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Significance of indicator minerals from till and esker samples, NTS 75-I, 75-J, 75-O, 75-P (Mary Frances Lake – Whitefish Lake– Thelon River area), Northwest Territories

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Introduction

This report presents indicator mineral picking counts from heavy mineral concentrates for surficial sediment diamicton (till) and esker (sand) samples that were collected in the 2012 summer field season. The study area is bounded by Mary Frances Lake (to the northwest), Whitefish Lake (to the southwest) and the Thelon River (to the east), and lies to the southwest of the Thelon wildlife sanctuary and to the east of the area of interest for Thaidene Nene (Fig. 1). The area encompasses approximately 3,500 km^2 (parts of NTS 75-1, 75-J, 75-O, 75-P).

J.B. Tyrrell made the first geological investigation of the area in 1896 (Tyrrell, 1896). Additional geological investigations accompanied the survey work by J.W. Tyrell (Tyrell, 1902). Bedrock geology and surficial materials where not subsequently examined systematically until the mid-1950s, when 1: 1-million scale bedrock and surficial studies were undertaken during GSC's Operation Thelon (Wright, 1957, Craig, 1964; Wright, 1967). Other than small areas mapped in detail by industry, the bedrock geology is poorly understood (Fig. 2). Studies related to uranium mineralization associated with the Thelon Basin have been published sporadically over the past 25 years (Davidson and Gandhi, 1989; Beyer et al., 2010). The surficial geology was re-examined in the 1980's via air-photo interpretation by Aylsworth and Shilts (1989a, b; see Fig. 3). A regional overview of the bedrock and surficial geology west of the study area, prepared for the Thaidene Nene Mineral and Energy Resource Assessment (MERA) study, are presented in Kjarsgaard et al. (2013a), and Kerr et al. (2013a), respectively.

Sample design and collection protocols

Surficial sediment samples collected in 2012 (165 samples) consisted of 60 esker samples and 105 till (diamicton) samples. A till sample was taken approximately every 100 square km, based on a 10 km x 10 km grid. An esker sample was taken approximately every 10 km along selected/major esker ridge crests. Sample sites are shown in Figure 4, and include 7 sites located just east of the Thaidene Nene study area that were collected during the MERA project (Kjarsgaard et al., 2013b; Kerr et al., 2013b; Sharpe et al., 2013). Coordinates for sample locations are listed in Appendix A1. At each till site a 15 kg sample was taken for heavy mineral recovery, a companion 1 kg sample for geochemical analysis (see Kjarsgaard et al., 2013c), 50 pebbles for pebble counts, and a 100 g sample for pXRF analysis (see Plourde et al., 2013). The sampling design and density replicates the protocol developed and used for the Thaidene Nene MERA study to the east of the study area (Kjarsgaard et al., 2013b). Each sample site was photographed, both for sample context and general landscape context (Fig. 5). Paleoflow indicators (striations, s-forms, etc.) were measured where bedrock was present adjacent to the sampling site. Standardized information about the sediment sample and the sampling site was digitally recorded on a Trimble Yuma utilizing a custom designed database. The location of all samples was captured with a global positioning system (GPS). Sampling teams consisted of two members: an experienced GSC geologist and an assistant.

Bedrock Geology

The bedrock in the study area is complex, with major rock units from three geological domains: the Rae Domain of the Churchill Province, the Taltson – Thelon magmatic-tectonic zone, and the Thelon basin. In the Rae, bedrock lithologies are dominanted by two Archean units: (1) undifferentiated gneiss, granite and migmatite, and; (2) gneisses derived from intermediate to felsic protoliths (i.e., granitic, Fig. 2). Archean migmatite, amphibolite and gneiss derived from intermediate to mafic protoliths are observed in the northwest corner of the study area (Fig. 2) in the vicinity of Radford, Williams and Mary Frances lakes (Fig. 1). In general the rock is strongly deformed, displaying evidence of multiple deformation events, with the exception of some late-Archean(?) granitic and tonalitic dykes and stocks that are weakly deformed. The Archean rocks have been intruded by Paleoproterozoic massive to weakly deformed plutons and plugs ranging in composition from gabbro/diorite to anorthosite/norite, to biotite-granite and quartz-monzonite. In the extreme northwest corner of the study area strongly deformed mylonite/tectonite, and schist and gneiss of the Taltson magmatic zone, as well as granitic gneisses and granitoids of the Thelon tectonic zone are observed. Bedrock geology west of the study area is described in Kjarsgaard et al., 2013a. At the eastern edge of the study area, sedimentary rocks of the Thelon Basin overlie the basement rocks. Sandstone and pebbly sandstone of the Barrenlands Group are widespread; they overlie quartz sandstone of the Amer Group as well as pelite and graphite-pelite inferred to be of Amer equivalent age (Fig. 2; Pehrsson et al., in press).

Mineralization

Two mineralized areas are known adjacent to the study area (data from NORMIN.DB). The Boomerang Lake area to the south (Fig. 2, #269) consists of a drilled showing, drilled prospect and a number of occurrences. These are unconformity-related uranium style mineralization, and have associated Au, Ag, and base metals, +/- PGE's (Davidson and Gandhi, 1989; Beyer et al., 2010). To the north of the study area are two showings (Fig. 2, #1351, #1352) that have U, and U plus Cu, respectively, in vein style mineralization within orthogneiss or paragneiss host rocks.

Regional Surficial Geology

The study area lies in the Keewatin Sector of the former Laurentide Ice Sheet (LIS) west of the Keewatin Ice Divide (KID, Lee et al., 1957; Lee, 1959). Terrain is low relief and consists of flat plains to rolling hills, elongate in an east to west orientation, parallel to regional flow from the KID west to Great Slave Lake (Prest et al., 1968; Shaw et al., 2010). Surficial features (Fig. 3) include eskers, ribbed moraines, and streamlined landforms that form a roughly concentric zonal pattern around the former KID (Aylsworth and Shilts, 1989a, b). Till, of varying thickness (~1-50 m) and eskers (sand) are the dominant surficial sediments. Reconnaissance work by Craig (1964) revealed common roches moutonnees, less common smooth rock knobs with sediment ridges, and crag-and-tail, whereas bedrock striae were poorly preserved. Drumlins (and drumlinoids) show wide variations in form. Transverse ridges, with boulder-covered ridge-tops can occur at right angles to drumlin (and drumlinoid) long axes. Predominant flow is roughly east to west; a secondary, older flow direction to the southwest is recorded at a few sites (Fig. 6). Indicator mineral samples have been taken from a number of different terrain architectural elements. For example, diamicton interpreted as till was sampled from drumlins, corridors, and terraces. These architectural elements may have different processes for erosion, transport and deposition of sediment and indicator minerals. A detailed description of terrain architecture is available in Sharpe et al. (2013, in prep.). The most recent surficial geology maps, based on air photo interpretation are available by NTS map sheet: NTS 75-O (Kerr et al., 2013c), 75-J (Kerr et al., 2013d), 75-I (Stea and Kerr, in press), 75-P (Dyke and Kerr, in prep).

Methods

At Overburden Drilling Management Ltd. Processing laboratory, a 500 g split was taken from all samples as future reference material. Samples were then wet sieved at 2.0 mm. The <2.0 mm fraction was run over a concentrating table and the visible gold grains and platinum group minerals (PGM's) were counted and classified (Appendix A2) as to degree of wear (i.e., rounding and sphericity, a proxy for distance of transport). Gold grains were further refined by micro-panning. The table concentrate was then dried, weighed and sieved to >0.25 mm. The <0.25 mm heavy mineral fraction of all samples was archived. The 0.25 - 2.0 mm concentrate material was processed using heavy liquids (acetone diluted methylene iodide, S.G. of 3.2) to produce a heavy mineral concentrate that underwent ferromagnetic separation to remove magnetite. The retained non-ferromagnetic heavies were cleansed with oxalic acid to remove limonite stains that would otherwise impede mineral identification. The samples were subsequently sieved at 0.25 mm, 0.5 mm and 1.0 mm. The 0.25 - 0.5 mm fraction was further sorted electromagnetically into mineralogically simpler non-paramagnetic and weakly, moderately and strongly paramagnetic fractions (Appendix A3) to ease indicator mineral picking.. The mineral processing flow sheet is illustrated in Figure 7.

All fractions were picked for indicator minerals and the picked grains were stored in labeled vials according to size and mineral type. Any difficult or ambiguous grains underwent additional analysis with the aid of qualitative SEM (Scanning Electron Microscope) to facilitate identification. Indicator mineral counts for all samples in the 0.25 – 0.5 mm, 0.5 – 1.0 mm and 1.0 – 2.0 mm fractions are listed in Appendix A4. Table 1 summarizes the minerals picked, the number of grains picked per mineral, and a possible parageneses.

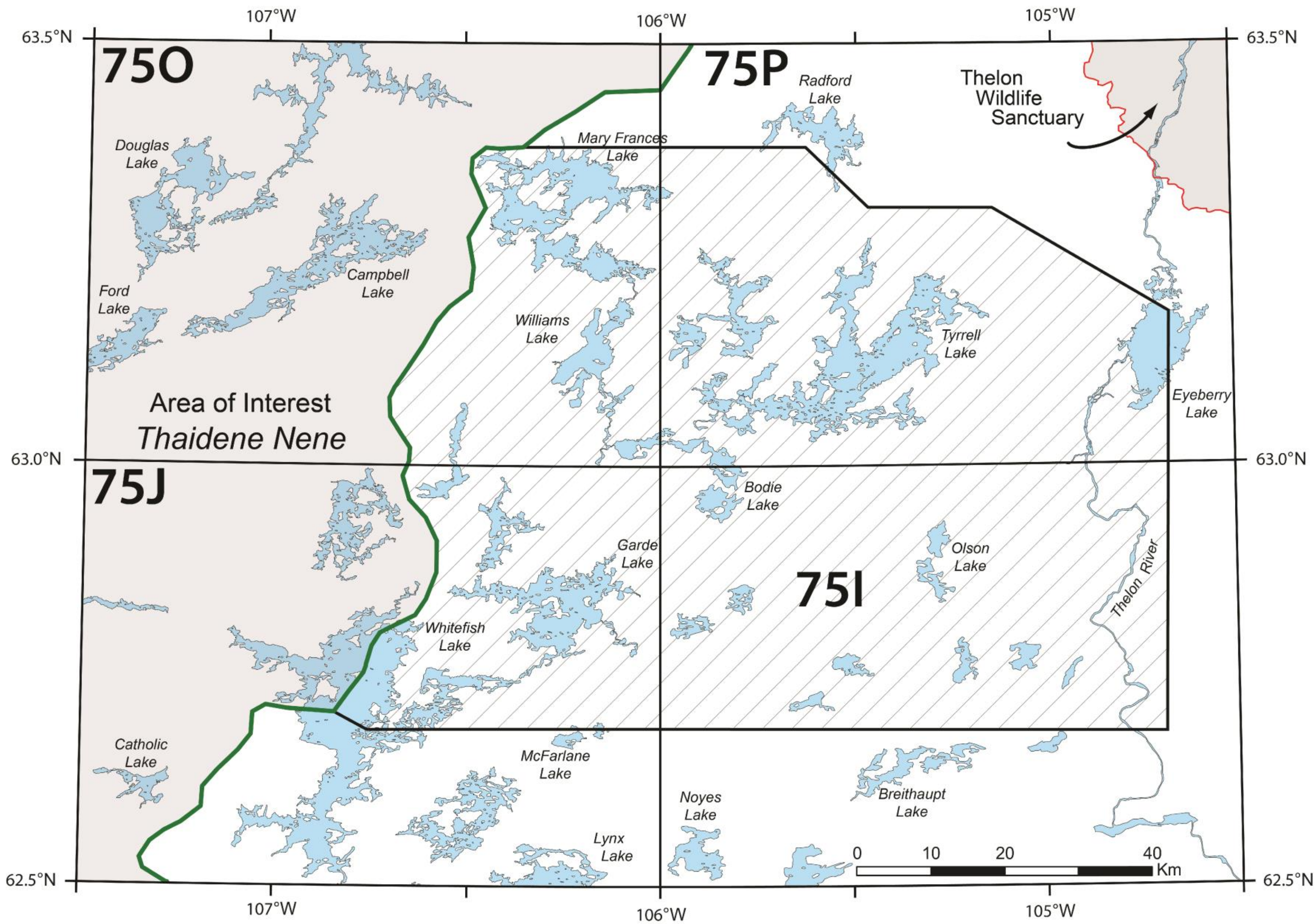

Figure 1. Location map of the study area (cross hatched), showing the major lakes and rivers, and location of the Thelon Wildlife Sanctuary (red outline, grey shading), and area of interest for Thaidene Nene (green outline, grey shading).

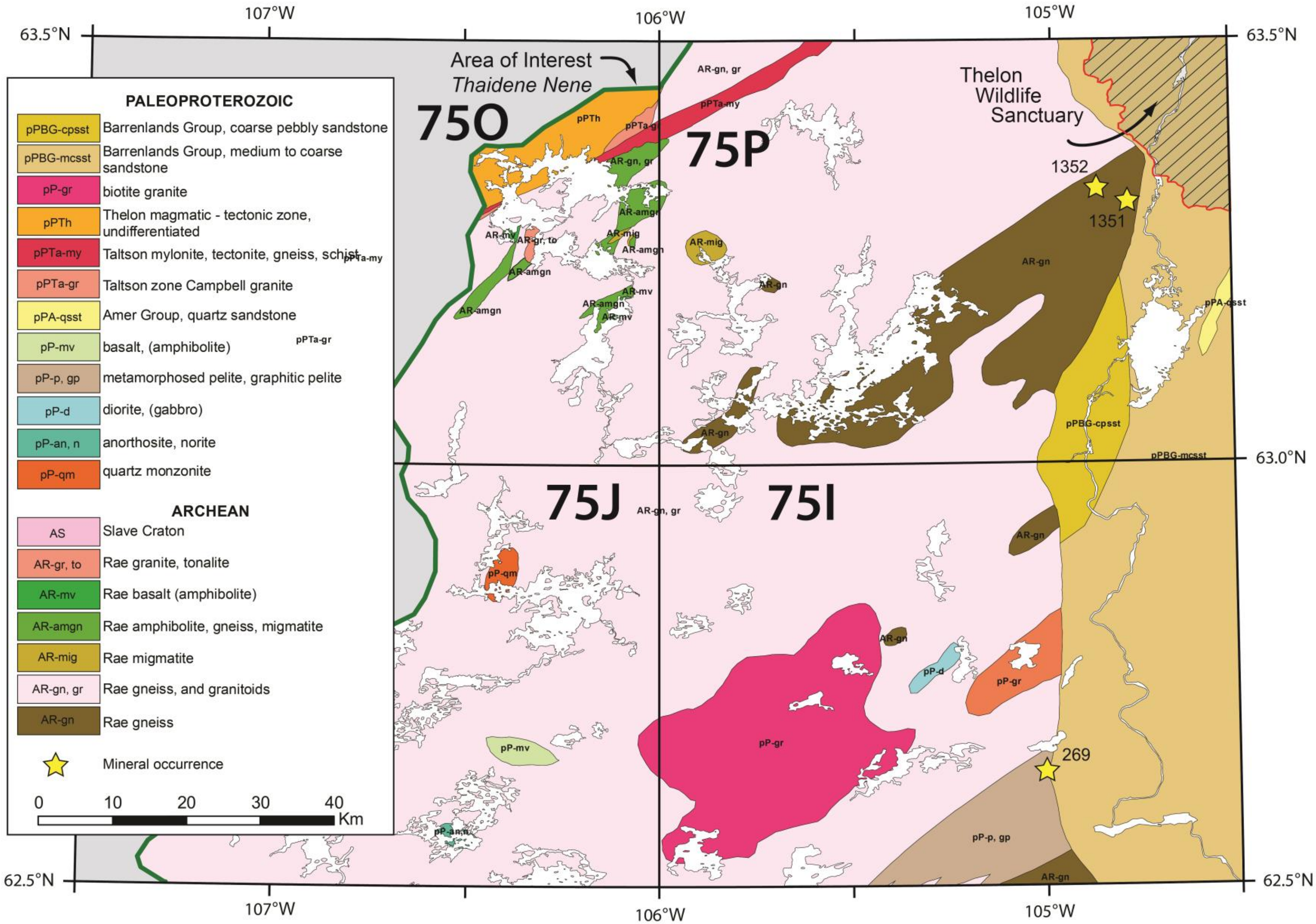

Figure 2. Bedrock geology map (1: 1-million scale), with mineral showings. West half from Kjarsgaard et al. (2013a); east half modified after Pehrsson et al. (2013, in press). Location information and data for mineral occurrences from NORMIN.DB (Northwest Territories Geoscience Office, Yellowknife).

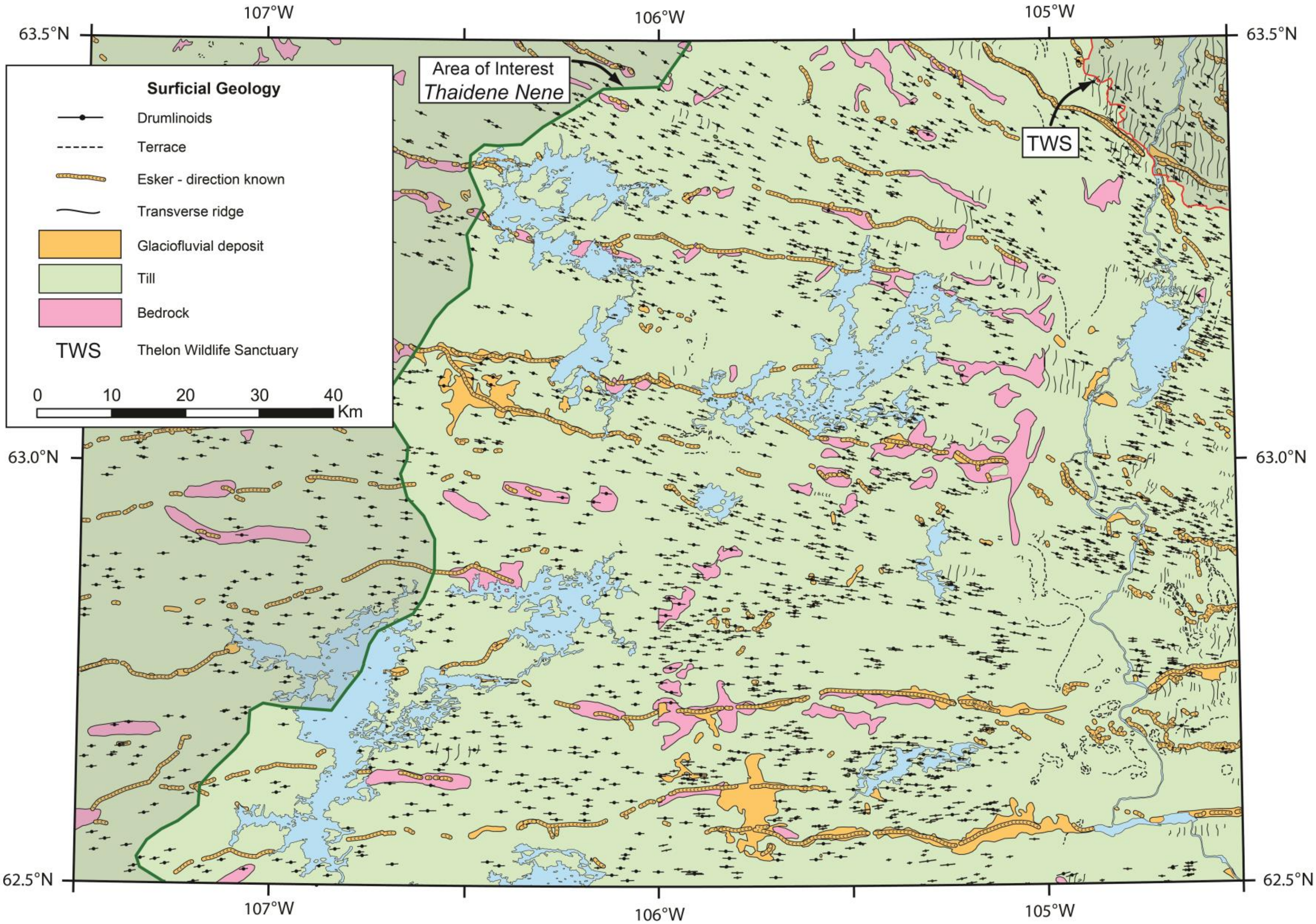

Figure 3. Simplified surficial geology, modified and updated from Craig (1964) and Aylsworth and Shilts (1989b). TWS = Thelon Wildlife Sanctuary.

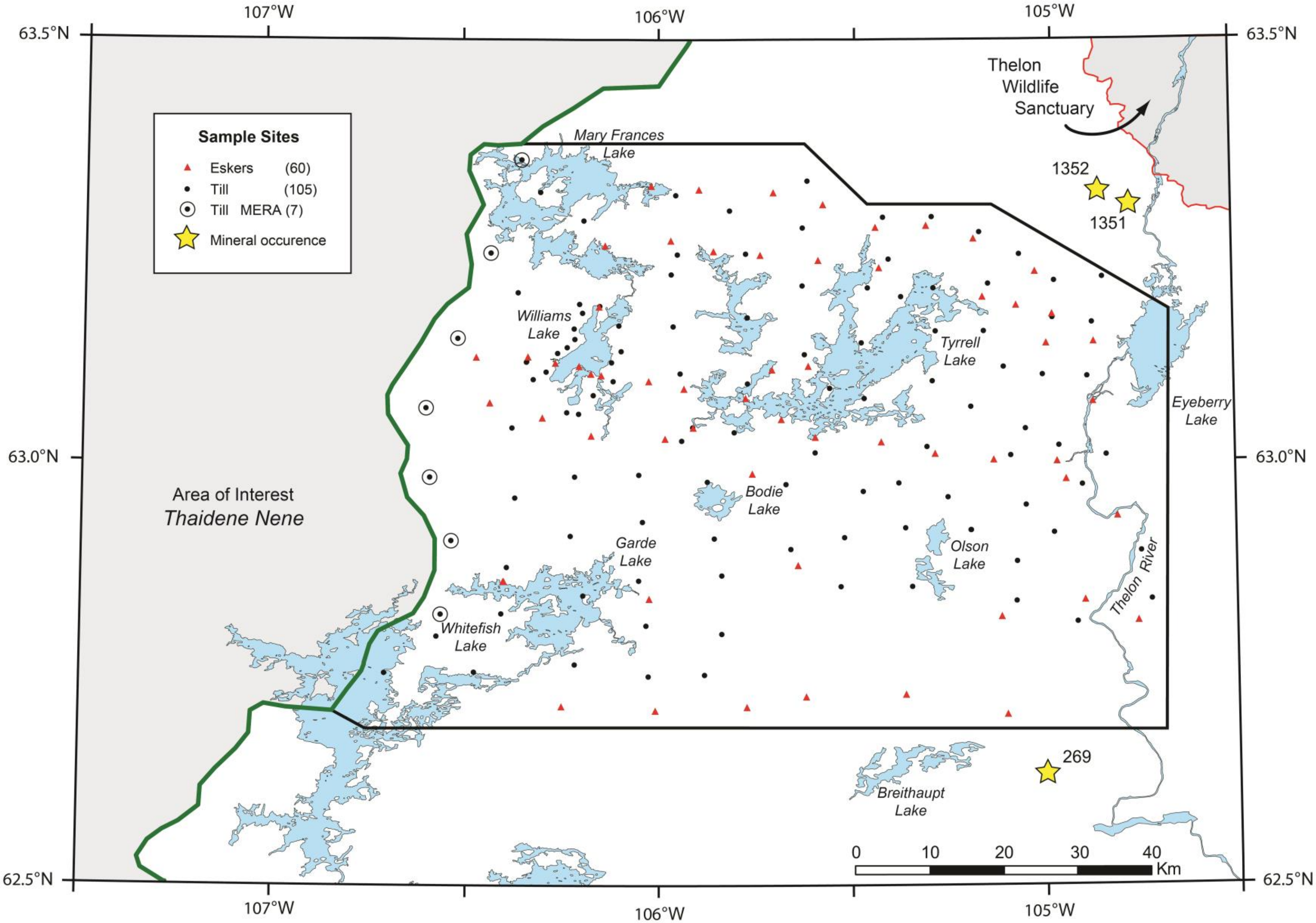

Figure 4. Sample map, with locations of till and esker sample sites. Till samples, black dots; esker samples, red triangles. Location information and data for mineral occurrences from NORMIN.DB (Northwest Territories Geoscience Office, Yellowknife).

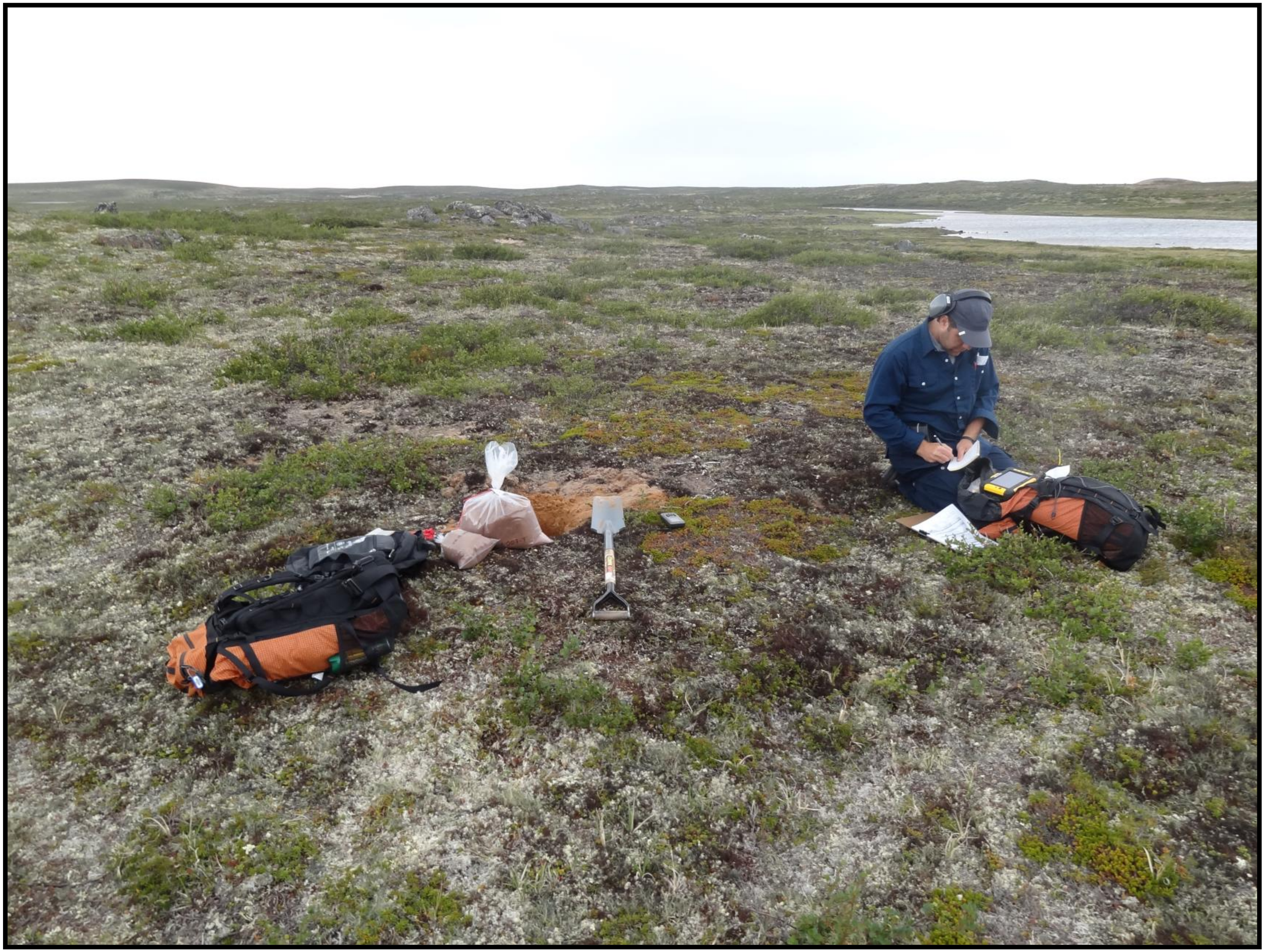

Figure 5. Typical till sample site with a 15 kg and 1 kg sample in a plastic bag. This site is located in an erosional esker corridor with thin till (<1m) on bedrock; note boulder concentration on bedrock exposed in the background.

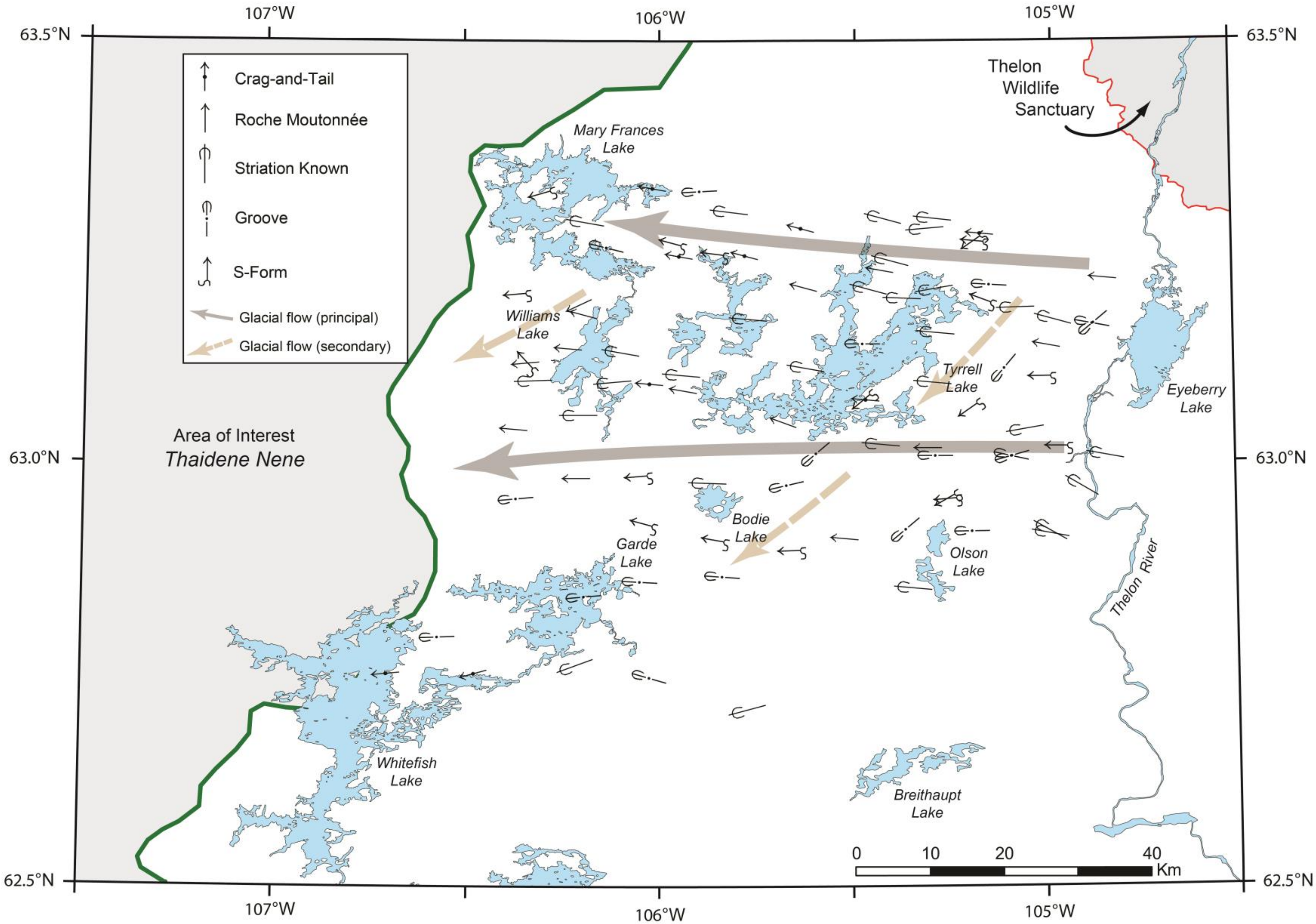

Figure 6. Glacial striae, groove, crag-and-tail, roche moutonnée and S-form data, with generalized flow direction.

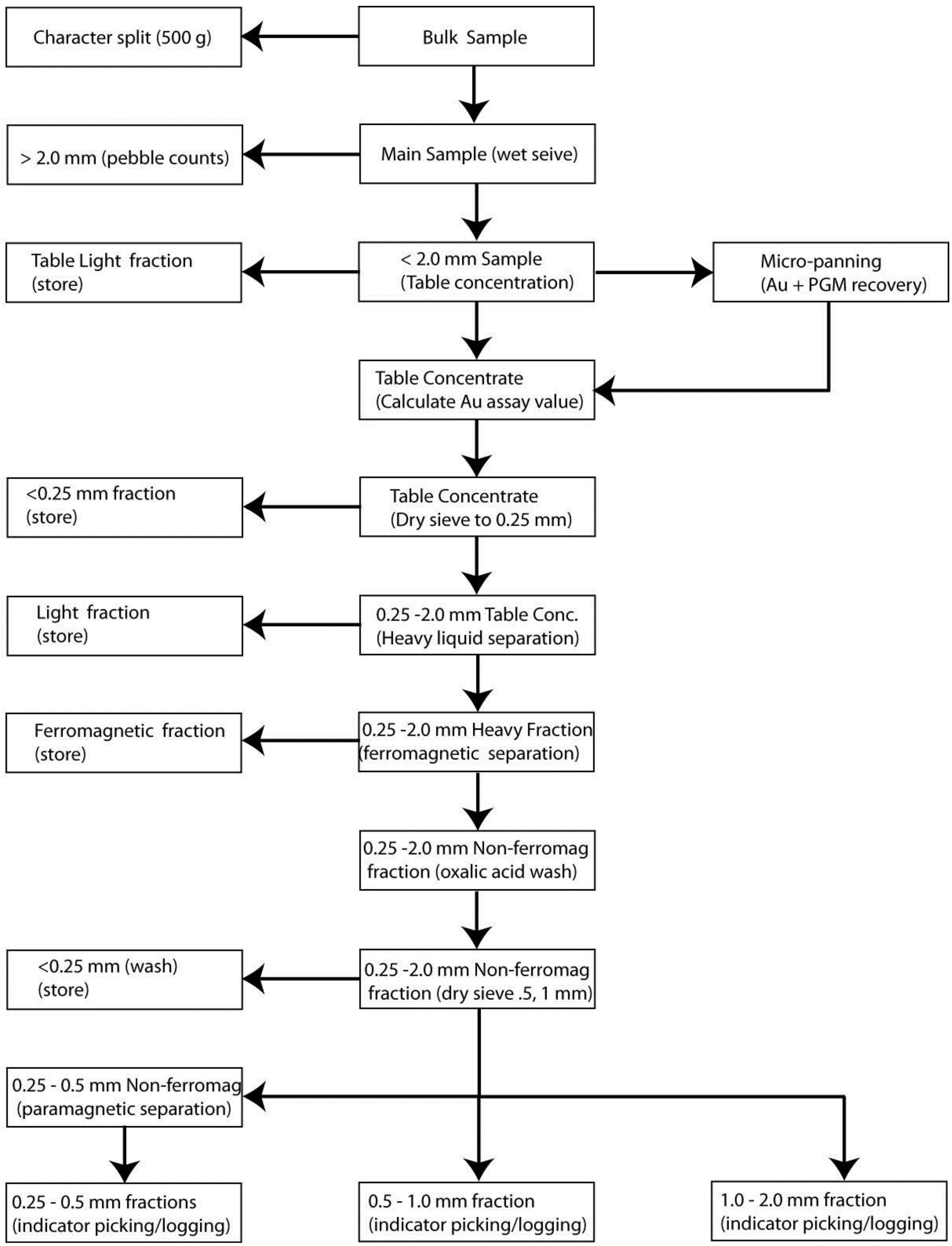

Figure 7. Mineral processing flowsheet.

Mineral	Paragenesis	# of grains
Barite	vein polymetallic SEDEX gangue	~500
Chalcopyrite ($CuFeS_2$)	massive sulphide, vein polymetallic, U-Cu sandstone IOCG deposits	1
Chromite ([Mg, Fe]Cr_2O_4)	ultramafic rocks, kimberlite	981
Corundum & ruby corundum & sapphire corundum	alkali syenite pegmatites, silica poor metamorphic rocks	40
Cr-diopside	Kimberlitic, mafic & ultramafic rocks and their metamorphosed equivalents	2
Eclogitic garnet	eclogite, may include crustal garnet	2
Cr-pyrope	Kimberlite and other deep seated magmas, peridotite	3
Gold	gold depostis, auriferous massive IOCG sulphide deposits	19
Kyanite	high pressure metamorphic rocks	3
Ilmenite	wide variety of igneous and metamorphic rocks; highly abundant in gabbro, norite, anorthosite, variable in kimberlite	9
Low-Cr diopside (Ca[Mg,Fe]Si_2O_6; <.5wt%Cr_2O_3)	mafic & ultramafic rocks and their metamorphosed equivalents	559
Mn-Epidote	medium grade basic metamorphic rocks, hydrothermally altered rocks	33
Olivine ($(Mg, Fe)_2SiO_4$)	ultramafic and mafic rocks, kimberlite	278
Hercynite ($FeAl_2O_4$) & spinel hercynite	basic and ultrabasic igneous rocks, metamorphosed pyroxenites	3
Molybdenite (MoS_2)	high temperature hydrothermal deposits, associated with chalcopyrite, sheelite, pyrite, fluorite	2
Pyrite	magmatic sulphide, massive sulphide, polymetallic vein deposit types	74
Mg (red)-rutile	common accessory miineral in a wide variety of plutonic igneous & metamorphic rocks	311
Sapphirine	Si-poor, Mg-, Al-rich, high grade metamorphic rocks and skarns,	39
Sperrylite ($PtAs_2$)	platimum group mineral from mafic, ultramafic rocks	4
Spinel	Si-poor, Mg-, Al-rich, high-temperature metamorphic rocks	18
Topaz	felsic igneous rock such as granites, granite pegmatites, rhyolites	2
Tourmaline	granite and pegmatite, hydrothermal veins	1

Table 1. Summary of minerals picked, a possible paragenesis, and the number of grains picked per mineral.

Indicator Mineral Picking Results

Picking counts for indicator minerals in till and esker samples are geographically plotted with the regional ice flow and glaciofluvial flow direction as a backdrop (generally from east to west). The indicator mineral counts are utilized as proxies for identifying potential mineral deposits, or for specific types of bedrock lithologies. The paragenesis (i.e. potential source, or sources) for each indicator mineral type is listed in Table 1. Samples are classified as anomalous when they contain mineral grains that cannot be accounted for by known mineralized occurrences or bedrock outcrops up-flow.

Gold grains

Gold grains were counted and classified by Overburden Drilling Management (ODM) into pristine, modified and reshaped (Appendix A2). These three categories are thought to reflect transport distances where pristine grains have been transported the least distance. Kerr et al. (2013e) discuss the methodology for the classification of gold grains used by ODM for till and esker samples collected west of the current study area. The same classification was used for this study. The regional distribution of gold grains observed by Kerr and Knight (2007) for the Slave craton, and Kerr et al., (2013e) for the MERA study area to the west indicates that up to five gold grains in either till or esker samples constitutes regional background. However, for this study, regional background levels appear to be even lower, with 10 till sites that contain one gold grain, one site that contains two gold grains and 101 sites with zero gold grains. For esker samples five sites contain one gold grain, one sample site contains two gold grains, and 54 sites contain zero gold grains (Fig. 8). All of the gold grains recovered are reshaped, and in the study area regional background gold levels are suggested to be zero grains per 10 kg.

Pyrite

Anomalous pyrite grain counts (greater than background of zero) are observed in eleven till and twelve esker sites, with higher pyrite grains counts being observed in the esker sites (maximum of 17 grains in an esker site, versus five grains in a till site). The highest concentration of grains occurs proximal to Williams Lake (Fig. 9). Higher pyrite grain counts are also observed in an esker sample site at the south end of Tyrrell Lake, and at an esker site approximately 20 km northwest of Breithaupt Lake (Fig. 9).

Mg-Rutile

Regional background levels of Mg-rutile are approximately zero to three grains per 10 kg. Twelve till sites contain elevated Mg-Rutile, with a maximum of 37 grains occurring in the south-eastern portion of the study area adjacent to a bend in the Thelon River (Fig. 10). A short distance north of this site is an esker site that contains 14 Mg-rutile grains. Numerous till and esker sites located proximal to Williams Lake contain elevated Mg-rutile grain counts, with a till and esker site containing 27 and 23 grains respectively (Fig. 10).

Platinum group minerals

Four occurrences of sperrylite ($PtAs_2$), the most common platinum group mineral observed in surficial sediments, occur within the study area (Fig. 11). Each sperrylite grain was obtained from an individual till sample, with none being observed in esker samples. Three of the four sperrylite grains were found in till samples taken adjacent to an esker near Williams Lake (i.e. in an esker corridor). The regional background distribution of sperrylite for the MERA study west of the current study area is zero to one grain per 10 kg (Kjarsgaard et al., 2013b). Thus platinum group minerals obtained from the current study fall within regional background values.

Olivine

Olivine grains, which are indicative of kimberlite, ultramafic, and mafic rocks have highly anomalous concentrations in the western portion of the study area, and anomalous concentrations in the eastern part of the study area north of Tyrrell Lake. Background levels of olivine are approximately zero to three grains per 10 kg sample. Fourteen till sites contain an anomalous amount of olivine grains, with a maximum of 86 grains occurring in a sample from the eastern shore of Garde Lake (Fig. 12). Three till locations 10 to 20 km down flow to the west of Garde Lake contain seven to ten olivine grains, and one esker site 10 km down flow contains four olivine grains. Olivine is also concentrated at till sites located around the central and southern portion of Williams Lake, with one till site just west of Williams Lake containing 37 olivine grains. Three sites to the east contain up to 10 grains of olivine. Seven anomalous esker sites contain up to 20 grains; two esker sites at Williams Lake contain 19 and 12 grains of olivine, while one site northwest of Tyrrell Lake contains 14 grains. No till or eskers samples in the southeast part of the study area contained olivine.

Chromite

Chromite is a prominent indicator mineral type in the study area. Two separate populations of chromite grains are observed: 1) west of the Thelon River to the central portion of Tyrrell Lake, and; 2) from the south end of Williams Lake to the west (Fig. 13). Within the first region, Burden et al. (1978) identified several small isolated outcrops of ultramafic rocks within a predominantly gneissic terrain. The possibility of additional ultramafic rocks outcropping along the north-south boundary between these gneissic rocks and the Thelon Basin sandstone is suggested to likely account for the chromite grains observed at surficial sampling sites between the Thelon River and Tyrrell Lake.

The second anomalous region, around Williams Lake, is the head of a well-defined chromite dispersal train first identified during the regional MERA study to the west (Kjarsgaard, 2013, Kjarsgaard et al., 2013b). This chromite dispersal train is approximately 120 km long, forming a fan shape that dissipates in abundance to the west at a similar rate for both till and esker sites (Fig. 14). The head of the dispersal train for both esker and till samples is located on the southeast side of Williams Lake, where there is an abundance of esker/corridor related surficial sands, with limited bedrock outcrops (Fig. 15).

Low Cr-Diopside

Low Cr-diopside is also a prominent indicator mineral type in the study area, however, in contrast to chromite grains, it predominantly occurs in only one location, proximal to and down flow from Williams Lake (Fig. 16**).** Background levels of low Cr-diopside are approximately zero to one grain per 10 kg sample. Fourteen till sites contain up to 55 low Cr-diopside grains, while 16 esker sites contain up to 94 grains (Fig. 16). One till, and two esker sites north of Williams Lake contain up to ten grains each.

Orthopyroxene

Orthopyroxene grains were not directly counted as the other listed heavy minerals. After heavy liquid separation, the minerals were further separated into nonmagnetic, ferromagnetic, and paramagnetic fractions. The paramagnetic fraction was further subdivided into > 0.8 A/m and < 0.8 A/m fractions, the latter of which was examined to determine a modal percentage of orthopyroxene. We assumed that this modal percentage is roughly equivalent to a mass percentage, and used this to calculate a whole-sample concentration of orthopyroxene. The units are stated as pseudo g/tonne to reflect this simplistic volume to mass conversion (Appendix A4). Orthopyroxene is observed at both till and esker sites in the northwest portion of the study area, predominantly around and west of Williams Lake (Fig. 17), however the highest counts in till are located on an island in Mary Francis Lake. Orthopyroxene is often associated with olivine in mafic and ultramafic rocks, as well as in peridotite xenoliths from deep-seated magmas such as kimberlite.

Garnets

Non-crustal (i.e. potential mantle eclogite or peridotite) garnets were observed at one till and two esker sites (Fig. 18). The till sample site is located on an island in Mary Francis Lake and is the same site where significant quantities of orthopyroxene grains were observed. At this site the grain was visually identified as a peridotitic Cr-pyrope garnet. The two esker sites are located on the southeast and west shore of Williams Lake. At each esker site both an orange "eclogitic" garnet and a peridotitic Cr-pyrope was picked based on visual identification (non-microprobe verified). The orange garnets may be sourced from mafic granulite lithologies that are observed southeast of Mary Frances Lake (Fig. 18).

Cobbles and boulders of mafic and ultramafic rocks

Adjacent to the western shore of Williams Lake, and a further 5 km to the west, two distinct types and sizes of mineralized boulders and cobbles were observed and collected or sampled. Several large layered boulders were observed (Fig. 19), with the layers consisting of variable proportions of magnetite, olivine, clinopyroxene, calcite and apatite. The silicate minerals are iron and manganese rich, with the olivine specifically in the form of Mn-rich fayalite, Mg# 44 (Mg# = Mg/Mg+Fe x 100) and the clinopyroxene specifically in the form of manganoan diopside (Fig. 20a, b). These boulders are considered to be metamorphosed Archean 'Algoma-type' Mn-rich banded iron formation. In contrast, the smaller boulders (Fig. 21) and cobbles have Cr-spinel with variably preserved magnesium-rich silicate minerals, olivine (Mg# 80, 2400 ppm Ni) and orthopyroxene (Mg# 89; Fig. 22a,b). The mineralogy and mineral chemistry of the cobbles is consistent with an ultramafic source rock.

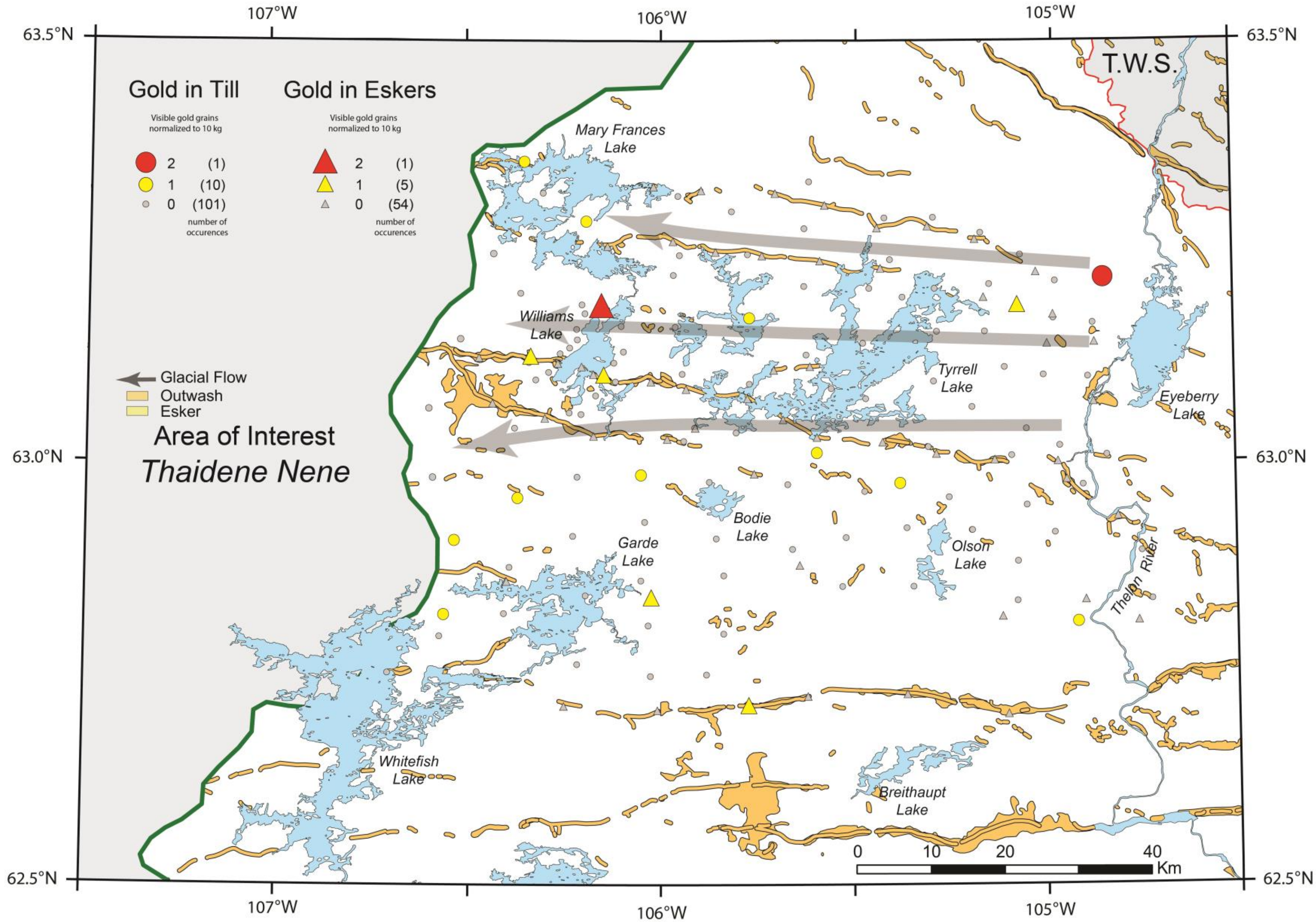

Figure 8. Map of picking results for gold grains in till and esker samples.

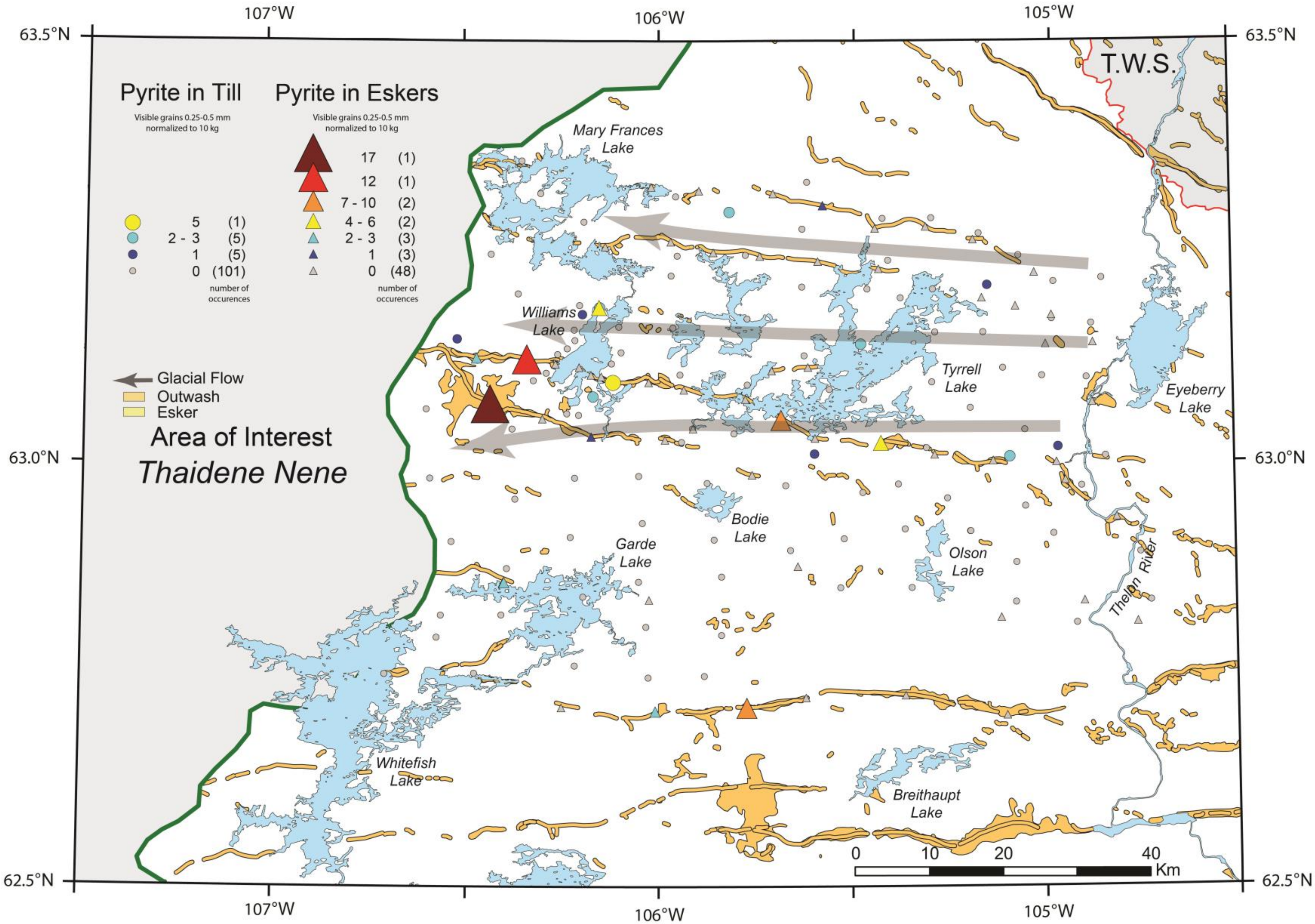

Figure 9. Map of picking results for pyrite grains in till and esker samples.

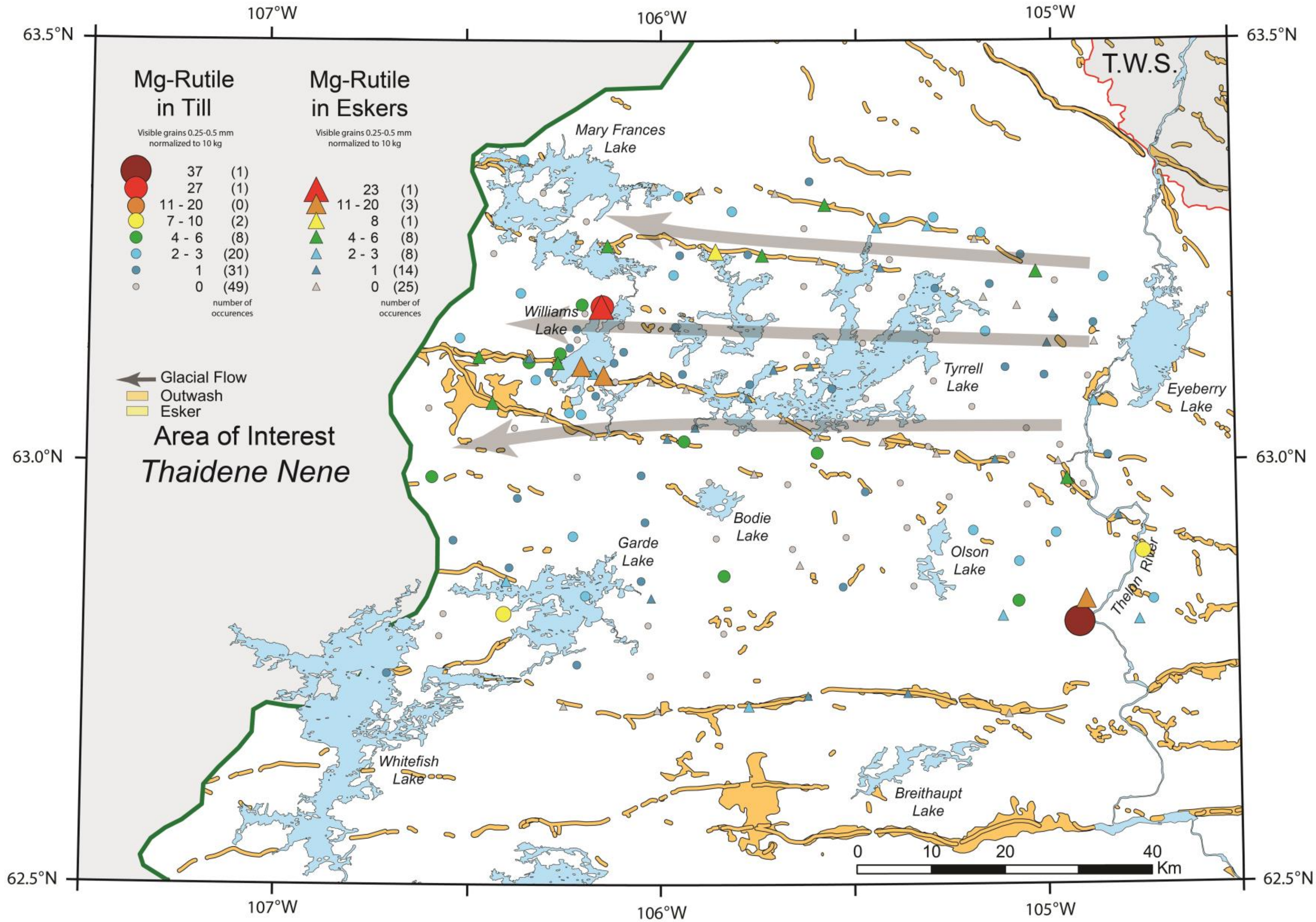

Figure 10. Map of picking results for Mg-rutile grains in till and esker samples.

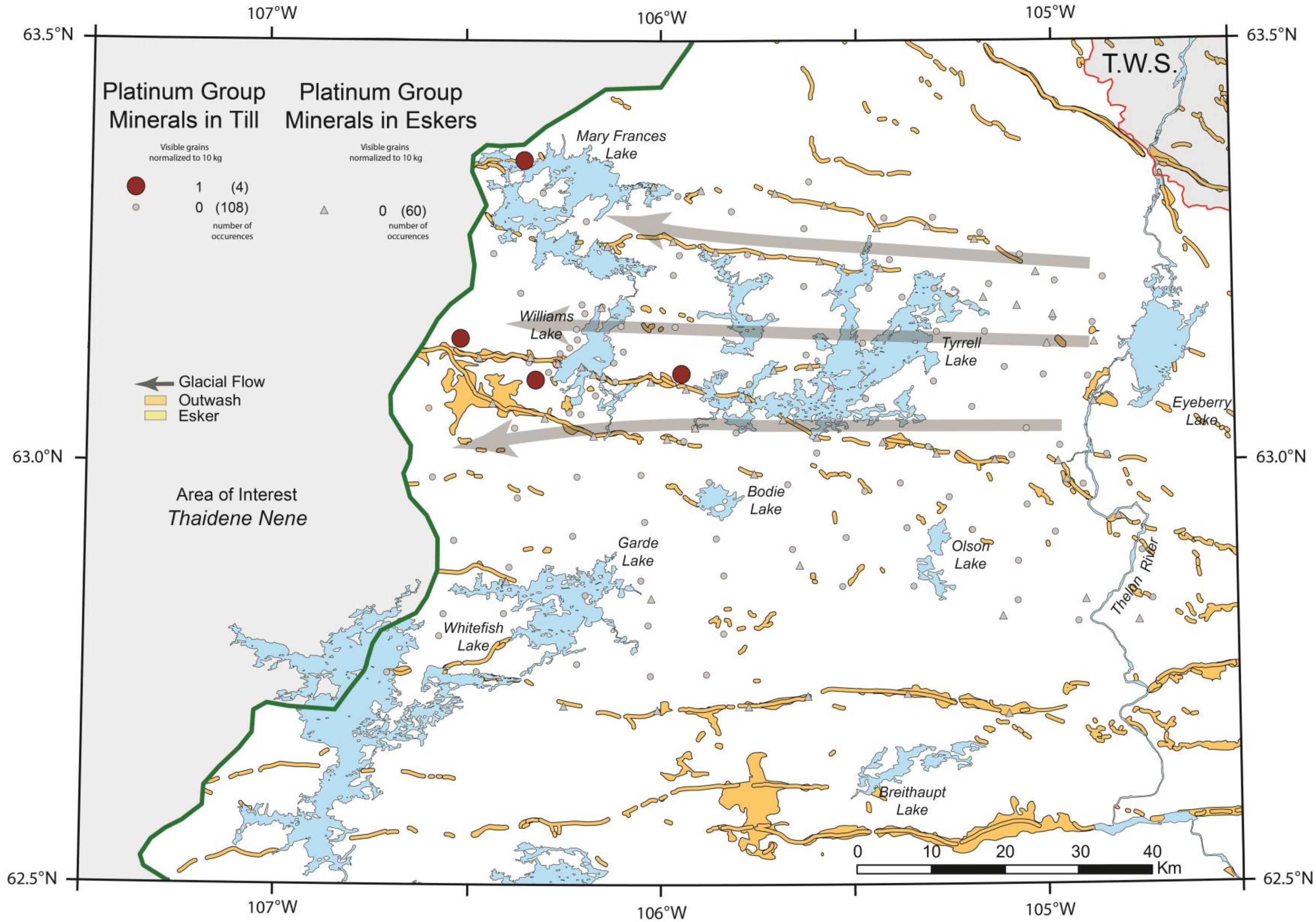

Figure 11. Map of picking results for platinum group minerals in till and esker samples.

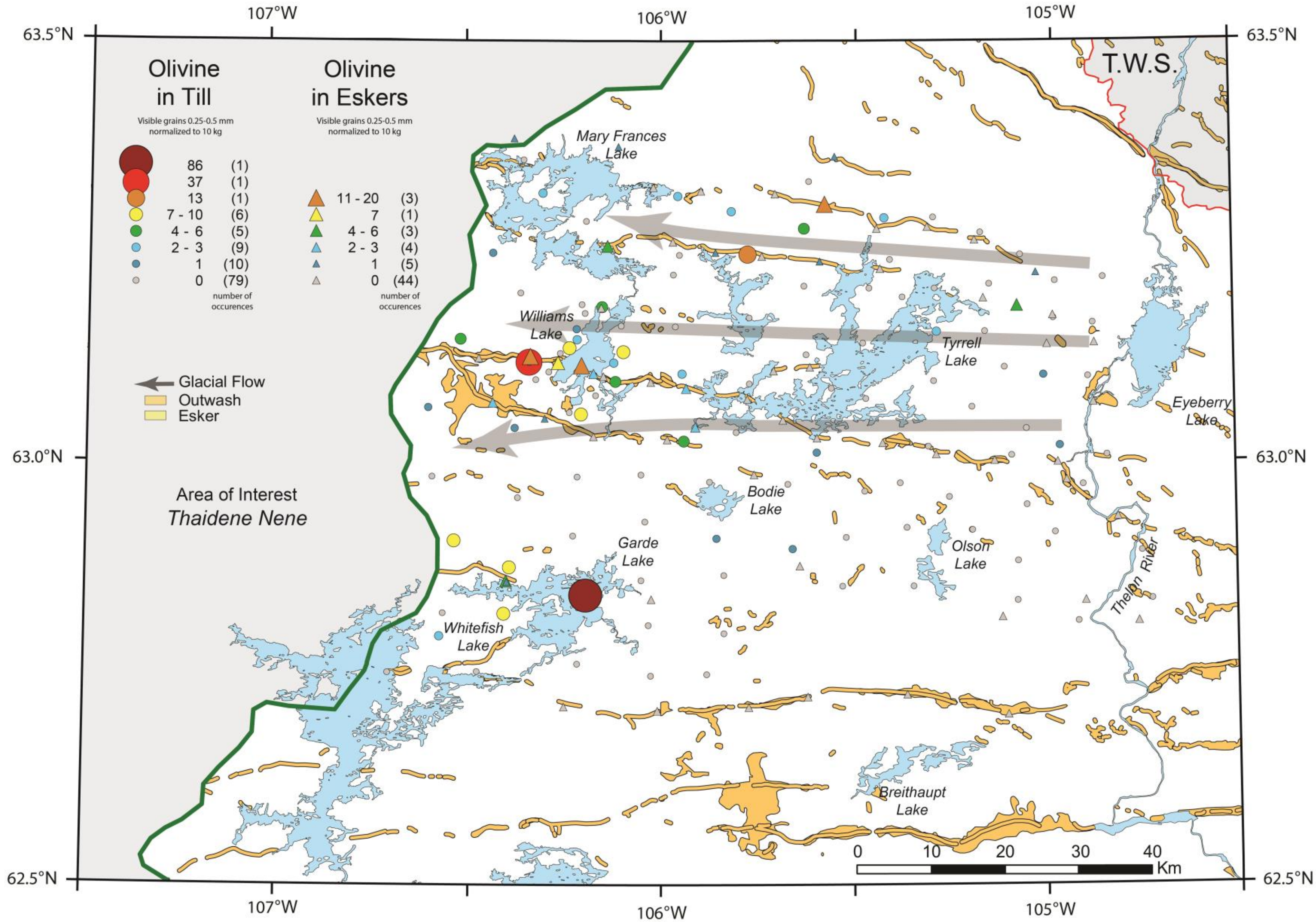

Figure 12. Map of picking results for olivine grains in till and esker samples.

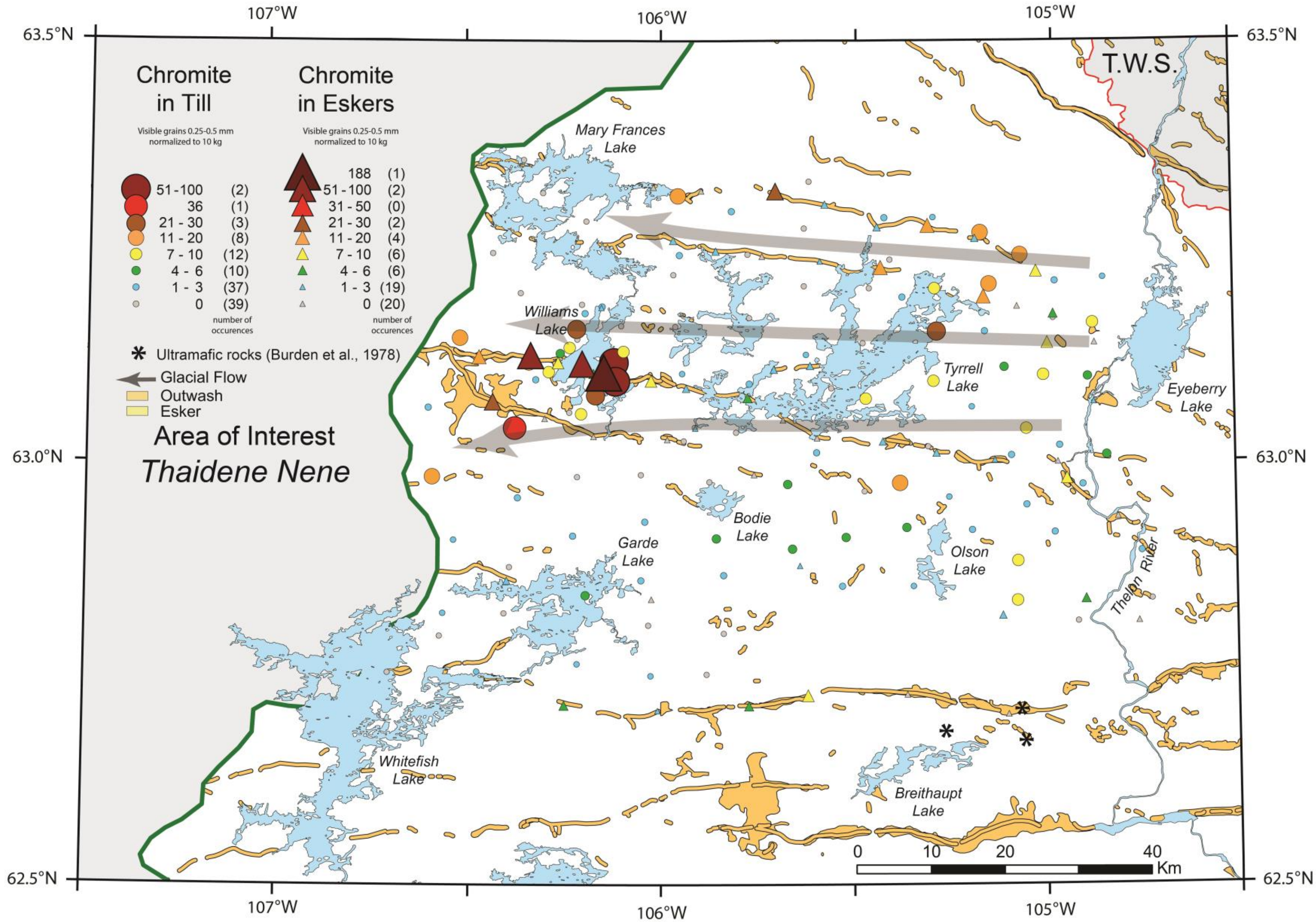

Figure 13. Map of picking results for chromite grains in till and esker samples.

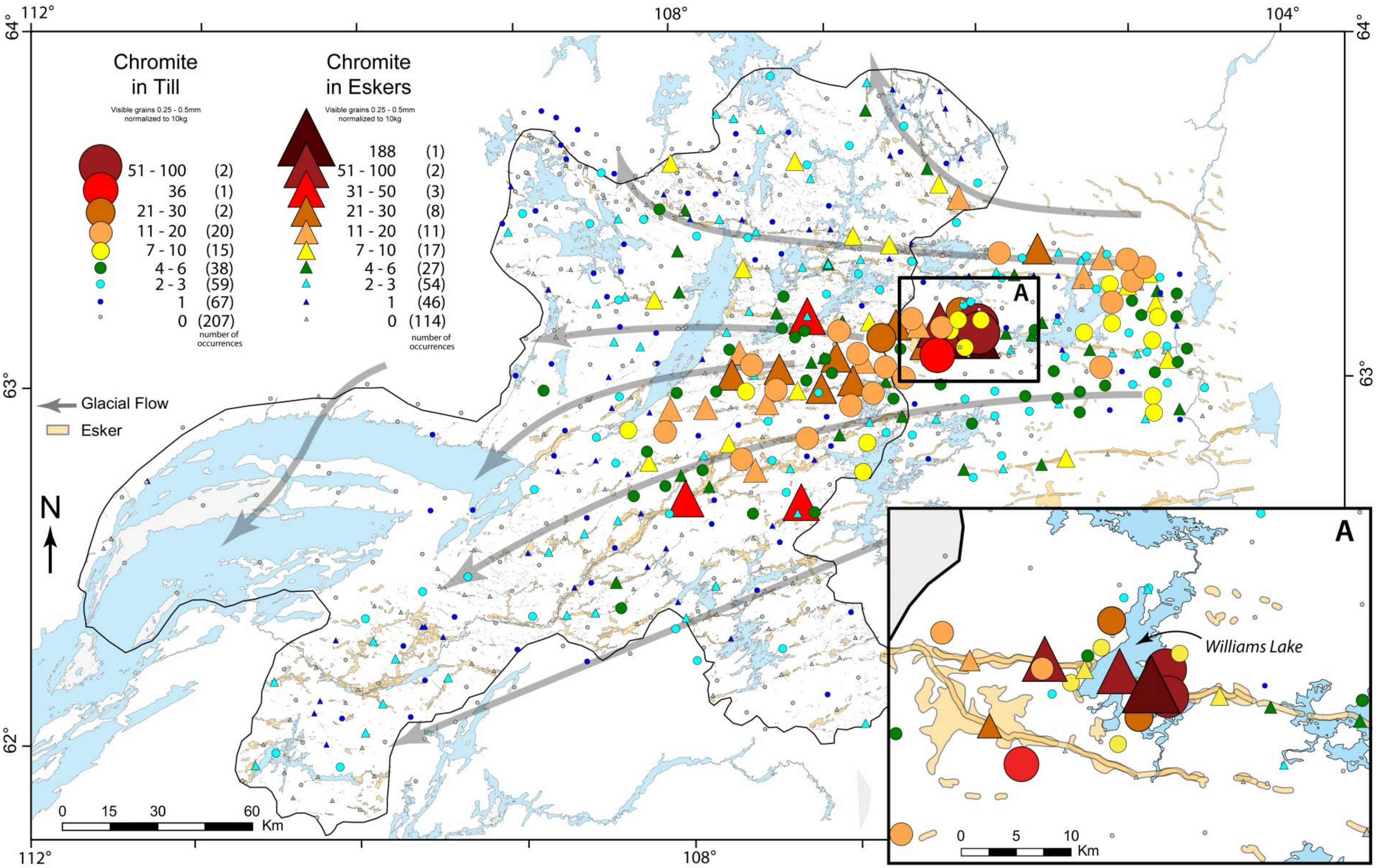

Figure 14. Chromite dispersal train of indicator mineral data from MERA study (Kjarsgaard et al., 2013c) and this study. Inset map A displays mineral grain counts at Williams Lake.

Figure 15. Esker sands on the east side of Williams Lake looking west towards Williams Lake (top of photo). This esker is located in an erosional corridor with scoured bedrock, till remnants and sandy deposits.

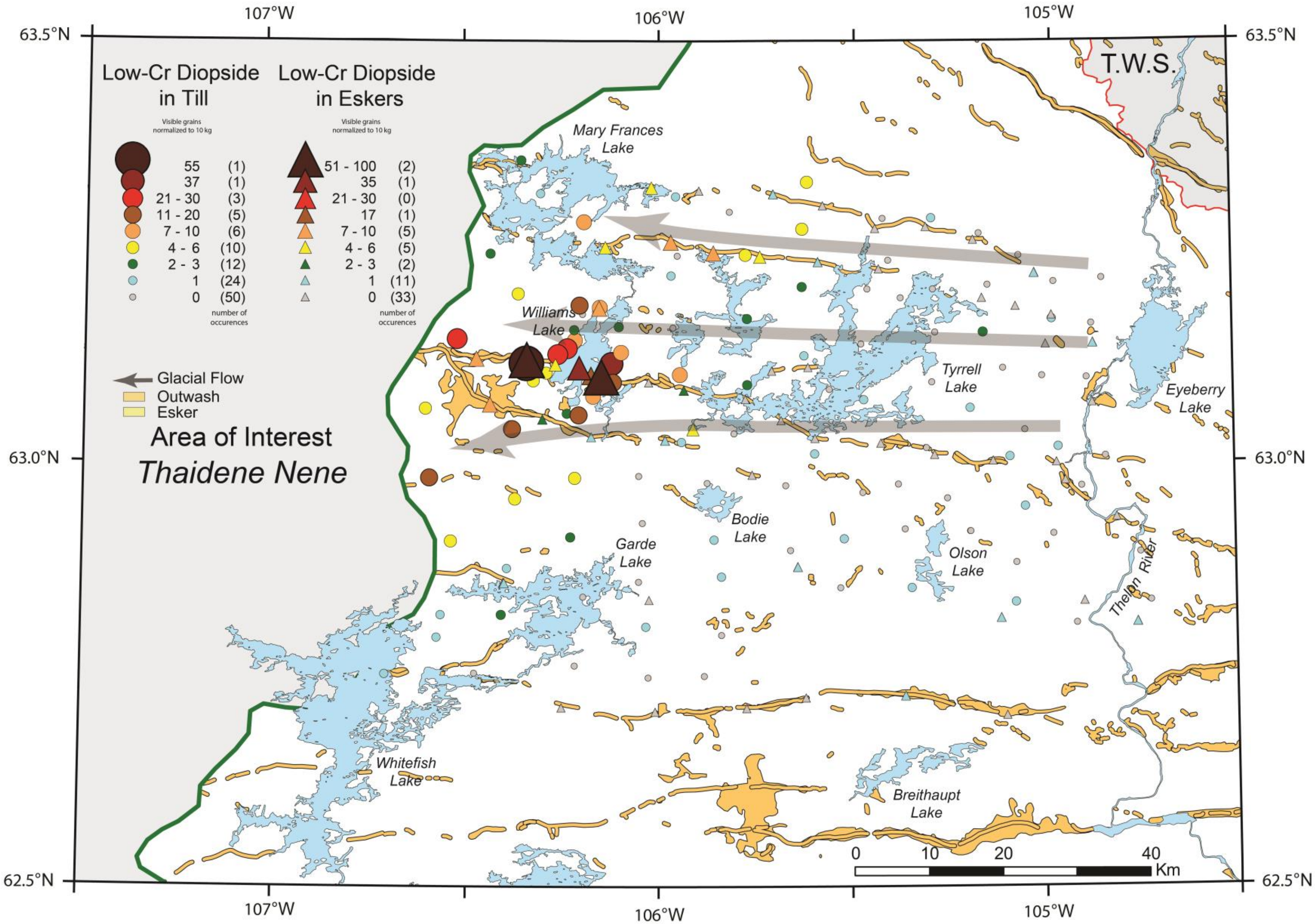

Figure 16. Map of picking results for low Cr-diopside grains in till and esker samples.

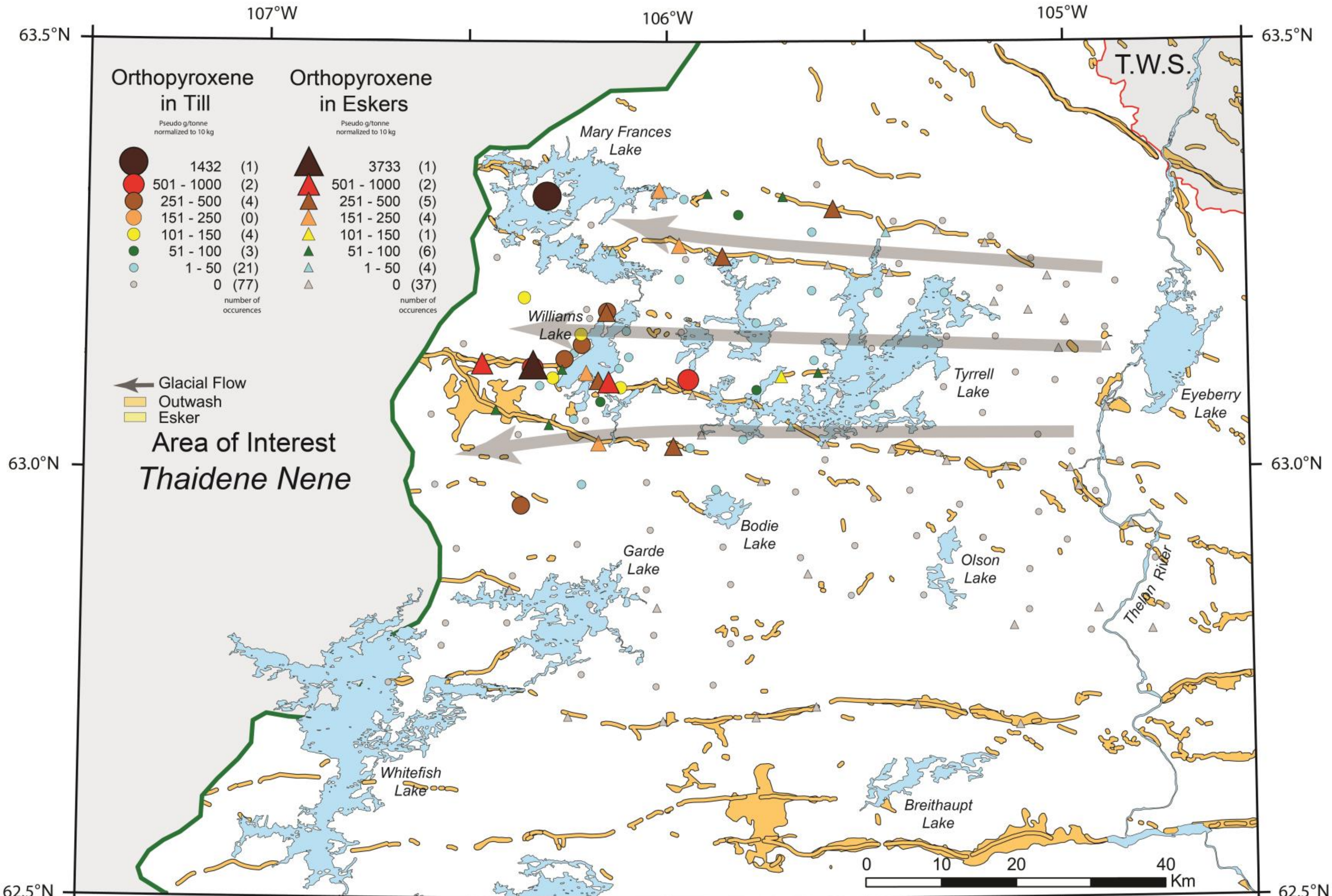

Figure 17. Map of picking results for orthopyroxene grains in till and esker samples.

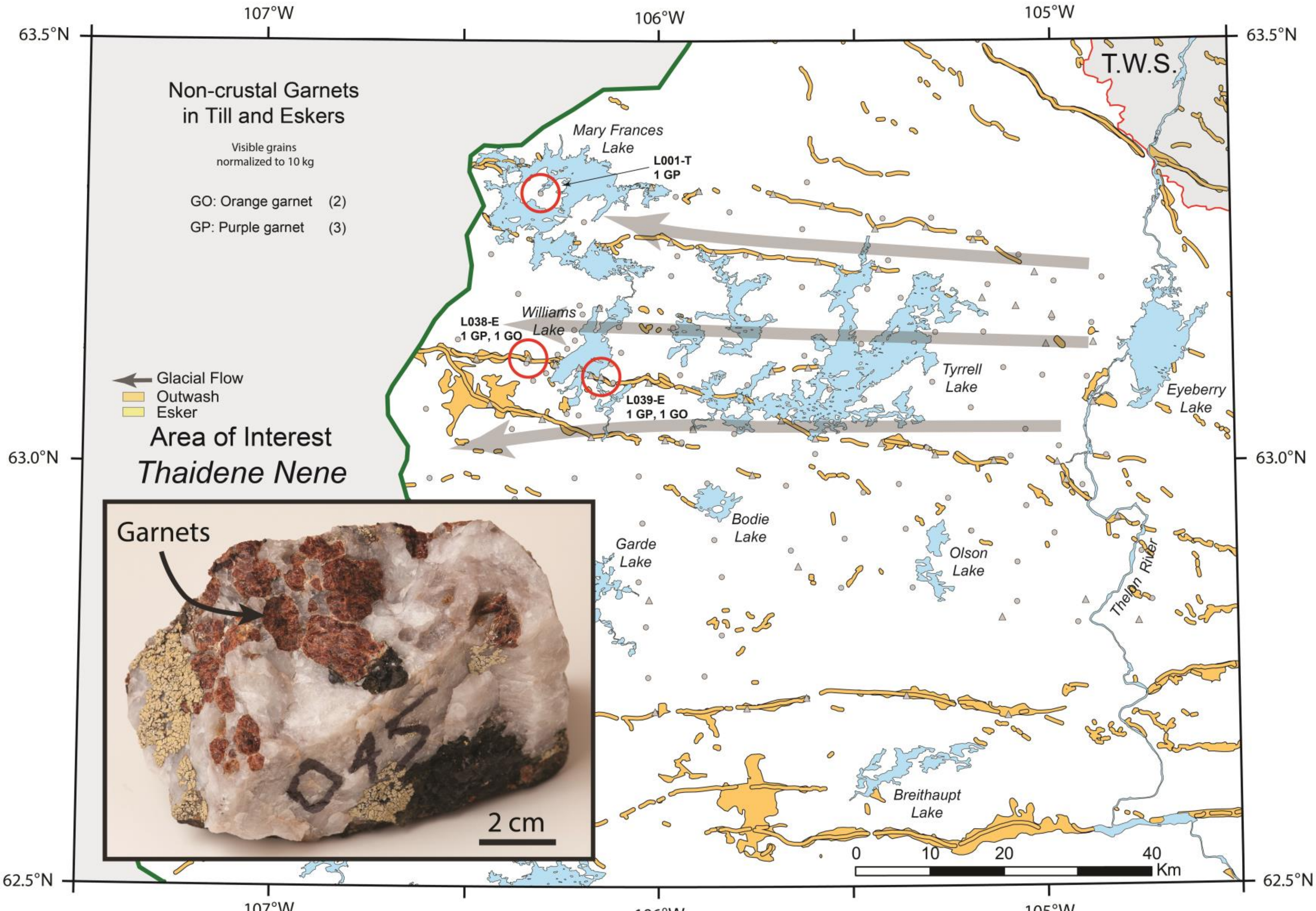

Figure 18. Map of picking results for non-crustal garnet grains in till and esker samples. Inset photo of orange garnets observed in a sample that outcrops on the east side of Williams Lake. Photo by C. Logan.

Figure 19. A large layered mineralized boulder (metamorphosed Mn-rich banded iron formation) observed near the western shore of Williams Lake.

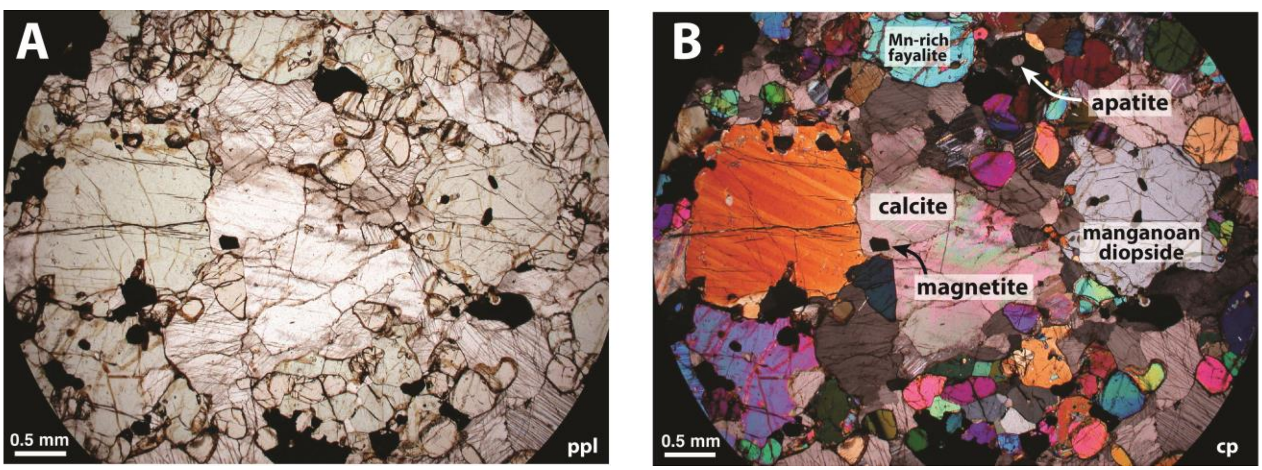

Figure 20. Photomicrograph in plane polarized light (ppl) and cross polars (cp) displaying olivine in the form of Mn-rich fayalite and clinopyroxene in the form of manganoan diopside.

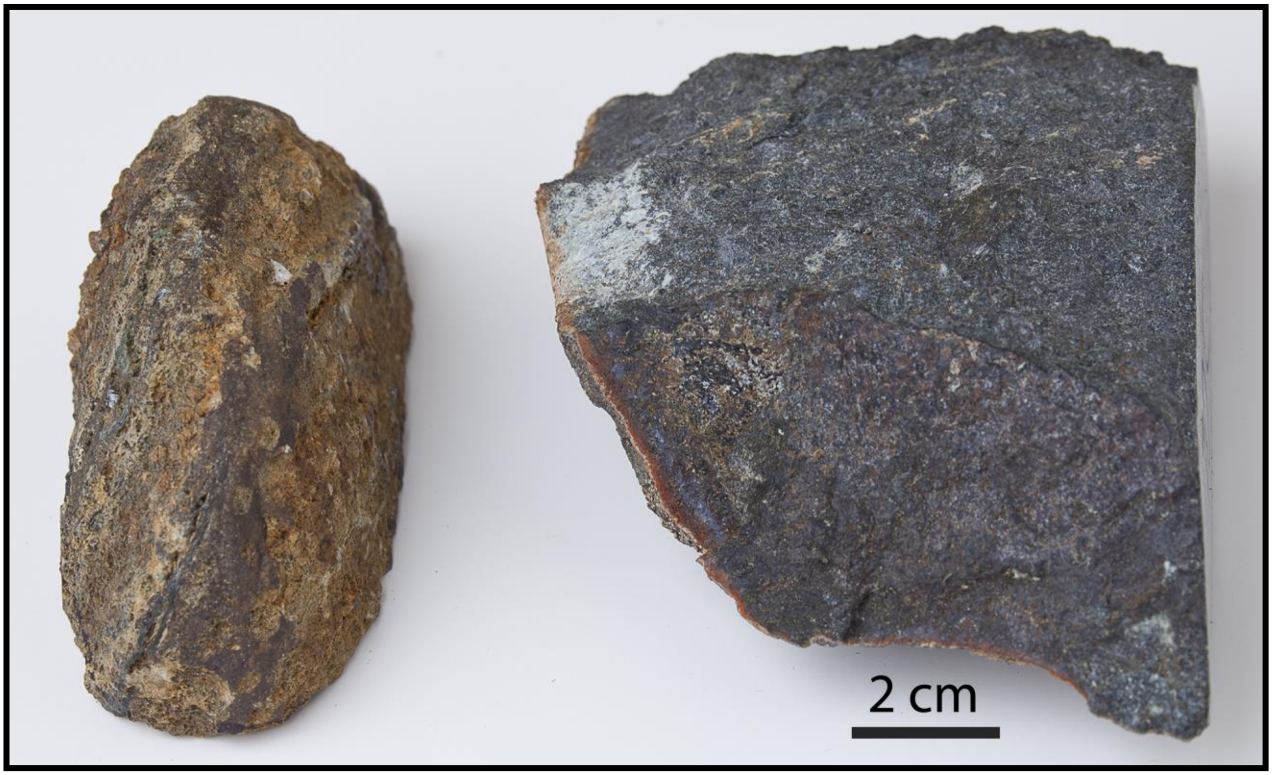

Figure 21. Ultramafic cobbles and pebbles with Cr-spinel, olivine and orthopyroxene. Note the layering in the pebble on the left side of the Figure.

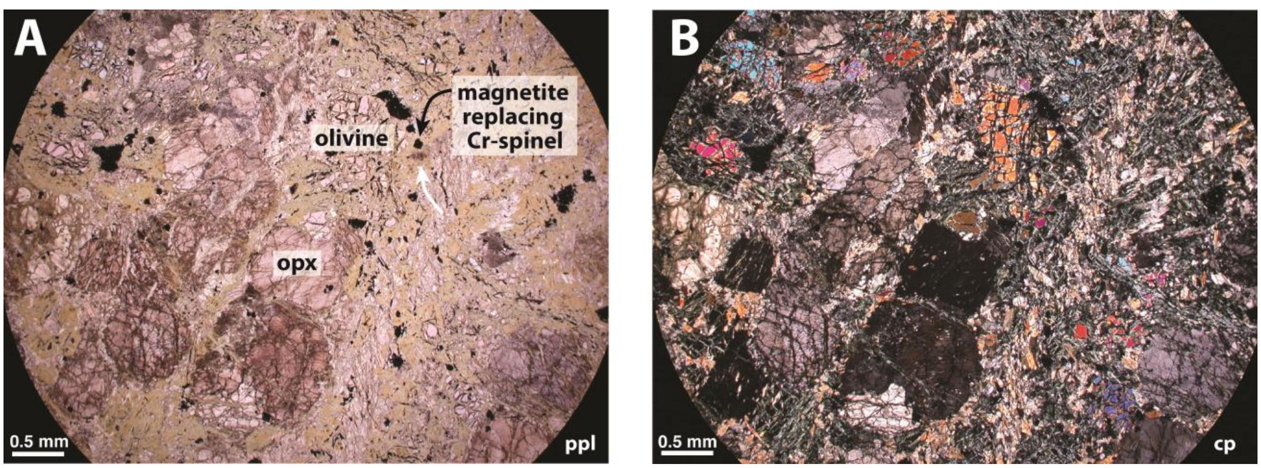

Figure 22. Photomicrograph in plane polarized light (ppl) and cross polars (cp) displaying olivine, orthopyroxene (opx), and magnetite replacing Cr-spinel.

Discussion

Indicator mineral identification for this study and the MERA study undertaken to the west (Kjarsgaard et al., 2013b) indicate that there is very little to no preferential concentration of indicator minerals between till or esker sample sites and that down flow dispersal and dilution to background levels occurs at a similar rate for both sediment facies.

A comparison of gold grain counts with those collected during the MERA study (Kerr et al., 2013e) and from the Slave Province (Kerr and Knight, 2007) indicate that the study area has lower background gold grain counts than the regional background levels for the MERA study area to the west, or the Slave Province.

The potential for chromite mineralization in the MERA study area was described by Kjarsgaard (2013) and highlighted in the dispersal pattern of chromite and Cr-spinel, and olivine and low Cr-diopside by Kjarsgaard et al. (2013b). For this study, the dispersal pattern was sampled up flow to its source area at Williams Lake (Figs. 13 and 14). The high olivine, chromite, and low Cr-diopside, as well as orthopyroxene and sperrylite counts, are not observed to the east of Williams Lake. Ultramafic cobbles with Cr-spinel, olivine, and orthopyroxene are also observed at, and down flow from Williams Lake. The Mg# and nickel contents of olivine from the ultramafic cobbles is consistent with those from olivine recovered from surficial sediments down-flow (see Fig. 12.7 in Kjarsgaard, 2013) The indicator mineral plume from this source area is approximately 120 km long and forms a fan shape (Fig 14).

Iron- and manganese-rich layered boulders observed on the west side of Williams Lake are diagnostic of a metamorphosed Algoma-type iron formation that corresponds to a bedrock type not previously recognized in the area and whose source is suggested to be local, based on the meter-scale size of the boulders.

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