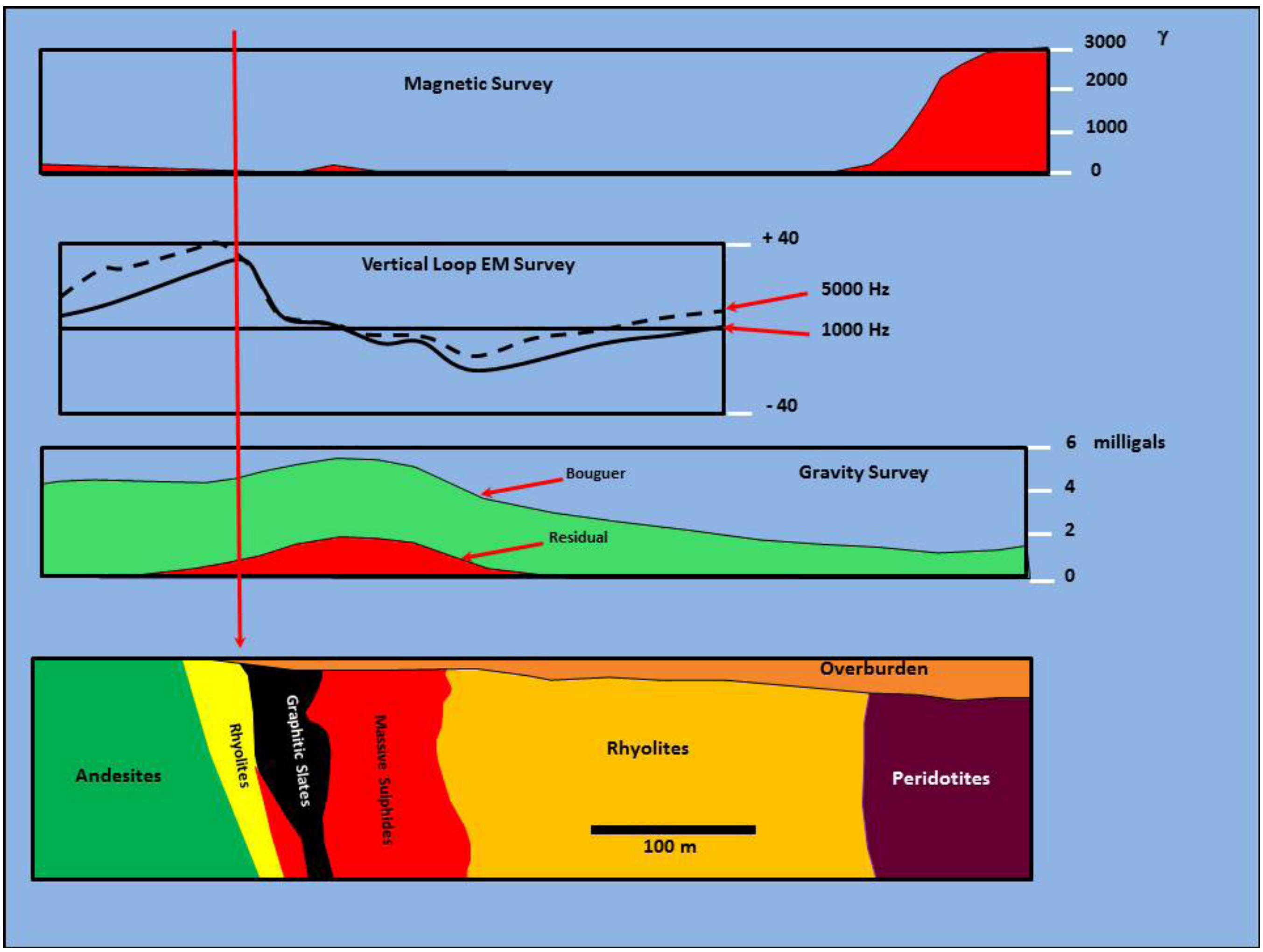

Figure 3. Geophysical response over the Kidd Creek VMS deposit (*after* Donohoo, Podolsky and Clayton 1970; and Bleeker 1999).

VMS Deposits: Porcupine Area

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Cobalt Potential in the Kirkland Lake District

HIGHLIGHTS

- **Cobalt demand to grow at 5% per annum.**
- **11 158 tonnes of historical cobalt production.**
- **Erratic productive ore shoots carry exceptionally high grades.**
- **Limited recent exploration.**

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Whilst demand growth for most metals stalled in recent years, cobalt demand grew strongly, spurred on by the increasing popularity of lithium-ion batteries, which also contain cobalt. CRU Group estimates that demand for cobalt will grow at an average rate of 5% per annum for the next 10 years. In October 2016, prices were up to US$13.4 per pound (Kitco News, October 10, 2016) and are expected to increase onwards in 2017 (*The Northern Miner*, October 3–9, 2016, p.4).

Cobalt was produced as a by-product of silver extraction in the Kirkland Lake Resident Geologist District. Since 1903, the district has produced approximately 553 million ounces of silver, 24.6 million pounds (11 158 tonnes) of cobalt, 3.6 million pounds (1633 tonnes) of nickel and 2.6 million ounces of copper from its silver deposits (Guindon et al. 2016). Table 1 shows historical production of cobalt and silver (± nickel, copper) from some mines in the district.

Silver-sulpharsenide vein deposits in the Kirkland Lake district occur along the north and northeastern margins of the Cobalt Embayment (Figure 1); as a result, 5 distinct silver-mining camps emerged, namely, the South Lorrain, Cobalt, Casey Township, Elk Lake and the Gowganda camps. The Cobalt Embayment is a large irregular domain of Huronian-age clastic sedimentary rocks intruded by Nipissing diabase sills and crosscut by regional-scale fault systems. The vein systems occur in faults and fault-related fracture systems hosted by Huronian sedimentary rocks, Archean basement rocks and Nipissing diabase sills. The vein systems are also often extensive; however, silver-sulpharsenide mineralization is highly restricted in occurrence to within about 200 m of the upper and lower diabase contacts or deep within the sills themselves. The Huronian sequence consists of a variety of coarse- to fine-grained clastic sedimentary rocks that have been subdivided into the Lorrain and Gowganda formations. The Gowganda formation, in turn, is locally subdivided into the Firstbrook and Coleman members. In the immediate vicinity of the Cobalt, Casey and Gowganda mining camps, mainly the Firstbrook and Coleman members are preserved. The Coleman member is the most important sediment host to the silver deposits (Andrews et al. 1986). The silver deposits are characterized by a complex ore mineralogy consisting of native silver and bismuth, copper-nickel-iron arsenides, sulpharsenides and sulphides of lead, zinc and copper (Marshall 2008; Smyk 1987; Petruk 1971). In contrast, the gangue mineralogy consists dominantly of carbonates (mainly calcite with lesser dolomite) and minor silicates (Jambor 1971).

There has been no metal production from the 5 abovementioned camps since 1990. Reasons span from depletion of ores and reduction in metal prices to exploration challenges, such as land not open to exploration, special requirements needed for exploration, and thick sequences of overlying Huronian sedimentary rocks, making exploration of buried targets difficult in some areas of the embayment. Unfortunately, there has been limited recent exploration for cobalt-bearing metals within

Cobalt: Kirkland Lake District

the district. In the mining camps, the silver-cobalt veins are typically narrow and pinch and swell. Productive ore shoots are erratic, but carry exceptionally high grades (Smyk 1987). Thus, there is potential for small, but high-grade deposits of cobalt-bearing metals in the embayment. Modern induced polarization (IP) and versatile time domain electromagnetic (VTEM) geophysical exploration techniques, which have the potential to penetrate through cover rocks and detect buried targets in areas undetected by older geophysical techniques, are recommended. Geophysical exploration and subsequent diamond drilling are, therefore, warranted in "ignored" but prospective areas, particularly in the North Williams–Barr–Brigstocke–Sladen–Rorke–Dufferin townships transect within the north-central section of the embayment (*see* Figure 1). In other parts of the world, for example the Democratic Republic of Congo, exploration for cobalt-bearing metals has centred on the re-evaluation and re-development of past mining centres (brownfield exploration sites), as well as identification and development of newly discovered or previously undeveloped deposits/prospects (Wilburn 2012). This approach could be relevant to the Cobalt Embayment.

Table 1. Historical production of selected mines in the Cobalt Embayment (*modified from* Guindon et al. 2016).

Mine	Mining Camp	Township	Tons Milled	Ag (oz)	Co (lb)	Ni (lb)	Cu (lb)	Years of Production
Curry	S. Lorr	S. Lorr	87	49 821	7 691			1916–1938
Keeley and Frontier	S. Lorr	S. Lorr	NA	19 197 413	3 310 556	27 252	10 292	1908–1965
Lorrain Lake	S. Lorr	S. Lorr	22 405	1 093 404	64 458			1924–1943
Nipissing Lorrain	S. Lorr	S. Lorr	NA	350 000	5 521			1925–1929
Wettlaufer	S. Lorr	S. Lorr	6 861	2 593 041	23 910			1909–1940
Cobalt Contact	Cob	Bucke	11 074	26 000	31 000			1912–1944
Cobalt Lode Silver	Cob	Coleman	263 140	4 493 542	2 545 117	610 716	459 078	1917–1956
Cobalt Townsite	Cob	Coleman	913 268	37 362 032	1 852 765	163 687	90 288	1907–1939
Foster Cobalt Mining	Cob	Coleman	2 818	1 159 390	457 164	21 766	24 121	1951–1956
Harrison–Hibert and Ruby	Cob	Bucke	NA	876 500	214 600	69 458		1920–1963
Kerr Lake Mining	Cob	Coleman	235 503	28 502 037	650 094		1 792	1905–1948
Nipissing	Cob	Coleman	1 066 589	32 000 000	3 636 704			1905–1951
Provincial	Cob	Gillies Limit	258	286 897	54 473	2 842		1908–1940
Casey Cobalt-Silver	Cas	Cas	NA	9 373 085	356 418	141 733	88 437	1908–1966
Langis	Cas	Cas, Harris	49 542	653 882	25 474	8 013	8 550	1983–1989
Lucky Godfrey Silver	E. Lake	Willet	NA	9 835	592			1908–1911
Shane–Darragh	E. Lake	Mickle	NA	63 471	1 214			1953–1955
Castle	Gow	Haultain	111 258	2 949 074	76 206	24 199	22 425	1979–1989
Castle–Tretheway	Gow	Haultain	254 311	6 461 021	299 847			1920–1931
Miller Lake O'Brien	Gow	Nicol	1 111 986	37 987 767	785 760	13 248	72 946	1910–1966
Millerett	Gow	Haultain	NA	611 822	5 000			1910–1912
Morrison	Gow	Nicol	24 945	719 201	22 018			1930–1954
Walsh	Gow	Nicol	19 677	453 424	3 555			1925–1940

Abbreviations: S. Lorr = South Lorrain, Cob = Cobalt, Cas = Casey Township, E. Lake = Elk Lake, Gow = Gowganda, NA = not available.

Cobalt: Kirkland Lake District

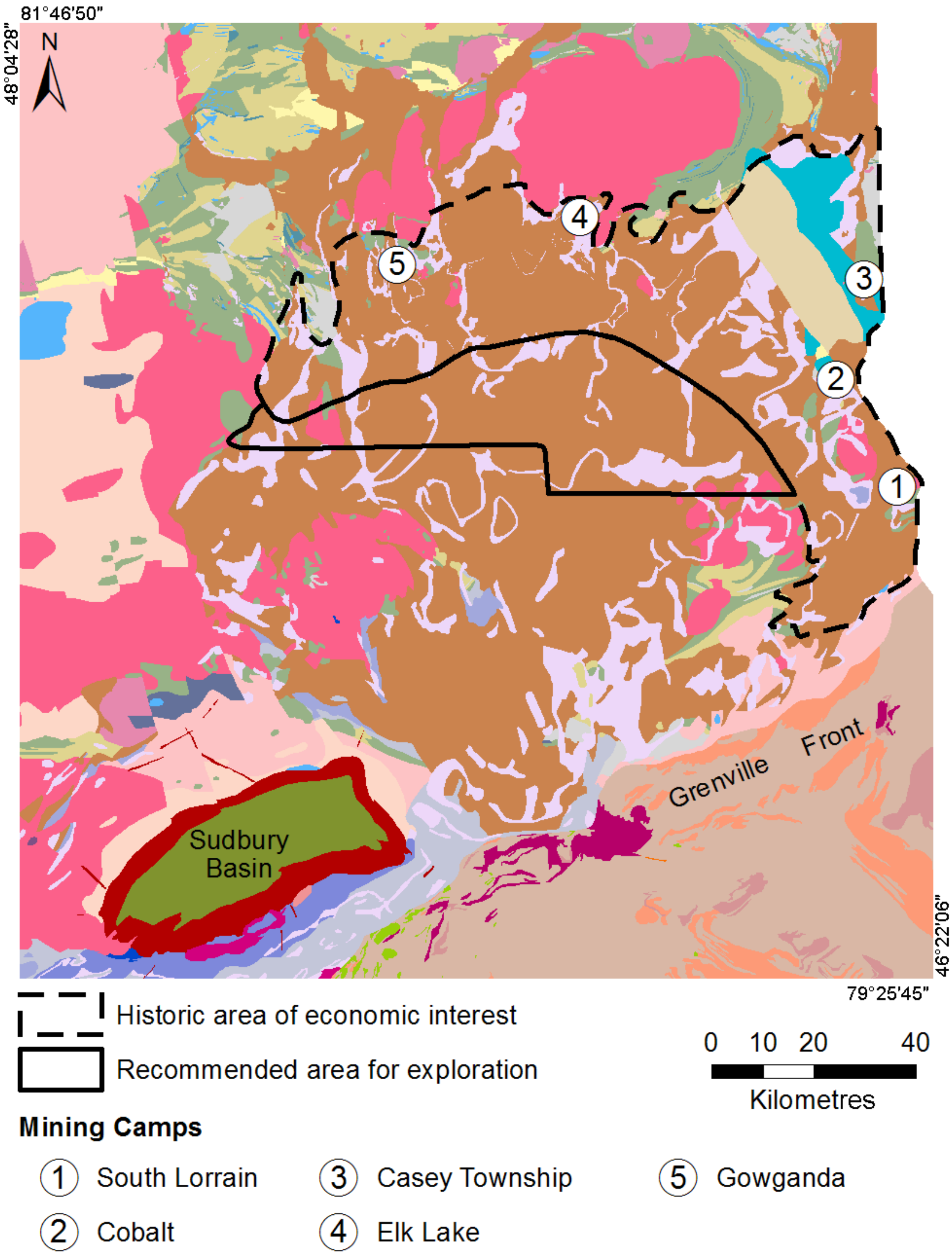

Figure 1. Geology of the Cobalt Embayment showing the general area encompassing historic mines, most occurrences of silver-cobalt mineralization, and proposed area for exploration (*modified from* Andrews et al. 1986; Ontario Geological Survey 2011).

Cobalt: Kirkland Lake District

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Data Mining of Surficial and Deep Overburden Samples in the Kirkland Lake Resident Geologist District

HIGHLIGHTS

- **Numerous regional geochemical surveys for the Kirkland Lake Resident Geologist District are available in digital format.**
- **Processing data using a Geographic Information System (GIS) can assist putting anomalous samples into a geological context.**
- **Data mining should provide numerous anomalies that have not been previously followed up. Significant areas have opened up because of cancellation of mining claims as a result of limited expenditures in the recent past.**

The Ontario Geological Survey has conducted regional geochemical surveys for more than 3 decades. Overtime, the surveys evolved in the type of media sampled, but the methodologies used to sample, process and report results for a particular media remained consistent. Initially, data was released in hard copy, usually as Open File Reports (OFR), but most of the survey data is now available in digital format, published as Miscellaneous Releases—Data (MRD) data sets (Table 1 and Figure 1). The development and availability of Geographical Information System (GIS) software has improved the speed and visual capabilities of displaying the data. Some data manipulation is required to get the data into a consistent format and to ensure that a consistent datum is used for point location.

Gold grain data is available for the till and alluvium surveys (*see* Table 1). Data is available for total gold grains observed per sample and further subdivided into 3 groupings as described by DiLabio (1990): pristine, modified and reshaped. Total gold grains observed was recorded for the Kirkland Lake Initiatives Program (KLIP) data set, and the number, size and shape per sample are listed for the Black River–Matheson (BRiM) data set, using the classification of Averill (1988): delicate, irregular and abraded.

Pristine grains do not appear to have been damaged by glacial transport, suggesting that the grains were found proximal to their point of origin (DiLabio 1990). As such, the total number of pristine grains recovered is a very low proportion of the total grains recovered. A recommendation for exploration using modern alluvium data in the Round Lake Batholith area was published in the 2015 Report of Activities (Guindon et al. 2016). A review of other data sets, using GIS to put the data into geological context, offers some interesting areas for follow up. A few are presented below.

Till sampling results from a survey in the Detour Lake and Burntbush area, north of Lake Abitibi, are shown in Figure 2. The red circles are the locations of till sample sites (Gao 2015a, 2015b), with total gold grain counts indicated on the left and pristine grain counts, on the right. Pristine grains were recovered from 2 samples that are underlain by clastic sedimentary rocks with banded iron formation. This may suggest that the pristine grains are from a deposit type similar to that found in the Geraldton area.

Two samples with abundant pristine gold grains were collected in Ingram Township, north of New Liskeard (Gao 2012; Figure 3). This is an unexpected location for the recovery of gold grains. Rocks that host silver-arsenide veins are located immediately to the north. Such veins are known for hosting high-grade silver and cobalt. Some of these deposits also contain some gold. Recent exploration by Brixton Metals Corporation intersected 4.9 g/t gold and 397 g/t silver over 4 m (Brixton Metals Corporation, press release August 11, 2016).

Many more targets can be found mining the data in these and other data sets from across the province.

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Data Mining of Overburden Samples: Kirkland Lake District

Table 1. OGS survey areas, sample media and associated publications. *See* Figure 1 for survey locations.

Area	Type	OFR	MRD	Authors
Cobalt–Mattawa	Alluvium	6088	MRD102	Reid, J.L.
Elk Lake–Cobalt	Alluvium	6119	MRD124	Reid, J.L.
Gogama–Shining Tree	Alluvium	6227	MRD220	Felix, V.E. and Matson, A.L.
Matachewan–Kirkland Lake	Alluvium	6124	MRD129	Guindon, D.L. and Reid, J.L.
Temagami–Marten River	Alluvium	6043	MRD072	Allan, S.E.
Peterlong Lake–Radisson Lake	Lake Sed	5942/6053	MRD027, MRD070	OFR5942: Bajc, A.F. et al.; MRD027: Hamilton, S.M.; OFR6053 and MRD070: OGS
Shining Tree	Lake Sed	6062	MRD081	Russell, D.F. and Hamilton, S.M.
Temagami	Lake Sed	6144	MRD137	Takats, P.A. and Dyer, R.D.
BRiM – backhoe	Overburden	5749	MRD001	OFR5749: McClenaghan, M.B; MRD001: OGS
BRiM – sonic	Overburden	5800	MRD001	OFR5800: McClenaghan, M.B; MRD001: OGS
Kirkland Lake Initiatives Program (KLIP)	Overburden	5335/ 5355/ 5356/ 5394/ 5395/ 5456/5506	MRD004	MRD004: OGS
Cobalt–New Liskeard	Till	6259	MRD284	Gao, C.
Detour Lake–Burntbush	Till	6297	MRD312	Gao, C.
Matachewan	Till	5957	MRD029	Bajc, A.F.
Peterlong Lake–Radisson Lake	Till	6060	MRD024	OFR6060: Bajc, A.F. and Crabtree, D.C.; MRD024: Bajc, A.F.

Data Mining of Overburden Samples: Kirkland Lake District

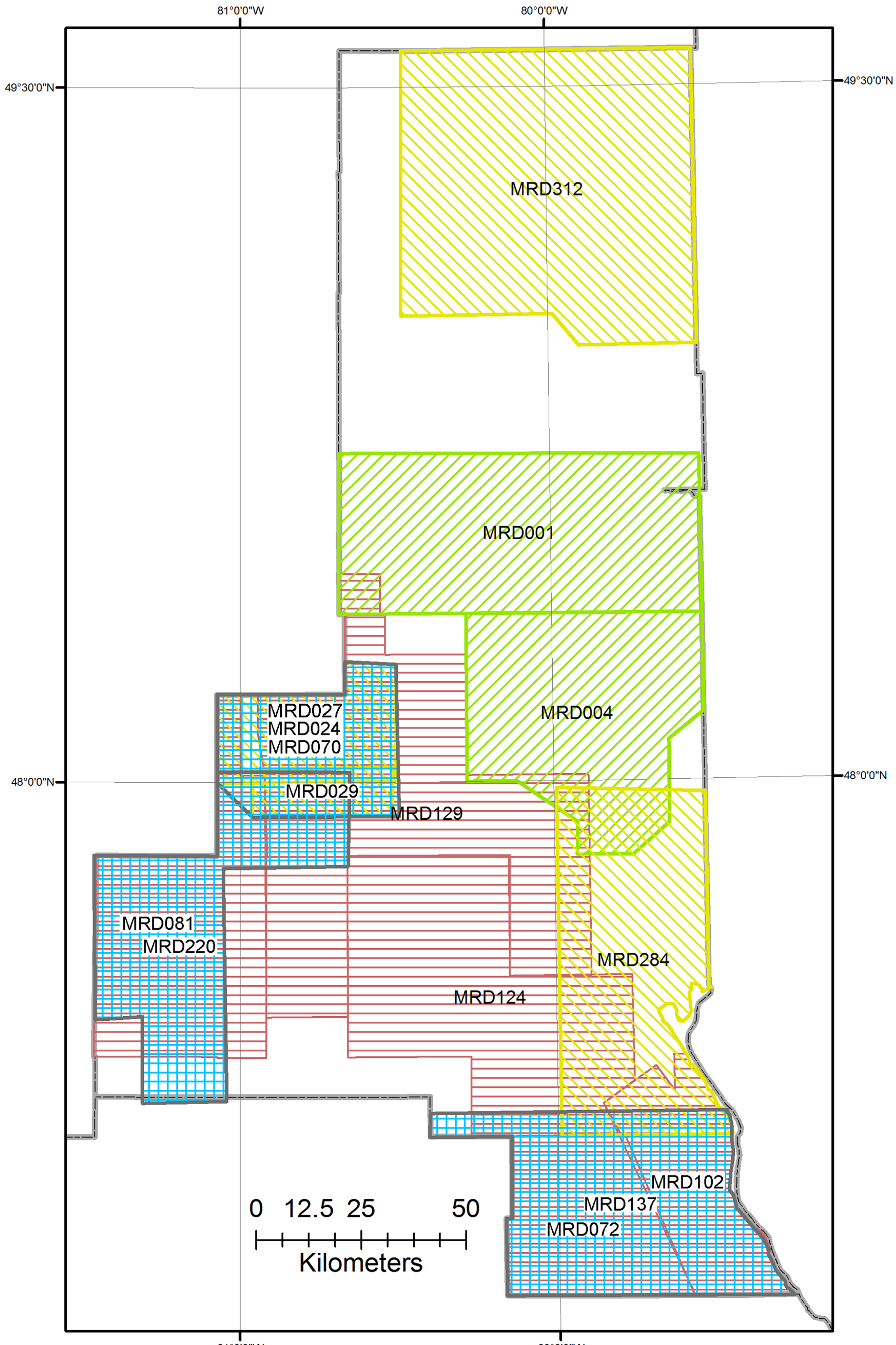

Figure 1. Locations of surveys (showing associated published Miscellaneous Release—Data) within the Kirkland Lake Resident Geologist District. Colours reflect survey type: alluvium (reddish brown), lake sediment (blue), overburden (green) and till (yellow).

Data Mining of Overburden Samples: Kirkland Lake District

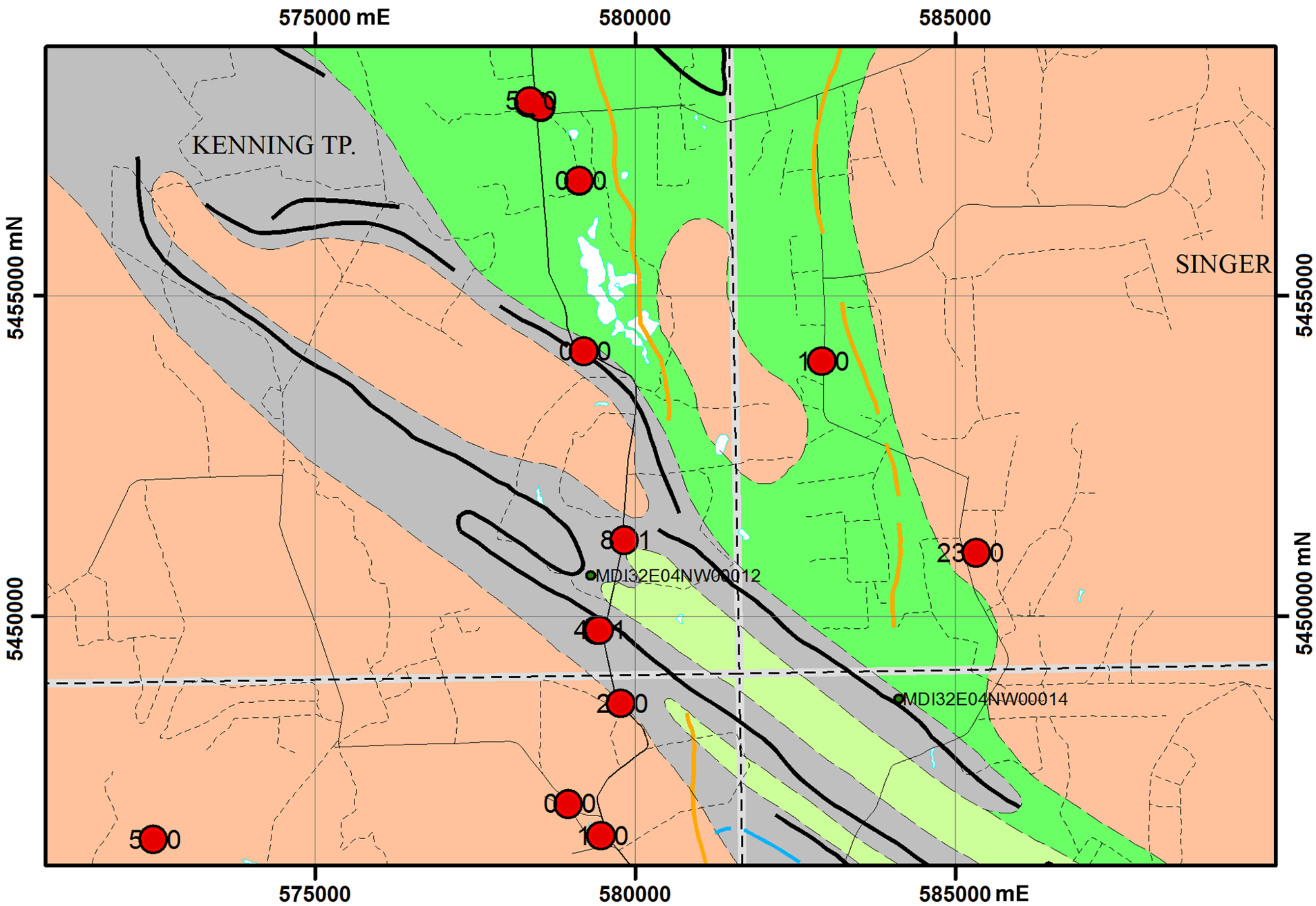

Figure 2. Location of till samples (red circles) in the Burntbush and Detour Lake area, showing total gold grain counts to the left and pristine gold grain counts to the right (Goa 2015a, 2015b) plotted on geology *from* Ayer et al. (2009). Pristine gold grains are underlain by clastic sedimentary rocks with associated iron formation. Universal Transverse Mercator (UTM) co-ordinates in North American Datum 1983 (NAD83), Zone 17.

Data Mining of Overburden Samples: Kirkland Lake District

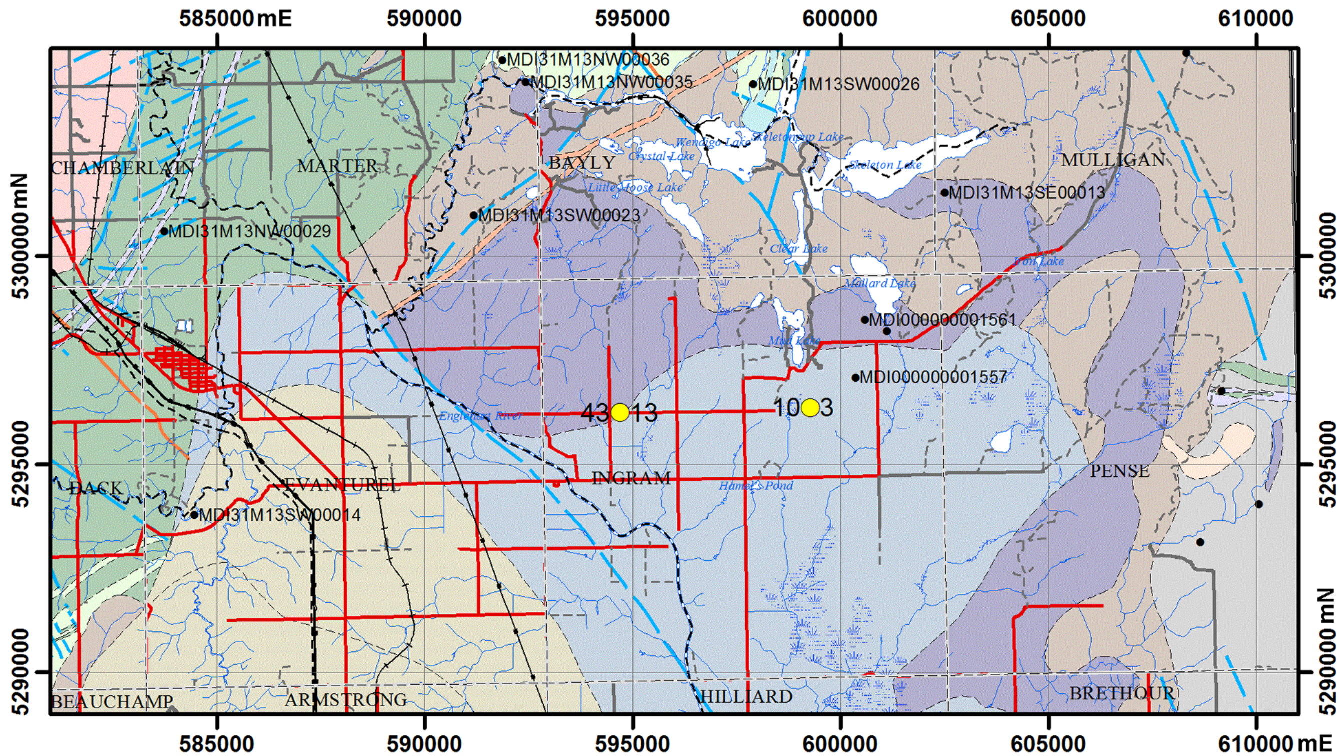

Figure 3. Location of 2 till samples (yellow circles) with abundant pristine gold grains, collected in Ingram Township, north of New Liskeard (Goa 2012). Total gold grain counts are shown on the left and pristine gold grain counts on the right. Geology *from* Ayer, Trowell and Josey (2004). Pristine gold grains are underlain by Paleozoic rocks but near areas with silver-arsenide vein mineralization. Universal Transverse Mercator (UTM) co-ordinates in North American Datum 1983 (NAD83), Zone 17.

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Soda Metasomatism as a Possible Iron Oxide-Copper-Gold (IOCG) Deposit Indicator in the Sudbury District

HIGHLIGHTS

- **Metasomatic band of albitized rocks share IOCG characteristics.**
- **Altered Paleoproterozoic rocks extend ~ 500 km.**
- **Deep intrusive body northeast of Lake Wanapitei may be related.**

Soda metasomatism in the Southern structural province of the Canadian Shield is well known, but not well understood. In the Sudbury area these regionally albitized rocks occur in a roughly arcuate trend, extending from near Bruce Mines in the west to the Temagami area northeast of Lake Wanapitei, passing south of the Sudbury Igneous Complex (SIC) (Gates 1991).

U/Pb geochronology of hydrothermal monazite in albitized rocks east of the Sudbury complex indicates that metasomatic albitization occurred in the Sudbury–Wanapitei Lake area at 1700±2 Ma, coeval with granitic plutonism in the Southern Province, between 1750 and 1700 Ma (Schandl, Gorton and Davis 1994).

It has been postulated that the regional soda metasomatism of the area may be related to the Sudbury impact event at 1850 Ma; however, the U/Pb geochronological evidence cited above indicates that later felsic plutonism or more deep-seated carbonatitic or alkalic intrusions at depth could have acted as the driving mechanism for the sodium-rich fluids.

In the Sudbury District, economic interest in these rocks has focused on several small deposits of gold (illustrated on Figure 1), but the characteristics of these deposits in many ways display an affinity with iron oxide-copper-gold (IOCG) deposits found in other parts of the world. It has been proposed that the former Scadding gold mine, east of the SIC is a modified IOCG deposit (Schandl and Gorton 2007).

Some of these shared characteristics include the follow:

- Proterozoic in age (most)
- Located along cratonic margins
- Common alterations include sodium, potassium, iron, calcium and silica
- Associated with major fault and/or fracture systems
- Mineralization includes copper and copper-iron sulphides, iron oxide, gold, uranium, silver, cobalt (all variable)
- Elevated levels of rare earth elements (REE)
- Brecciated country rocks.

With these factors in mind, it is recommended that prospecting be carried out for potential IOCG deposits in Paleoproterozoic Huronian rocks along the aforementioned arcuate trend of soda-rich rocks as well as in townships northeast of Lake Wanapitei underlain by the Wanapitei aeromagnetic anomaly. This anomaly indicates the presence of an intrusive body up to 5 km deep underlying an area between eastern Lake Wanapitei and western Lake Temagami.

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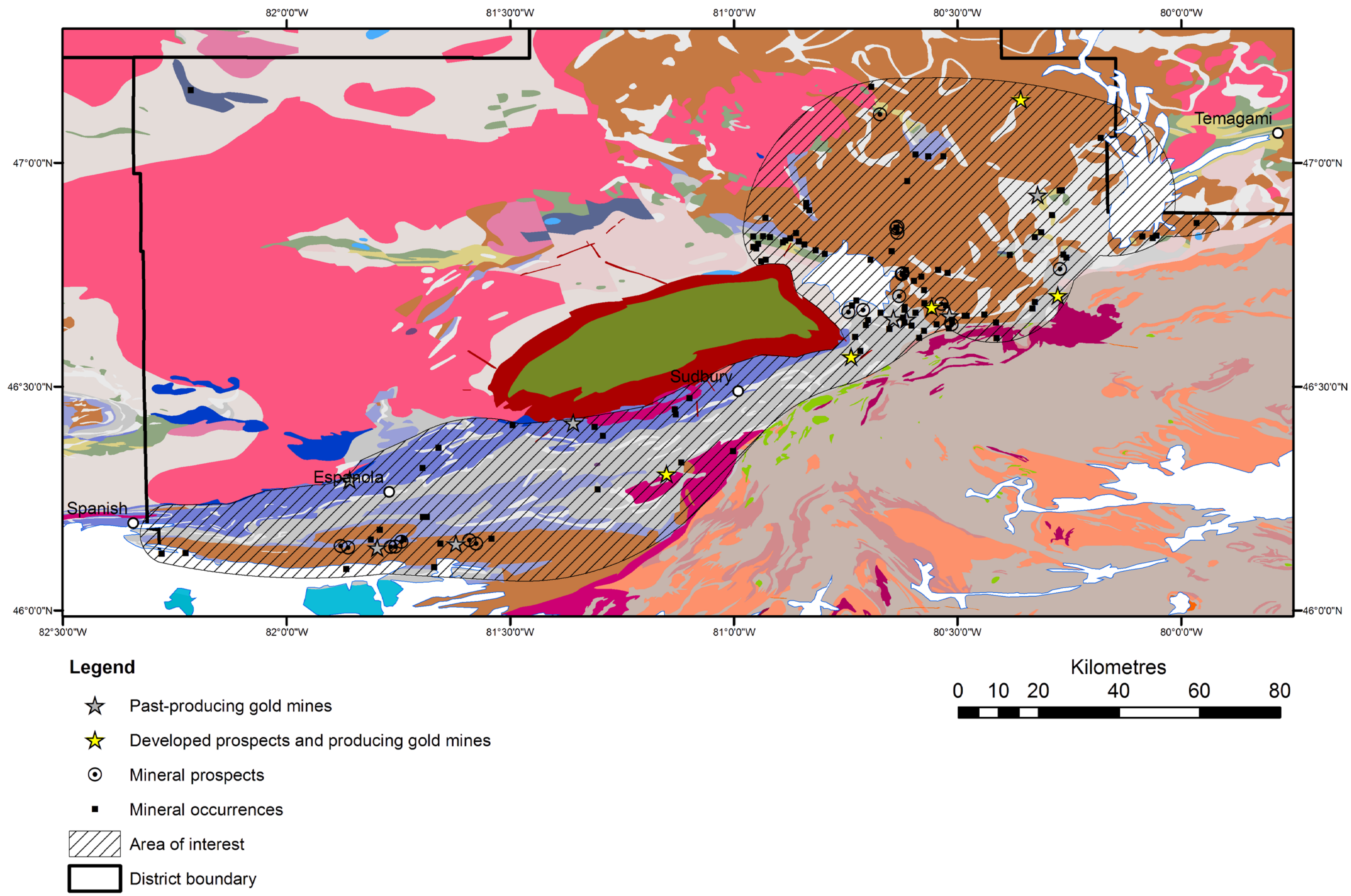

Figure 1. Sodium metasomatic mineralization and mineral occurrences in the Sudbury District (geology *modified from* Ontario Geological Survey 2011).

IOCG Deposits: Sudbury District

Metasomatic soda-rich rocks are mostly pink, sometimes tan coloured. They are easily recognized in contrasting host rocks such as greywacke, siltstones, paraconglomerates, limestones and diabase. They are difficult to recognize in similarly coloured rocks, such as feldspathic quartzites, arkoses and granite (Meyer 1987).

Townships within the area of interest include Phyllis, Vogt, Hobbs, Pardo, Clement, Scholes, Afton, Macbeth, McNish, Janes, Davis, Kelly, McCarthy, Sheppard, Mackelcan, Rathbun, Scadding, Street, Falconbridge, Dryden, Neelon, Dill, Broder, Waters, Tilton, Bevin, Caen, Goschen, Stalin, Dieppe, Killarney, Rutherford, Roosevelt, Truman, Foster, Curtin, Merritt, Mongowin and McKinnon.

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Nickel-Copper-(Cobalt-PGM) Mineralization in Southeastern Ontario

HIGHLIGHTS

- **Historic occurrences of magmatic nickel-copper mineralization contain minor cobalt and anomalous PGEs.**
- **Little previous exploration has been done with modern geophysical surveys.**
- **Mafic intrusions widespread throughout the Central Metasedimentary Belt and may be more abundant than previously thought in the Central Gneiss Belt.**

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Nickel and cobalt, along with lithium and graphite, are important components of the rapidly growing battery market. It has been estimated that the electric vehicle battery market will increase by 5 times the current level while the market for stationary electric storage will increase 8-fold between 2015 and 2020 (Benchmark Mineral Intelligence Magazine, December 2015, Q4; www.benchmarkminerals.com).

About 75% of the global cobalt output is the result of by-product from copper and nickel processing. Low base metals prices have resulted in cuts to production of copper and nickel, which may leave cobalt in short supply as demand increases.

Southern Ontario Nickel-Copper Occurrences and Previous Exploration

Several nickel-copper prospects discovered in southeastern Ontario prior to 1965 have seen little additional exploration work since that time, with the exception of some activity in the 1990s by various companies and from 2008 to 2012 by First Nickel Inc.

Table 1 lists nickel-copper occurrences in southeastern Ontario that are associated with mafic intrusions. The locations of these occurrences are shown in Figure 1. More complete details are available in the Mineral Deposits Inventory online database of the OGS.

First Nickel Inc. completed 2 airborne electromagnetic (EM) and magnetometer surveys in 2008, covering several of the known nickel-copper occurrences listed in Table 1 as well as prospective mafic intrusions in the Bancroft to Marmora area. The northern survey area, the Raglan Hills project, was centred on the Raglan Hills gabbro, which hosts the Raglan Township occurrences (numbers 7 to 10, Figure 1). The southern survey area, the Belmont project, covered numerous smaller mafic intrusions, including those hosting the Lake, Limerick, and Marmora township occurrences (numbers 1, 2 and 4, Figure 1).

From 2009 to 2012, First Nickel Inc. completed prospecting and ground verification of airborne EM anomalies, followed by diamond drilling on several of the prospects. On the Belmont project, 19 diamond-drill holes totaling 4230 m were completed and on the Raglan project, 47 holes were drilled for a total of 7520 m. First Nickel Inc. reported assays from diamond-drill core of up to 0.47% Ni and 0.64% Cu across 5.8 m from the Raglan prospect (Easton, Duguet and Magnus 2011). The bulk of the drilling on the Raglan prospect was done on only 2 properties. Despite a proposal for additional work in both areas and the presence of numerous untested geophysical targets, no diamond drilling was done on claim blocks in Marmora Lake area or Belmont Township in the southern project area, and no further work was done in the Raglan area. In 2013, the company, going through financial hardship, halted its exploration efforts in southern Ontario (First Nickel Inc., news release, April 2, 2013: "First Nickel Reports 2012 Financial and Operating Results").

Nickel-Copper-(Cobalt-PGM) Mineralization: Southeastern Ontario

The First Nickel Inc. airborne geophysical survey data was purchased by the Ontario Geological Survey and released as a data set and a series of maps (Ontario Geological Survey 2010a-e). Outlines of the survey areas are shown on Figure 1.

Table 1. Magmatic nickel-copper occurrences in southeastern Ontario. Numbers correspond to locations shown in Figure 1.

Occurrence Name and Number	Township	Lot/Con.	Significant Mineralization
1. Crowe River	Lake	14-17/3	Zone 53 m long, avg 2.3% Cu /2.1 m (dd, Alsof Mines, 1958)
2. Macassa	Limerick	28-29/6-7	3.5 Mt @ 0.8% Ni, 0.25% Cu, 0.05% Co (dd, Lac Minerals, 1971)
3. Simon	Lyndoch	1/B	S. zone amph gneiss, 230 000t @ 1.09% Cu N. zone gabbro, cp, po, mgt (dd,Young-Davidson Mines, 1965)
4. Bonter	Marmora	27/5	0.45% Ni, 0.26% Cu /54.0 m (dd, Ontario Nickel, 1953)
5. Ellerington	McClintock	18/9	1.36% Ni, 0.2% Cu, 0.098% Co /4.5 m (dd, Slocan Van Roi Mines, 1959); 1.12 g/t Pt, Orogrande Resources, 1997)
6. Sharbot Lake	Olden	10/6	Sulphide zone 228 m long, 46 m wide; 0.3% Ni, 0.3% Cu, 0.14% Co /5.5 m (dd, Sharbot Lake Mines, 1957)
7. Ameranium	Raglan	10/6	Surface sampling 0.5% Ni, 1957
8. Genricks L.	Raglan	17/6	Surface sampling 0.5% Ni, 1957
9. Landolac	Raglan	20/4	Surface sampling 1.9% Cu, 0.85% Ni, 0.07% Co, 2 to 12 ppb Pd (Wilson 1994)
10. Raglan	Raglan	20/4	0.25% Cu, 0.04% Ni /1.37 m (dd, Raglan Nickel Mines, 1956); 81 ppb Pt, 133 ppb Pd (McArthur Mills Expl., 1986)
11. Lingham L.	Tudor	2/3	0.9% Ni, 0.35% Cu (dd, Louada Expl., 1969)

Abbreviations: amph – amphibole; dd – drill hole; mgt – magnetite.

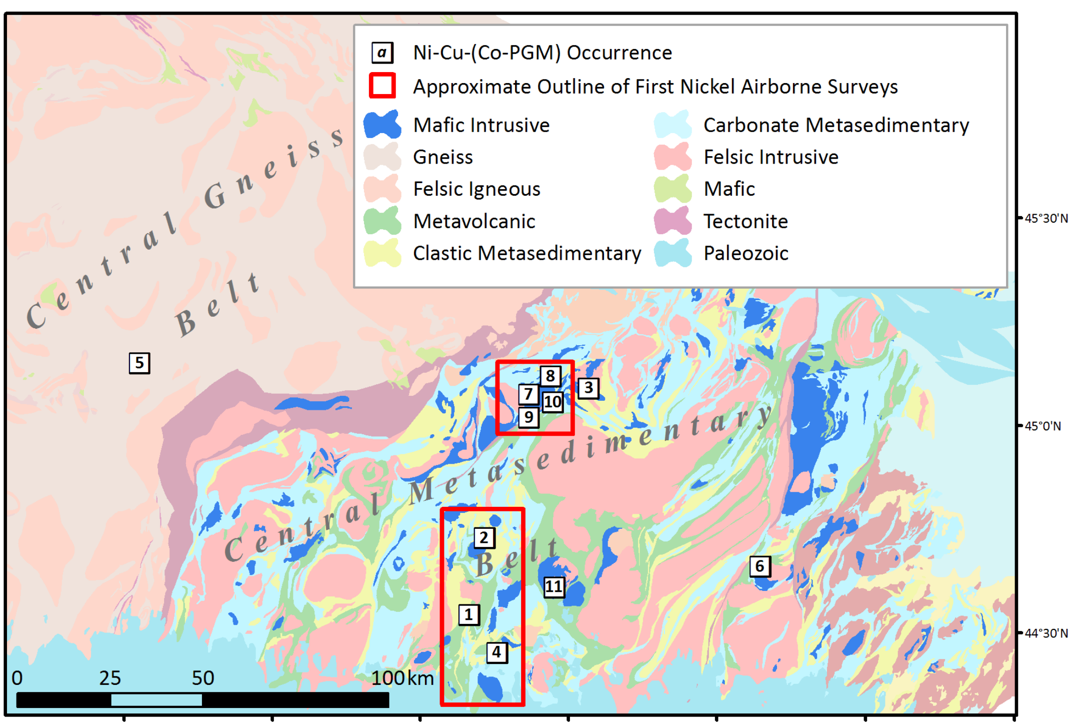

Figure 1. Geology of southeastern Ontario, showing locations of magmatic nickel-copper occurrences associated with mafic intrusions (keyed to Table 1). Geology *from* Ontario Geological Survey (1991).

Nickel-Copper-(Cobalt-PGM) Mineralization: Southeastern Ontario

Geology of the Nickel-Copper Occurrences

Easton (1992) identified 2 suites of gabbroic intrusions within the Central Metasedimentary Belt (CMB) in Ontario: an older "Killer Creek" suite (older than 1270 Ma) and a younger "Lavant" suite (1250–1230 Ma). Nickel-copper mineralization occurs in both suites, and in the absence of geochronological data, the suites may be difficult to distinguish. Examples of occurrences in the CMB and of 1 occurrence in the Central Gneiss Belt (CGB) are described below.

Central Metasedimentary Belt

Mineralization at the Macassa nickel-copper deposit consists of disseminated pyrrhotite, pentlandite, chalcopyrite and pyrite in a band of metapyroxenite within the Thanet Gabbro of the Lavant suite. The main zone, containing a drill-indicated resource of 3.5 Mt grading 0.8% Ni, 0.25% Cu, and 0.05% Co, is about 320 m long, averages 17 m in width, and has been drilled to a depth of 365 m. A second zone, about 1200 m to the south, contains 1.2 Mt @ 0.3% Ni (Carter 1984). Limerick Mines Ltd. drilled 4 diamond-drill holes to confirm results of previous drilling and did ground magnetic surveys on other parts of the property in 2004.

The Raglan Hills Gabbro, which is lithologically similar to the Killer Creek suite (Easton 1992), is predominantly a gabbro-anorthosite intrusion with hornblendite at the margins and pyroxenite to olivine pyroxenite in the central part. The Raglan occurrence consists of a 155 m long, 90 m wide, 6 to 15 m thick lens of disseminated pyrrhotite, chalcopyrite and pyrite hosted by anorthositic metagabbro (Carter 1984). Work to date has focussed on 4 sulphide occurrences discovered in 1956, where First Nickel Inc. reported a diamond-drill core intersection of 0.47% Ni and 0.64% Cu across 5.8 m (Easton, Duguet and Magnus 2011). The presence of nickel-copper mineralization with anomalous PGM values (Table 1) indicates that additional work is warranted in this large intrusive complex.

Central Gneiss Belt

Metagabbroic anorthosite bodies tens of metres wide and tens of kilometres long occur in the Fishog and McClintock domains of the Algonquin Terrane of the CGB. Easton (1992) considers these to be layered anorthositic intrusions with a likely emplacement age of 1400–1300 Ma. Wilson (1994) describes a layered mafic intrusion in Sri Lanka that has been flattened to one-twentieth its original thickness and stretched to 20 times its original length during granulite facies metamorphism, and suggests that the thin, extensive mafic bodies in the CGB have potential for nickel-copper mineralization.

In McClintock Township, Randsburg International Gold Corporation has intersected several nickel-copper-cobalt–bearing sulphide zones with anomalous PGM values (Table 1, Ellerington occurrence) within a 4 to 5 km wide band of anorthosite, gabbro, diorite, and ultramafic rocks flanked by paragneiss (Tweed Resident Geologist Office, MDI file MDI31E07SW00033). Although the occurrence was discovered in 1941, there has been very little exploration work in the surrounding area, and the geology has not been mapped in detail. This occurrence lies within an area mapped by Lumbers and Vertolli (2003) as monzogranite, suggesting that the distribution of mafic rocks in the area may be more extensive than is indicated.

Possible "Indicator Mineral" Occurrences

Most of the southeastern Ontario nickel-copper occurrences are located at, or near, the margins of intrusions, indicating that wall-rock assimilation may have induced sulphide saturation in the magma (Easton and Fyon 1992). Eckstrand (1996) suggests that high zinc content in chromite associated with mafic-ultramafic intrusions may indicate assimilation of zinc-bearing sulphidic metasediments. Similarly, green spinel, which may be iron-rich (hercynite) or zinc-rich (gahnite), may also be the product of sulphidic wall-rock assimilation. Green spinel has been reported in marginal phases of the Chenaux Gabbro (Wilson 1994), the Lavant-Oso Gabbro (Wolff 1985) and in pyroxenites in several locations in the McClintock Township area (Adams and Barlow 1910). A stream sediment anomaly consisting of 23 grains of gahnite from a sample taken within 500 m of the Killer Creek Gabbro, and

Nickel-Copper-(Cobalt-PGM) Mineralization: Southeastern Ontario

a second anomaly of 17 gahnite grains located about 24 km to the south (Felix, Reid and Easton 2006) may be derived from the Killer Creek intrusion.

Summary

Southeastern Ontario nickel-copper occurrences, in some cases with significant copper and anomalous PGM values, are hosted by a variety of mafic to ultramafic intrusive rocks, locations of which are well-defined on geological maps within the CMB and less so within the CGB. In both areas, the intrusions should be examined in more detail for features such as evidence of magma mixing and wall-rock assimilation. Many are located near the contact zones between metasedimentary and metavolcanic rocks: these are favourable sites for the presence of pyritic, rusty schists, which are common in the CMB.

Based upon the relatively low level of previous exploration for magmatic nickel-copper deposits in southeastern Ontario, additional exploration is recommended. Limited airborne electromagnetic and magnetometer surveys by First Nickel Inc. were successful in locating targets for magmatic sulphide exploration and are recommended for areas of mafic intrusions not covered by the surveys shown in Figure 1, particularly in the area of the Lavant Gabbro Complex, the large mafic intrusion located north of the Sharbot Lake nickel-copper-cobalt occurrence (No. 6 on Figure 1).

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HIGHLIGHTS

- **Graphite demand for the battery market is expected to increase by 10 to 15% per year to 2020.**
- **All of Ontario's historical production of graphite is from southern Ontario.**
- **High-quality flake graphite associated with transition zones between carbonate and siliceous metasedimentary rocks in areas of high-grade regional metamorphism.**
- **Association of graphite with sulphide-bearing siliceous gneisses, traceable by magnetic and electromagnetic surveys.**

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Flake Graphite in the Grenville Province of Southern Ontario

The global demand for graphite has increased steadily since 2012. Projections for increased demand to 2020 range from 3 to 5% per year for traditional applications such as refractories, lubricants, foundries and recarburizing, to 10 to 15% per year for batteries (Shaw 2015). The projected increase in demand for high-purity flake graphite is based upon increasing use of lithium-ion and other graphite-component batteries in electric vehicles, cell phones and energy storage systems.

Total consumption of natural graphite in the United States in 2015 was 55 500 tonnes. Tesla Motors' proposed lithium-ion battery "gigafactory", expected to begin production in 2017, is estimated to require up to 95 000 tonnes of flake graphite per year at full production. There are currently no producing graphite mines in the United States and only 2 in Canada (British Columbia and Quebec), producing a total of 30 000 tonnes of graphite per year (Olsen 2016).

Historical Graphite Production and Exploration in Southern Ontario

Graphite mining in southern Ontario began in 1870 at the Globe graphite mine and continued until the closure of Canada's largest graphite producer, the Black Donald Mine, in 1954. The Black Donald produced a total of about 87 000 tonnes of graphite, making it one of the most important producers of flake and amorphous graphite in North America. Graphite production, totalling less than 1000 tonnes, was also obtained from 3 other mines, the Tonkin-Dupont, National Graphite, and Timmins mines, during this period. Locations of the mines are shown on Figure 1.

More recent production of graphite in southern Ontario has come from the Kearney Mine, which operated from 1989 to 1994, during which time it produced 17 000 tonnes of flake graphite concentrate from almost 1 million tonnes of ore.

An increase in the price of flake graphite in the 1980s generated new exploration activity, primarily on previously known occurrences, which resulted in the definition of 2 significant deposits in the Central Gneiss Belt (Kearney and Bissett Creek, see Figure 1). More recent exploration in the Central Metasedimentary Belt resulted in the discovery of new graphite occurrences in the Bobcaygeon area and at the Malcolm prospect, an extension of the previously known Little-Bryan occurrence (*see* Figure 1). Table 1 shows a list of graphite prospects with resource estimates in southern Ontario.

Flake Graphite: Grenville Province, Southern Ontario

Table 1. Graphite prospects with resources, southern Ontario. NI-43-101-compliant resource: Measured and Indicated (M&Ind), Inferred (Inf); all others non-NI-43-101-compliant.

Property	Township	Resource	Reference
Northern Graphite (Bissett Creek)	Maria	69.8 Mt@ 1.74% Cg (M&Ind) 24.0 Mt@ 1.65% Cg (Inf)	www.northerngraphite.com
Ontario Graphite (Kearney)	Butt	51.5 Mt@ 2.14% Cg (M&Ind) 46.8 Mt@ 2.0% Cg (Inf)	www.ontariographite.com
Victoria Graphite (Portland)	Bastard	295 000 t @ 6% Cg	MacKinnon and LeBaron 1992
Kirkham Graphite (Stewart Lake)	Bedford	1.6 Mt @ 9.5% Cg	MacKinnon and LeBaron 1992
Globe Graphite	North Elmsley	50 000t@7% Cg	MacKinnon and LeBaron 1992
Timmins Graphite	North Burgess	1.0Mt@8% Cg	MacKinnon and LeBaron 1992
National Graphite	Cardiff	1.4Mt@4.1% Cg	Hewitt 1965

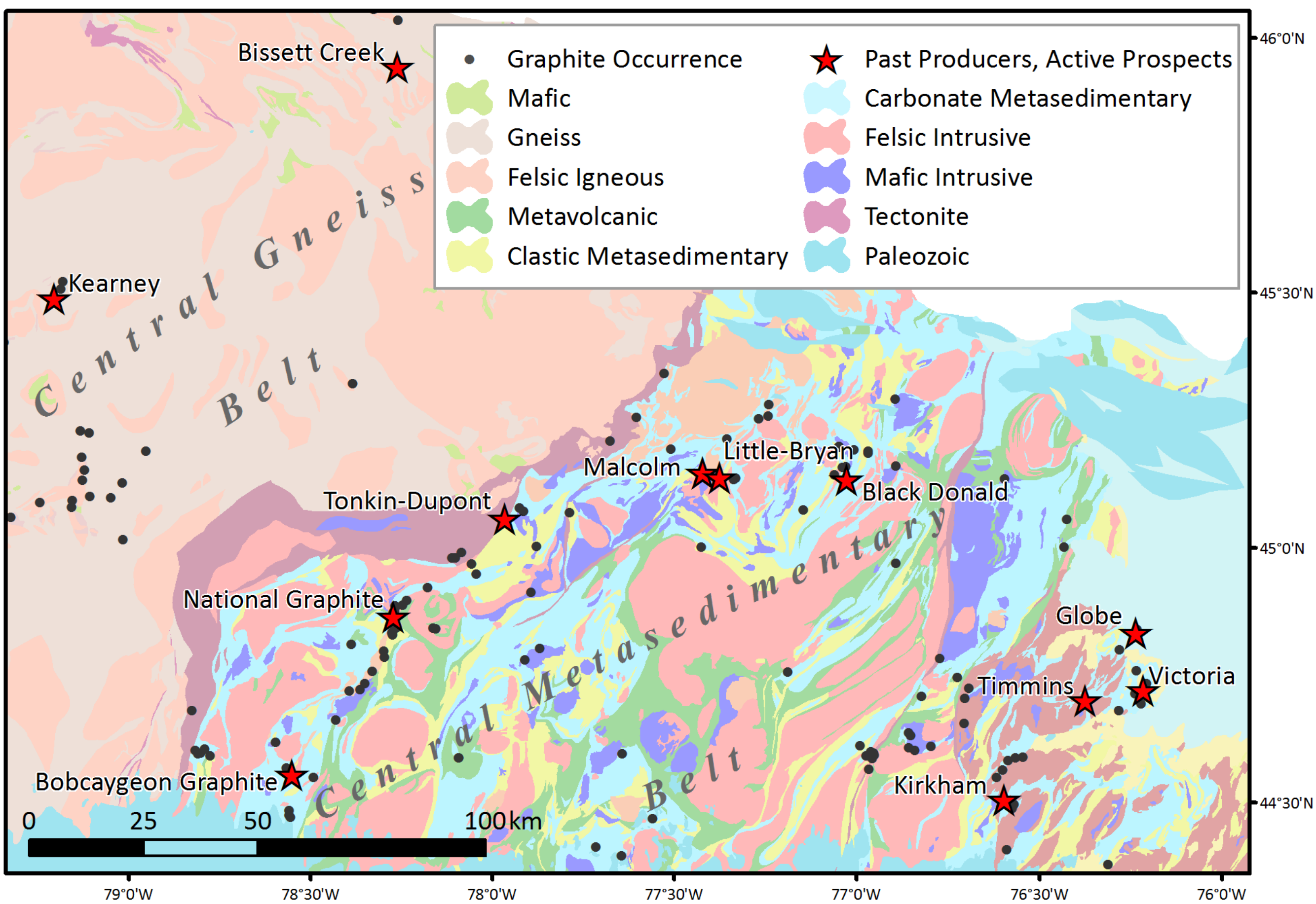

Figure 1. Locations of southern Ontario graphite occurrences, past-producing mines, and active prospects (geology *from* Ontario Geological Survey 1991).

Flake Graphite: Grenville Province, Southern Ontario

Geology of the Graphite Occurrences

Graphite occurs in both the Central Gneiss Belt (CGB) and the Central Metasedimentary Belt (CMB) of southern Ontario (*see* Figure 1).

The CGB is dominated by quartzofeldspathic gneisses, intruded by a variety of mafic to felsic plutonic rocks. Metamorphic grade is generally upper amphibolite to granulite. The CMB hosts rocks of the Grenville Supergroup, a sequence of metavolcanics, marbles, quartzites, calc-silicates, paragneisses, and amphibolites, all intruded by mafic to felsic plutonic rocks. Metamorphic grade ranges from greenschist in the south central area to upper amphibolite in the north and west (Bancroft Terrane) and upper amphibolite to granulite in the southeast. (Frontenac Terrane).

Graphite in the Central Gneiss Belt

The 2 major graphite deposits of the CGB, Bissett Creek and Kearney, consist of disseminated, large-flake graphite in rusty-weathering, banded, biotite-rich quartzofeldspathic paragneiss with minor pyrite and pyrrhotite. Non-graphitic gneiss includes pale grey, quartz-rich, pale to dark green-grey, diopside-rich and brownish biotite-amphibole-garnet–bearing varieties (Figure 2).

Although the original character of the host rock in most cases has been obliterated by the high degree of metamorphism involved, the overall composition, mineralogy and geological setting indicate a sedimentary rock, usually quartz-rich, as the host. The presence of calc-silicate minerals in some of the gneissic units suggests that there may have been a carbonate component, either as a cement or as interbedded layers in the siliceous sediments.

Figure 2. Bissett Creek deposit, pit in high-grade graphite zone, rock face 3 m high; inset, at bottom right of photo, shows hanging wall of barren, quartz-feldspar-biotite gneiss with granitic leucosomes.

Flake Graphite: Grenville Province, Southern Ontario

Graphite in the Central Metasedimentary Belt

Graphite occurrences within the CMB are concentrated in areas dominated by highly metamorphosed sedimentary rocks of the Bancroft Terrane in the northwest and the Frontenac Terrane in the southeast (Figure 1). All occur either within crystalline marble or siliceous metasedimentary rocks within or close to transition zones between carbonate-dominated units and siliceous paragneisses, indicating a shallow, nearshore marine depositional environment favourable for the accumulation of organic material, which is the most probable source of carbon in these deposits. For example, the Black Donald mine stratigraphy consists of a graphitic marble unit containing minor calc-silcates and chlorite, overlain by siliceous marble containing quartz, phlogopite, diopside, scapolite and tremolite; and underlain by quartzite and limy quartzite, followed by beds of white to grey marble. The quartzites are rich in pyrite and pyrrhotite and weather rusty brown (Hewitt 1965).

Another example of graphite occurring with siliceous, pyrrhotite-rich metasedimentary rocks is seen at the Little-Bryan and Malcolm properties in Lyndoch Township. Two conductive (graphite-pyrrhotite) zones (Figure 3) occur within a southerly dipping sequence of metasedimentary rocks, including calcitic and dolomitic marble and hornblende-quartz-feldspar-biotite paragneiss. The southern graphite-pyrrhotite unit occurs within a transition zone between carbonate-rich units to the north and siliceous paragneiss to the south. A significant difference between the graphite mineralization observed on the Malcolm and the Little-Bryan properties is that the Malcolm zone includes marble-hosted graphite with little to no pyrrhotite in addition to the quartz-rich, rusty, graphite-pyrrhotite–bearing gneiss of the Little-Bryan zone.

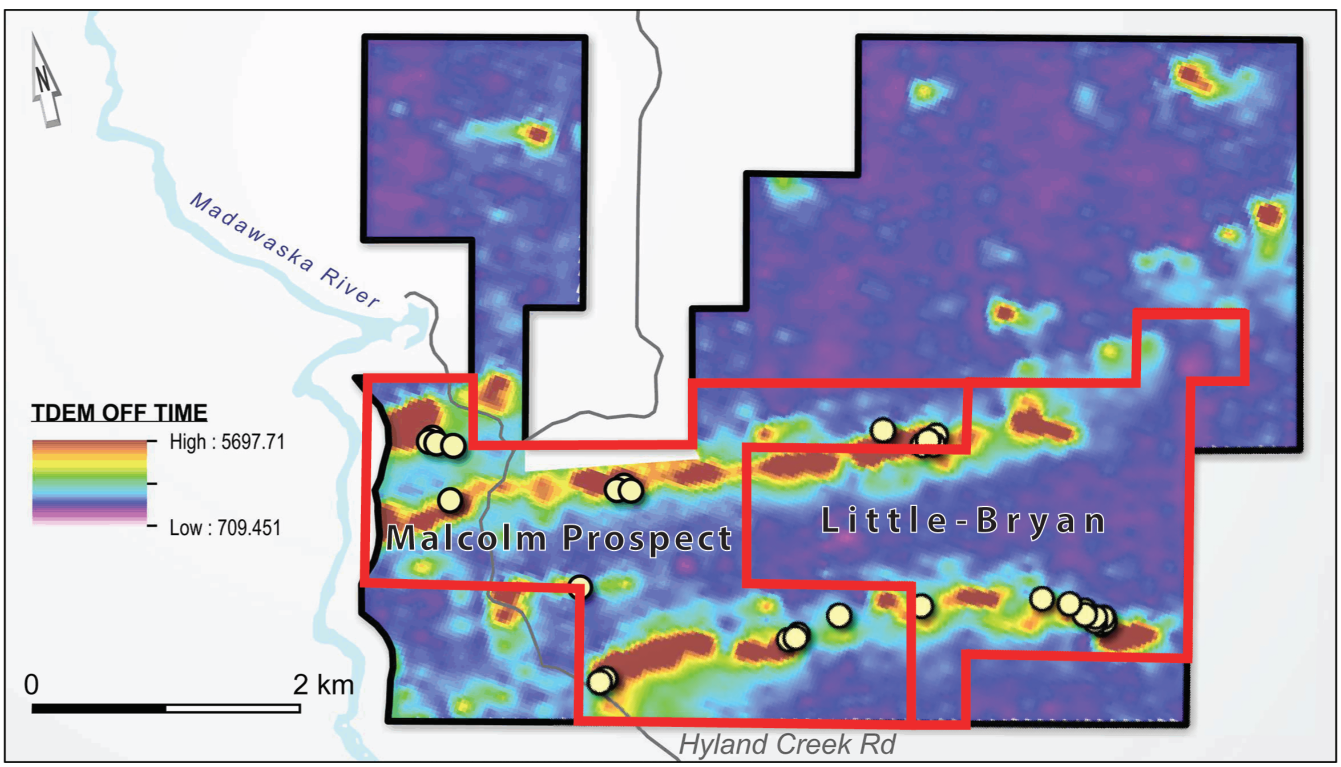

Figure 3. Airborne time domain electromagnetic (TDEM) survey results, showing linear conductive zones, graphite-bearing sample locations (yellow circles outlined in black) and the location of the Malcolm and Little-Bryan claim blocks, outlined in red (*modified from* Standard Graphite Corp., "Standard Graphite Completes TDEM Survey on Little Bryan", news release, February 21, 2012; www.standardgraphite.com, under "news", "2012"). The claim blocks are located approximately 8 km west-northwest of the community of Griffith.

Flake Graphite: Grenville Province, Southern Ontario

In 2015, the Ontario Geological Survey discovered 5 new graphite occurrences associated with sulphide-rich schists and gneisses in the Centennial Lake area, about 13 km southwest of the Black Donald Mine and within the same general stratigraphy. The occurrences are located along the edges of regional magnetic anomalies shown on the Renfrew area aeromagnetic survey (Ontario Geological Survey 2014) and are described by Duguet, Duparc and Mayer (2015).

Recommendations for Exploration

Exploration for graphite deposits is recommended in both the CGB and the CMB of the Grenville Province in southern Ontario.

Most of Ontario's past graphite production has come from mines within the CMB, where favourable stratigraphy consisting of transition zones between marble and siliceous metasedimentary rocks hosts flake graphite deposits in areas of upper amphibolite to granulite facies metamorphism. Linear magnetic anomalies may indicate zones of pyrrhotite mineralization that have been observed to occur with, or in close spatial association with, graphite mineralization. Airborne EM surveys have also been successful in locating zones of pyrrhotite and graphite mineralization.

Graphite mineralization in the CGB is associated with sulphide-bearing quartzofeldspathic gneiss sequences where calc-silicates may indicate former carbonate units that may have been a source of organic material. The CGB deposits discovered to date are very large tonnage, relatively low-grade deposits which produce a high-purity, large-flake, high-value concentrate. A regional bedrock map by the Ontario Geological Survey (OGS 1991) identifies areas of the CGB that are underlain predominantly by paragneiss and migmatite. Airborne magnetic surveys in these areas may be useful in locating zones of pyrite-pyrrhotite mineralization that are associated with graphite in the known deposits. Narrow zones of higher grade graphite and/or sulphide mineralization may respond to EM survey methods.

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Notes

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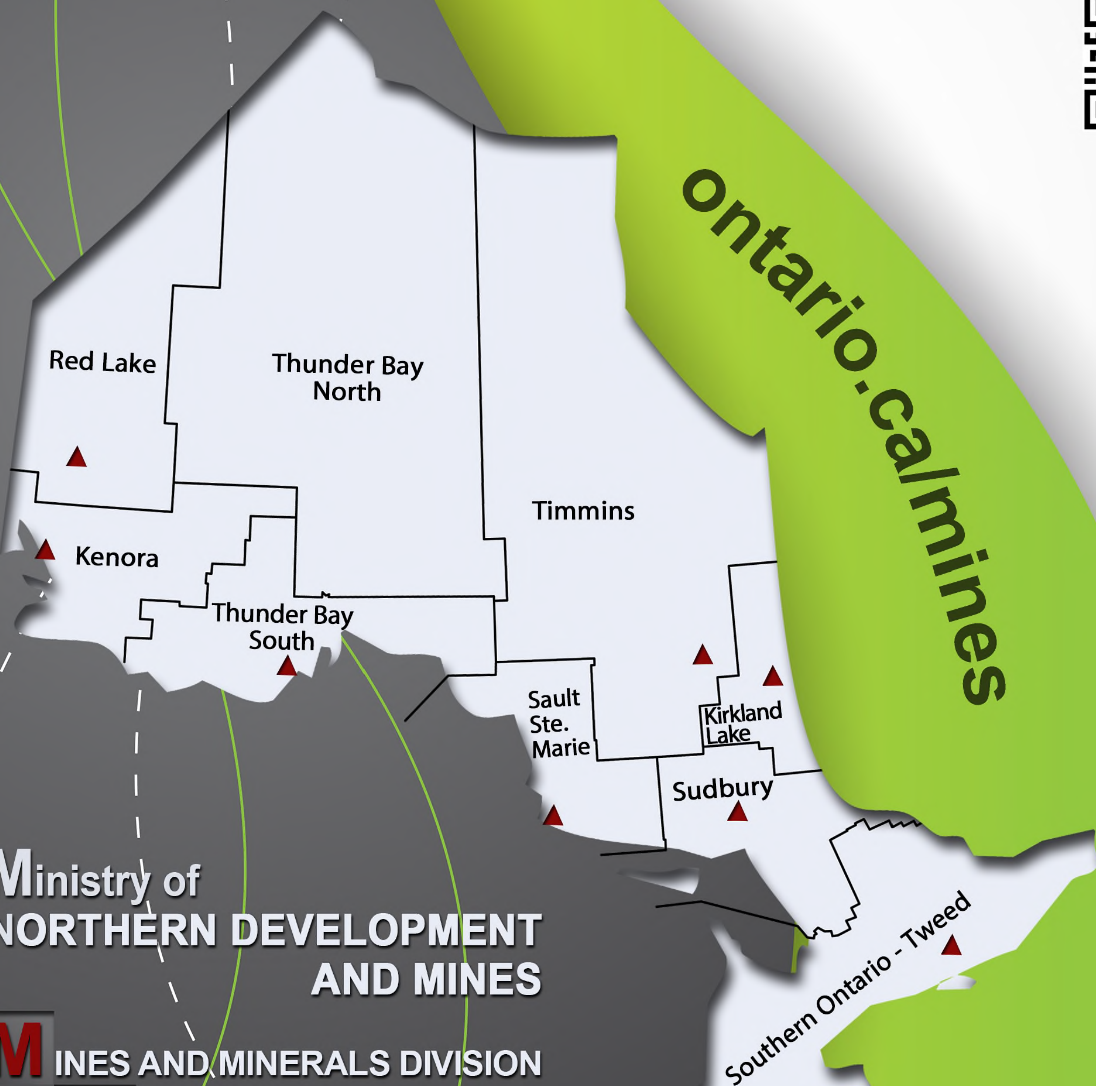

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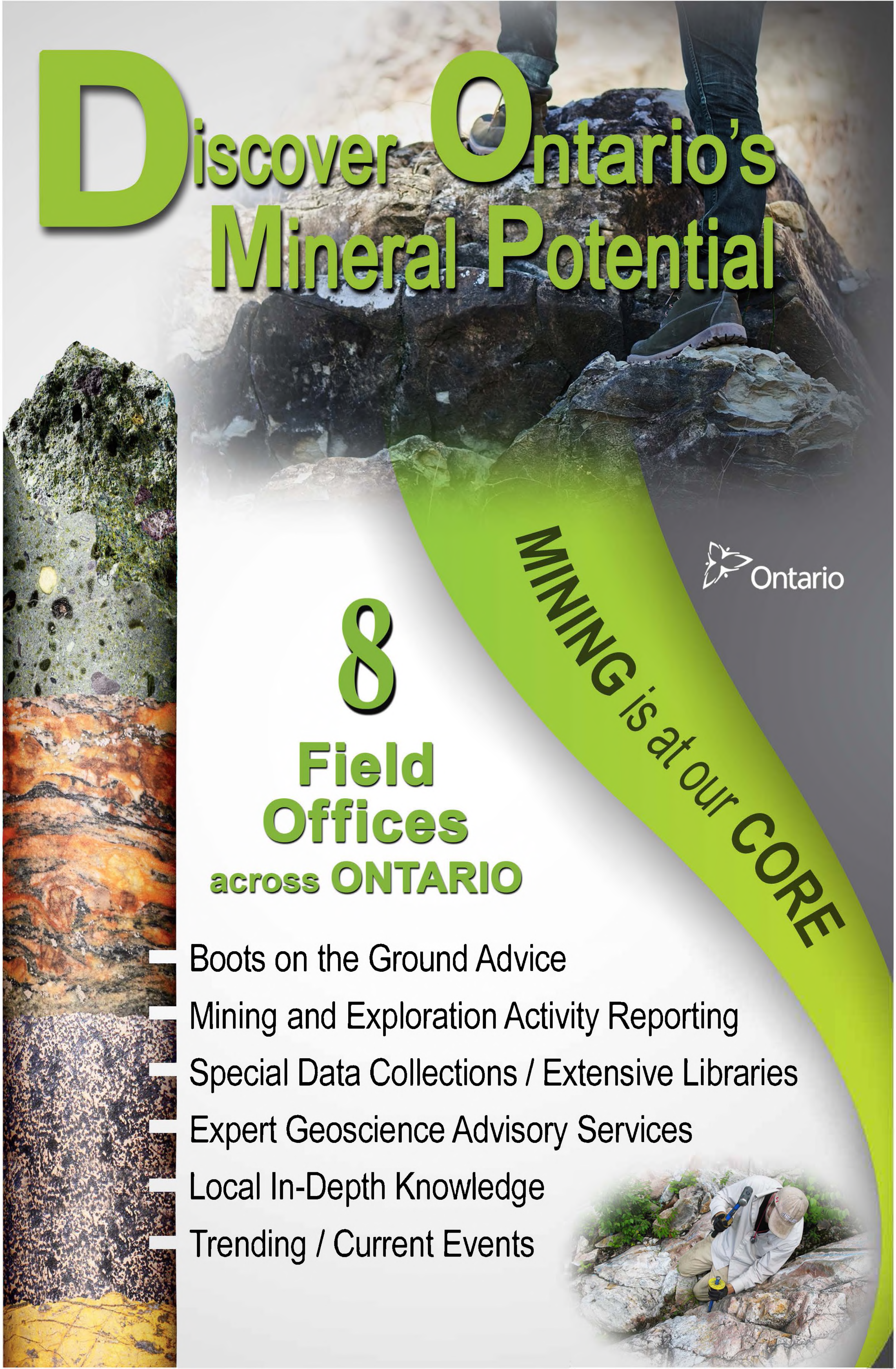
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