GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7351

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# Introduction

This report presents geochemical analyses of till samples that were collected in the 2012 summer field season. The study area is approximately bounded by Mary Frances Lake (to the northeast), 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 study area encompasses 3,500 km$^2$ (parts of NTS 75-1, 75-J, 75-O, 75-P).

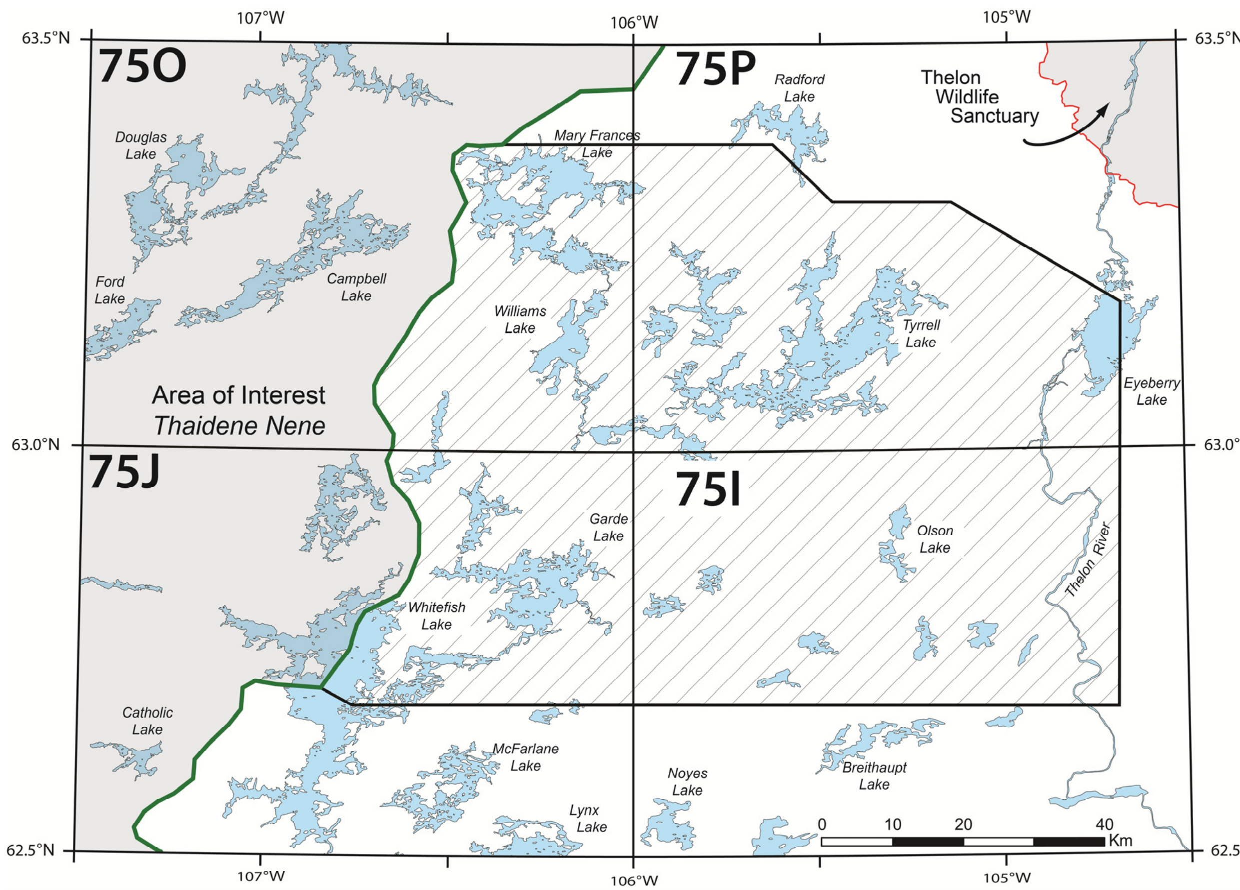


Figure 1. Location map of the study area (cross hatched), showing the major lakes and rivers, and location of the Thelon Wildlife Sanctuary (red outline, grey shading), and area of interest for Thaidene Nene (green outline, grey shading).

In general, a paucity of government geoscience activities where previously undertaken in the study area. The earliest work was a geological investigation by J.B. Tyrrell (Tyrrell, 1896), and surveying work, with geological investigations by J.W. Tyrell (Tyrell, 1902). The bedrock geology and surficial materials of the study area where not systematically examined until the mid-1950s, via Operation Thelon (Wright, 1957, Craig, 1964; Wright, 1967). The bedrock geology is poorly understood, with mapping at 1:1-million scale (Fig. 2), other than small areas mapped in detail by industry, adjacent to the Thelon River. The surficial geology was re-examined via air-photo interpretation in the 1980's by Aylsworth and Shilts (1989a, b; see Fig. 3).

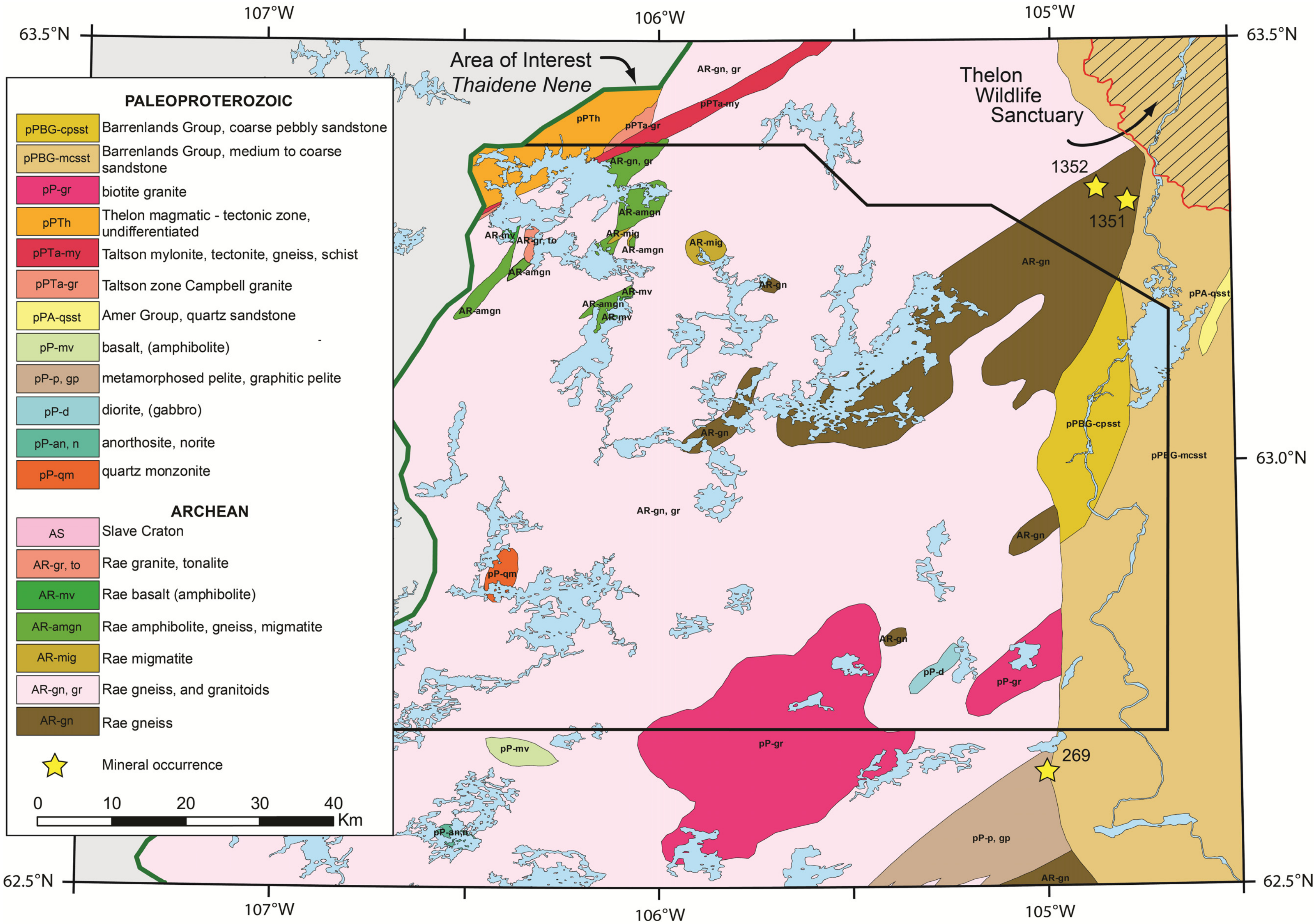


Figure 2. Bedrock geology map (1: 1-million scale), with mineral showings. West half from Kjarsgaard et al., 2013b, in press; east half modified after Pehrsson et al., 2013, in press. Location information and data for mineral occurrences from NORMIN.DB (Northwest Territories Geoscience Office, Yellowknife).

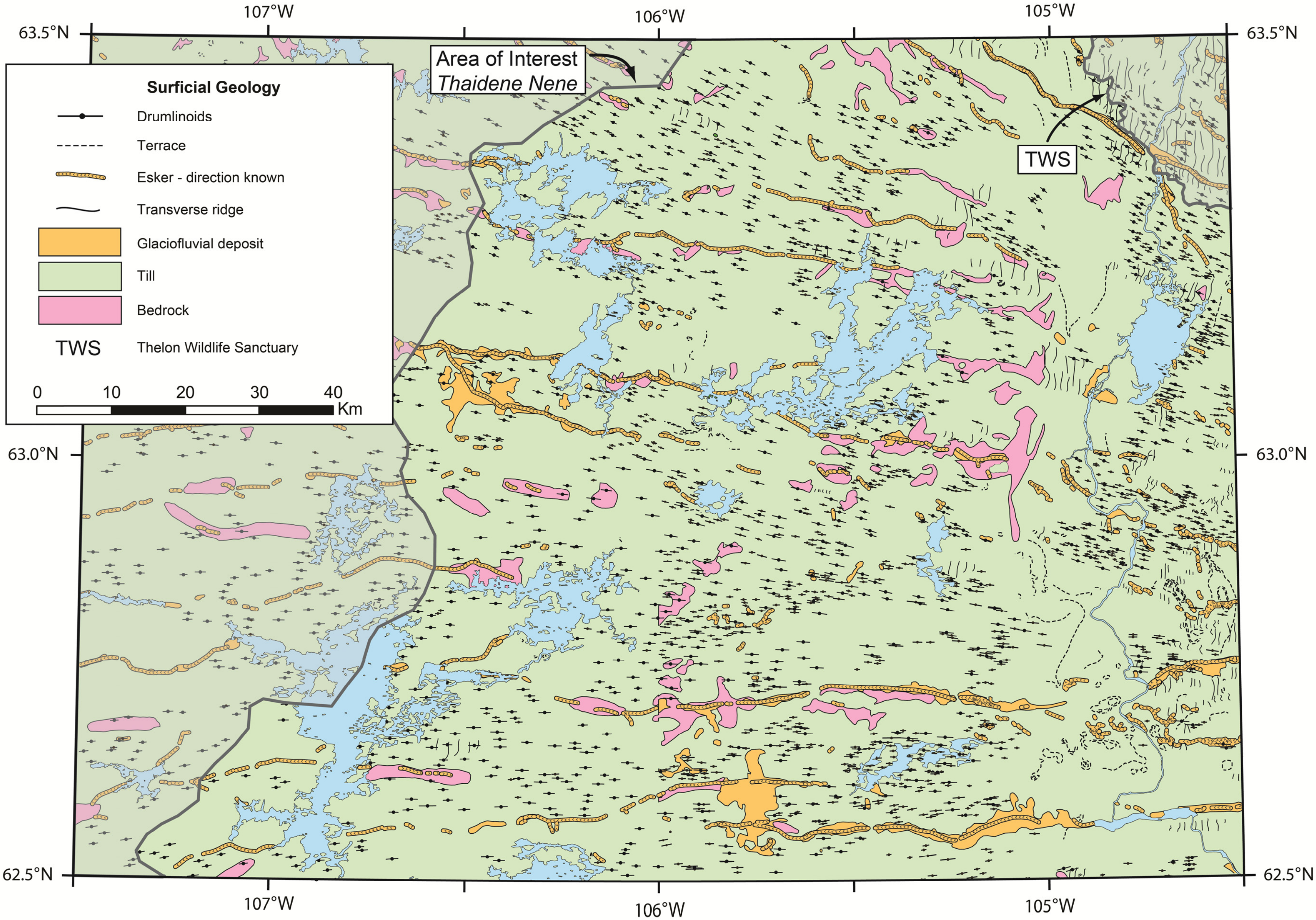


Figure 3. Simplified surficial geology, modified and updated from Craig (1964) and Aylsworth and Shilts (1989b). TWS = Thelon Wildlife Sanctuary

Studies related to uranium mineralization associated with the Thelon Basin have been published sporadically the past 25 years (Davidson and Gandhi, 1989; Beyer, 2010). More recently, the Northwest Territories Geoscience Office (NTGO) conducted a lake sediment survey (Cairns et al., in prep.) that partly overlaps the southern region of the present study area. A regional overview of the surficial geology and glacial history west of the study area, prepared for the Thaidene Nene MERA study, is presented in Kerr et al., 2013a, b).

## Sample design and collection protocols

Surficial sediment samples collected in 2012 (181 samples) consisted of 76 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. Co-ordinates for the till sample locations are listed in Appendix A. At each till site a 15 kg sample was taken for heavy mineral recovery, a companion 1 kg sample for geochemical analysis, 50 pebbles for pebble counts, and a 100 g sample for pXRF analysis. 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., 2013a). Each sample site was photographed, both for sample context and general landscape context. 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 scientist and an assistant.

The heavy mineral and pXRF data (for till and eskers) are presented separately (Knight et al., in prep; Plourde et al., in prep, respectively). The till samples where directly shipped to Acme Analytical Laboratories Ltd. (Acme) in Vancouver, B.C. for processing and analysis.

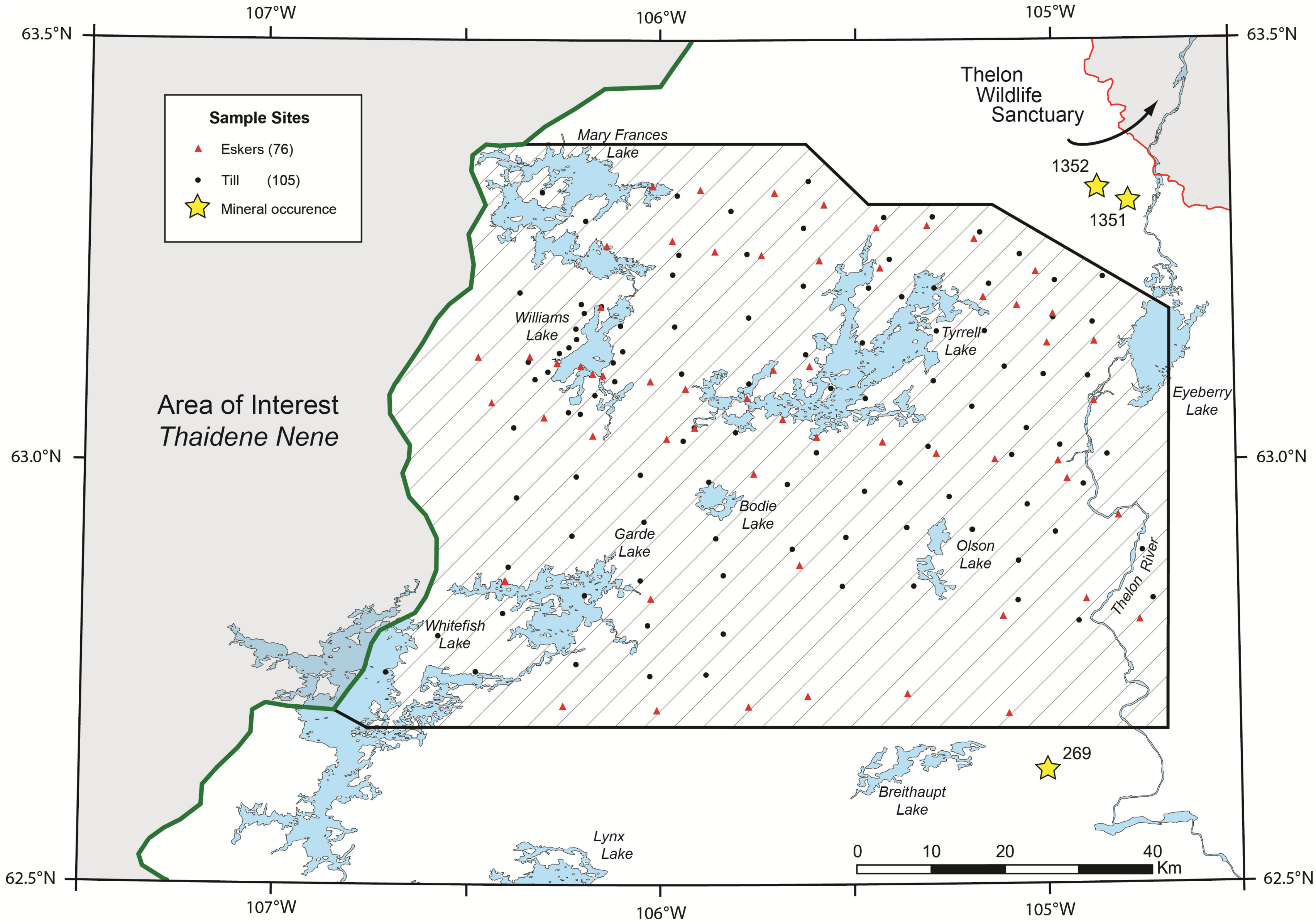


Figure 4. Sample map, with locations of till and esker sample sites. Till samples, black dots; esker samples, red triangles. Location information and data for mineral occurrences from NORMIN.DB (Northwest Territories Geoscience Office, Yellowknife).

## Analysis of till samples

### Background information regarding digestion techniques

Till geochemistry studies at the Geological Survey of Canada typically use an aqua regia partial digestion coupled with ICP analysis, for the detection of gold, volcanogenic massive sulphide base metal and uranium deposits (Shilts, 1975, 1984; Kerr, 2006; McMartin et al., 2011; Paulen and McClenaghan, in Jefferson et al., 2011). However, the use of aqua regia digestion on surficial till samples is unsuitable for application to a number of different ore deposit types e.g., kimberlite-hosted diamond, chromitite, magmatic Ni-Cu, rare earth and rare metal, and uranium (Kjarsgaard et al., 2013a, in press and references therein). Hence, all samples where analysed using three different techniques: aqua regia (partial digestion); 4-acid digestion (a near total digestion), and; lithium metaborate/teraborate fusion (total digestion). Furthermore, for all digestions, specially devised custom analytical routines were utilized, following the protocols devised for the Thaidene Nene MERA (Kjarsgaard et al., 2013a). Combined, these three methods provide information for the detection of a complete spectrum of mineral deposit types. In addition, the study area (Rae domain of the Churchill Province, Fig. 2) has regions of highly deformed, medium- to high-grade metamorphic rocks, and thus potentially metamorphosed mineral deposits, which are less amenable to discovery via exploration geochemistry using the aqua regia digestion method, due to the crystalline nature of metamorphic minerals that resist digestion (Kjarsgaard et al., 2013a). A tabulation of the elements analysed by each method is listed in Table 1.

### Analytical methods and reference standards

At Acme a 500 g split of the till sample was dried at 60 °C and sieved to 230 mesh (63 µm, clay + silt fraction). The three analytical procedures employed at Acme were as follows: (1) aqua regia, a hot (95°C) $HNO_3$-HCl digestion, followed by Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) analysis; (2) 4-acid, a hot dissolution in $HNO_3$-$HClO_4$-HF, taken to dryness and then the residue dissolved in HCl, followed by ICP-MS analysis; (3) fusion, a lithium metaborate/tetraborate fusion followed by dilute nitric acid digestion of the fused disc, and analysis by Inductively Coupled Plasma Emission Spectroscopy ICP-ES (major elements) and ICP-MS (trace elements). The complete data set is listed in Appendix A. For the analyses, the incorporation of reference standards material was as follows. The first five samples consisted of sample TCA8010 (GSC internal reference standard, pulp) followed by Till 1, Till 2, Till 3 and Till 4 (CanMet reference standards, pulps; Lynch, 1996). After every twenty-five till samples, TCA8010 was inserted, and after every fifty samples, TCA8010 and Till 1 through Till 4 were inserted. The final five samples consisted of TCA8010 plus Till 1 through Till 4. The incorporation of the TCA8010 samples was to monitor instrument drift over the time frame of the sample batch, whereas the CanMet reference standards were utilized to monitor precision and accuracy. In addition, Acme also inserted their own internal reference standards and split duplicate samples. All standards data including split duplicate data and sample blanks are listed in Appendix A, by digestion type.

| Aqua Regia | 4 Acid | Fusion |
|---|---|---|
| **all ICP-MS** | **all ICP-MS** | **ICP-ES & MS** |
| | | |
| **"% Element"** | **"% Element"** | **"Wt.% Oxide"** |
| Ti | Ti | SiO2 **(ICP-ES)** |
| Al | Al | TiO2 **(ICP-ES)** |
| Fe | Fe | Al2O3 **(ICP-ES)** |
| Mg | Mg | Cr2O3 **(ICP-ES)** |
| Ca | Ca | Fe2O3 **(ICP-ES)** |
| Na | Na | MnO **(ICP-ES)** |
| K | K | MgO **(ICP-ES)** |
| P | P | CaO **(ICP-ES)** |
| S | S | Na2O **(ICP-ES)** |
| | | K2O **(ICP-ES)** |
| | | P2O5 **(ICP-ES)** |
| | | TOT/S **(LECO)** |
| | | TOT/C **(LECO)** |
| | | LOI |
| | | |
| **ppm** | **ppm** | **ppm (ICP-MS)** |
| Li | Li | |
| Rb | Rb | Rb |
| Cs | Cs | Cs |
| Be | Be | Be |
| Sr | Sr | Sr |
| Ba | Ba | Ba |
| Zr | Zr | Zr |
| Nb | Nb | Nb |
| Hf | Hf | Hf |
| Ta | Ta | Ta |
| Y | Y | Y |
| Sc | Sc | Sc |
| V | V | V |
| Cr | Cr | Cr (from Cr2O3) |
| Mn | Mn | Mn (from MnO) |
| Co | Co | Co |
| Ni | Ni | Ni |
| Cu | Cu | Cu |
| Zn | Zn | Zn |
| Pb | Pb | Pb |
| Tl | Tl | |
| Mo | Mo | Mo |

| Aqua Regia | 4 Acid | Fusion |
|---|---|---|
| **all ICP-MS** | **all ICP-MS** | **ICP-MS** |
| | | |
| **ppm** | **ppm** | **ppm** |
| W | W | W |
| As | As | |
| Sb | Sb | |
| Bi | Bi | |
| B | | |
| Se | Se | |
| Te | Te | |
| Ga | Ga | Ga |
| Ge | | |
| Cd | Cd | |
| Sn | Sn | Sn |
| In | In | |
| | La | La |
| | Ce | Ce |
| | Pr | Pr |
| | Nd | Nd |
| | Sm | Sm |
| | Eu | Eu |
| | Gd | Gd |
| | Tb | Tb |
| | Dy | Dy |
| | Ho | Ho |
| | Er | Er |
| | Tm | Tm |
| | Yb | Yb |
| | Lu | Lu |
| Th | Th | Th |
| U | U | U |
| | Au | |
| | Re | |
| | | |
| **ppb** | **ppb** | |
| Ag | Ag | |
| Au | | |
| Pd | | |
| Pt | | |
| Hg | | |

Table 1. Summary of elements analysed by each of the three digestion methods.

## Bedrock Geology

The bedrock geology of the study area is dominated by two units: (1) an undifferentiated Archean unit consisting of gneiss, granite and migmatite, and; (2) an Archean unit, comprised mainly of gneisses derived from intermediate to felsic protoliths (i.e., granitic, Fig. 2). Archean migmatite, amphibolite and gneiss derived from protoliths of intermediate to mafic composition are found in the northwest corner of the study area in the vicinity of Radford, Williams and Mary Frances lakes (Fig. 2). All these Archean rock units are part of the Rae Domain of the Churchill Province. In general the Archean rocks units are strongly deformed and typically show 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 subsequently been intruded by massive to weakly deformed plutons and plugs ranging in composition from gabbro/diorite to anorthosite/norite, to biotite granite and quartz monzonite (Kjarsgaard, in prep.). These igneous intrusions are inferred to be of Paleoproterozoic age. In the extreme northwest corner of the study area are 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. At the eastern edge of the study area, basement rocks and granitoids are overlain by sedimentary rocks of the Thelon Basin. Sandstone and pebbly sandstone of the Barrenlands Group are widespread, and overlie quartz sandstone of the Amer Group, and pelite and graphite pelite inferred to be of Amer equivalent age (Fig. 2; Pehrsson et al., 2013).

## 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.

## Glacial landscape architecture and sediment sampling

### 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). Surficial features (Fig. 3) in the study area (e.g., eskers, ribbed moraines, streamlined landforms) form a roughly concentric zonal pattern around the former KID (Aylsworth and Shilts, 1989a, b). The study area lies in the transition area from zone 2 (ribbed moraine, transverse ridges) to zone 3 (streamlined terrain) of this landform classification. Till and sand are the dominant sediments, and occur as streamlined

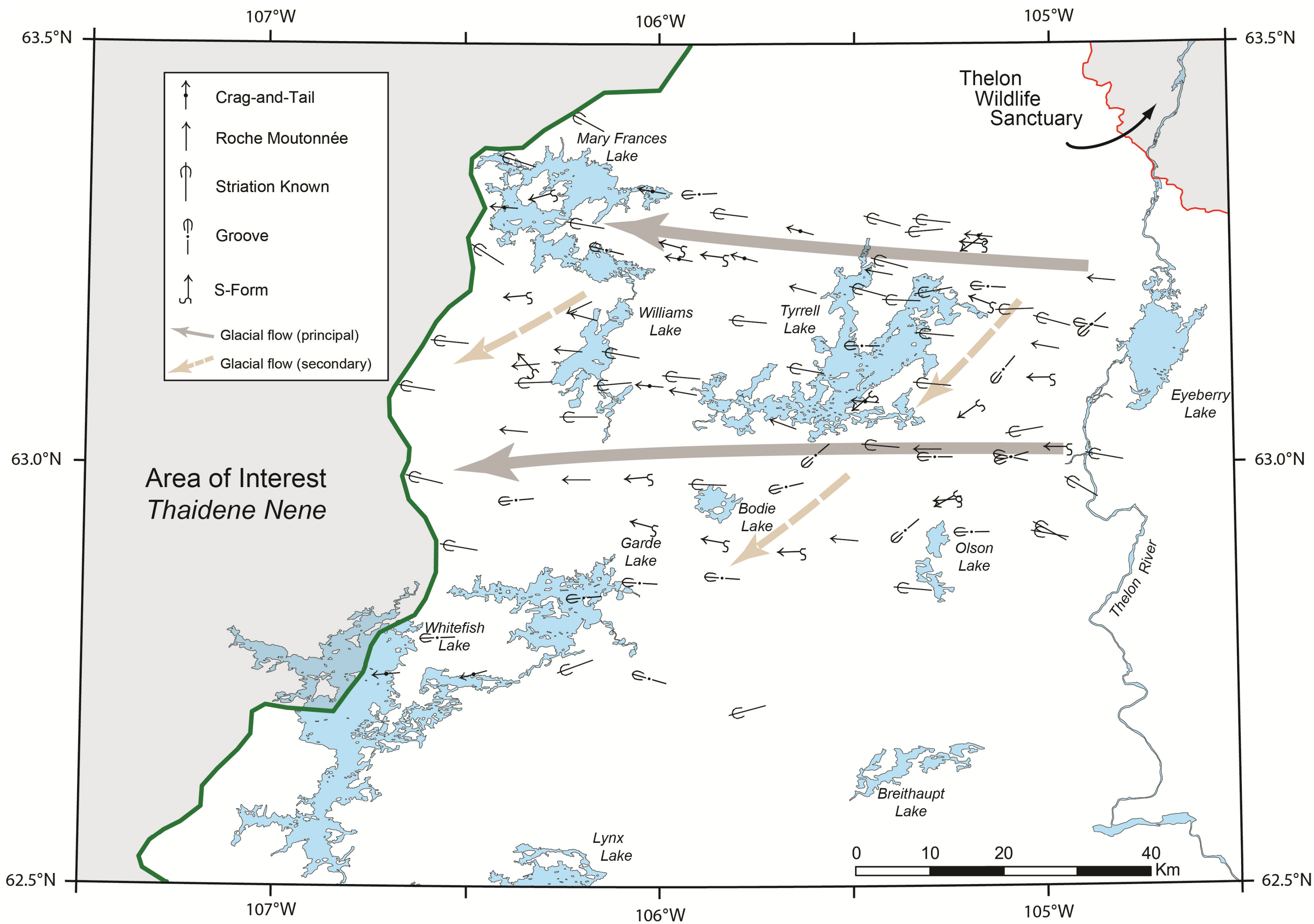


Figure 5. Small directional flow features (e.g., striae, s-forms) with generalized flow directions indicated.

terrain, eskers and till veneer, of varying thickness (~1-50 m). 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). The surficial geology immediately to the west of the current study area is described by Kerr et al. (2013a,b).

Reconnaissance field work in and surrounding the study area (Craig, 1965), 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. Most drumlins reveal till in shallow exposures, while some contain medium-grained sand and a few boulders (e.g. exposed drumlin south of Garde Lake). Transverse ridges, with boulder-covered ridge-tops can occur at right angles to drumlin (and drumlinoid) long axes. Craig (1965) mapped a dendritic network of eskers; most have flat tops with steep side slopes. A few eskers have terraces along their sides and in places may show three or four parallel ridges; some are inferred to record former lake shorelines.

### Landscape architecture

The present study further describes the main terrain elements of the area so as to provide a framework for sediment sampling (Fig. 4) and analysis of transported minerals and elements (Sharpe et al., in prep). Small erosional forms on bedrock include; striations, grooves, roches moutonees, sculpted forms, scarps and channels (Fig. 5). Predominant flow is roughly east to west; a secondary flow direction to the southwest is recorded at a few sites. Larger mapped landforms include; drumlins, drumlinoids, crag-and-tails, corridors, eskers/hummocks, transverse ridges, terraces and strandlines.

Sampling design targeted till and esker (sand) as primary sediment samples. However, the samples may have been taken from a number of different terrain architectural elements that may have affected the erosion, transport and deposition of sediment and mineral indicators. For example, diamicton interpreted as till was sampled from drumlins, corridors, and terraces. Most workers (e.g. Craig, 1965; Aylsworth and Shilts, 1989a) infer that streamlined landforms in the region are constructional, whereas our early interpretation of lateral scarps, boulder lags etc., indicate that drumlins in the study area are likely erosional.

## Presentation and interpretation of till geochemical data

A periodic table of the elements is used to display the elements analysed by each digestion method (aqua regia, Fig. 6; 4-acid, Fig. 7; fusion, Fig. 8) and also highlights elements for which single element 'anomaly' maps have been generated (see Figs. 6, 7 and 8 and Appendix B). Single element maps were produced using the Natural Neighbor Interpolator of Vertical Mapper operating within MapInfo™. The interpolated grid was created using a cell size of 100 meters with an aggregation distance of 500 meters and a fixed color profile for the 0, 50$^{th}$, 95$^{th}$, 98$^{th}$, and 100$^{th}$ percentiles. Representative single element maps for Cr, Co, Ni, Cu, Pb, Zn, U, Ti, Nb, Ce, Yb, and $SiO_2$ are shown in figures 9 through 20.

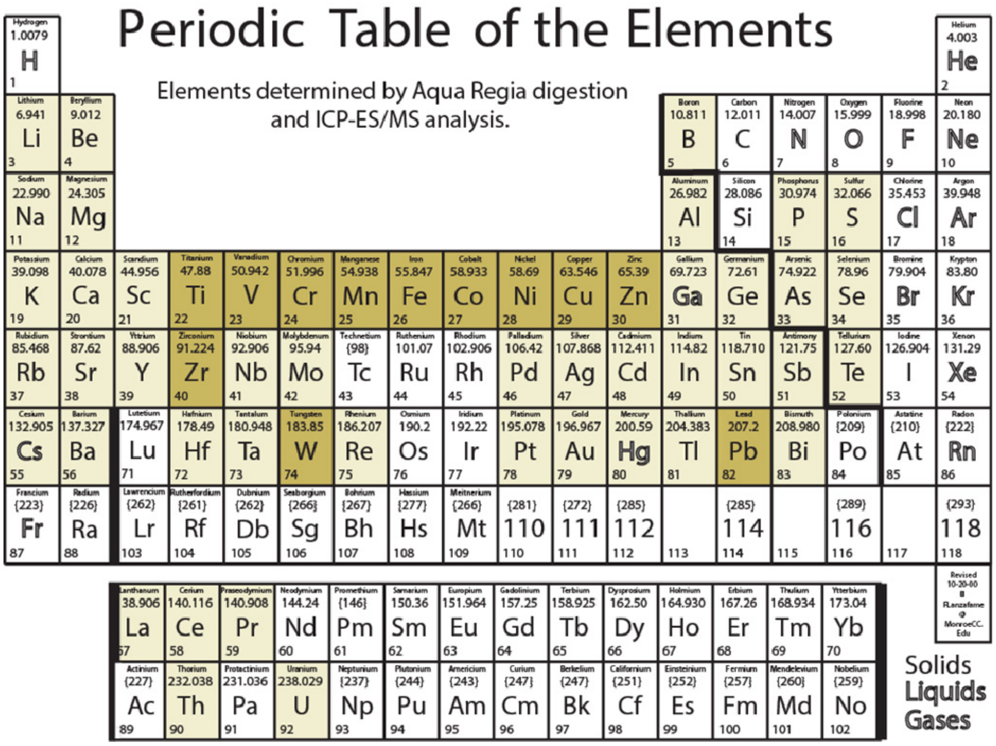


Figure 6. Periodic table of the elements. Highlighted elements determined by aqua regia digestion and ICP-MS analysis. Darker highlighted elements are linked to interpolated concentration maps in Appendix B.

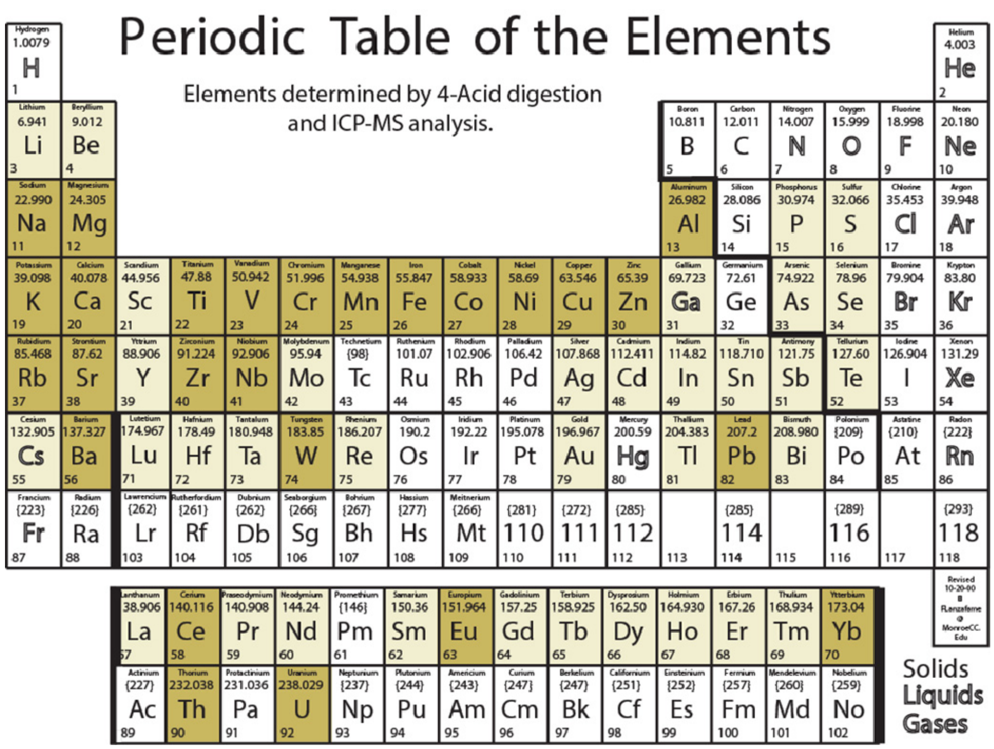


Figure 7. Periodic table of the elements. Highlighted elements determined by 4-Acid digestion and ICP-MS analysis. Darker highlighted elements linked to interpolated concentration maps in Appendix B.

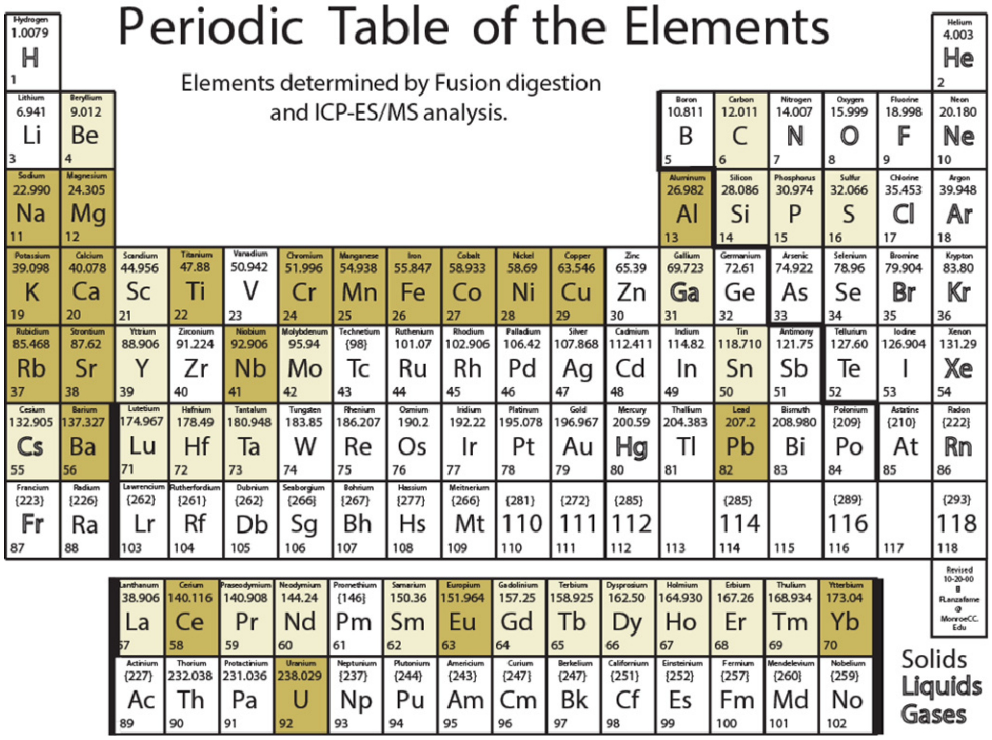


Figure 8. Periodic table of the elements. Highlighted elements determined by fusion digestion and ICP-ES/MS analysis (see Table 1). Darker highlighted elements linked to interpolated concentration maps in Appendix B.

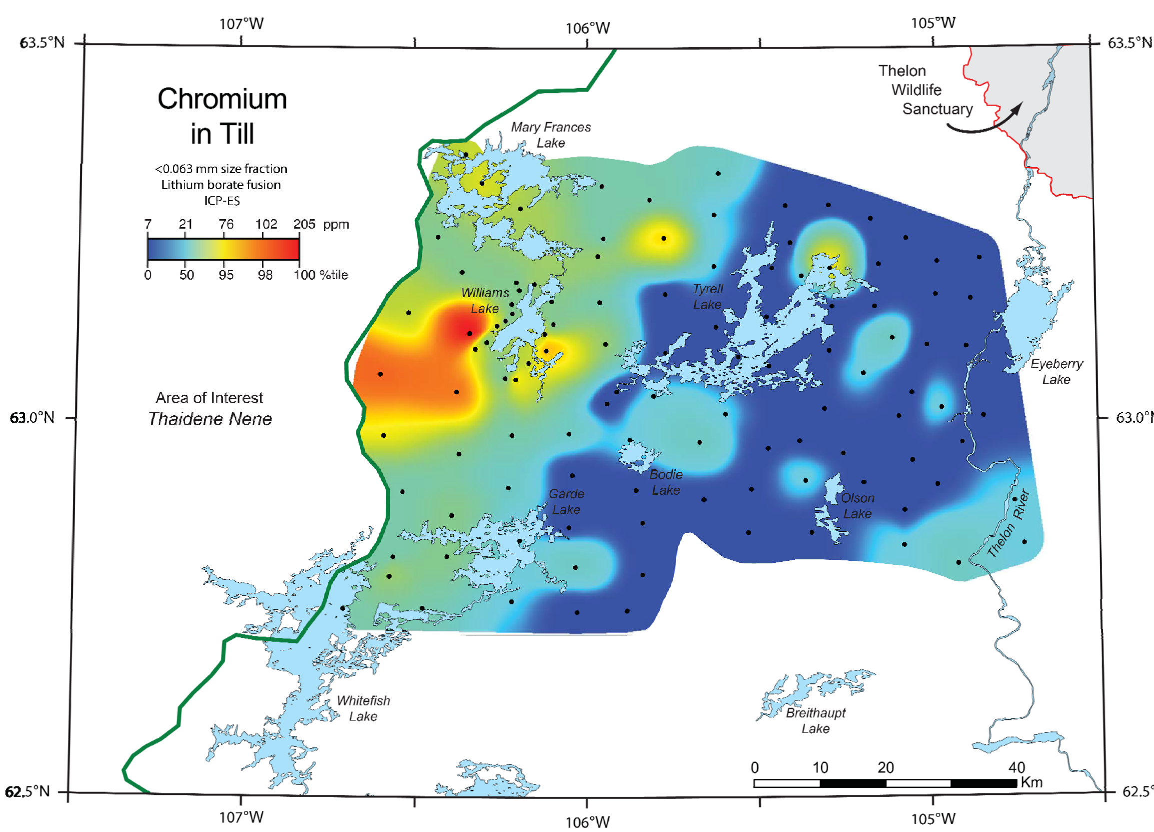


Figure 9. Single element map for chromium (Cr) by fusion digestion and ICP-ES analysis.

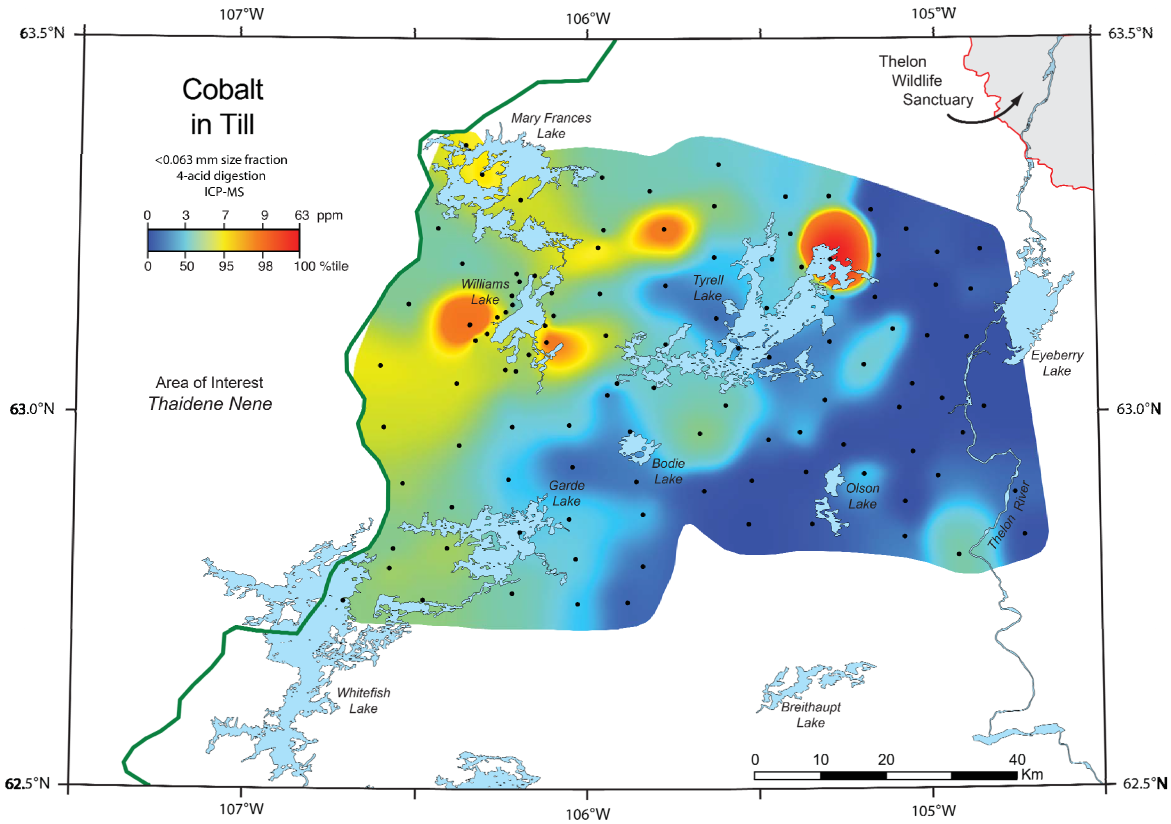


Figure 10. Single element map for cobalt (Co) by 4-acid digestion and ICP-MS analysis.

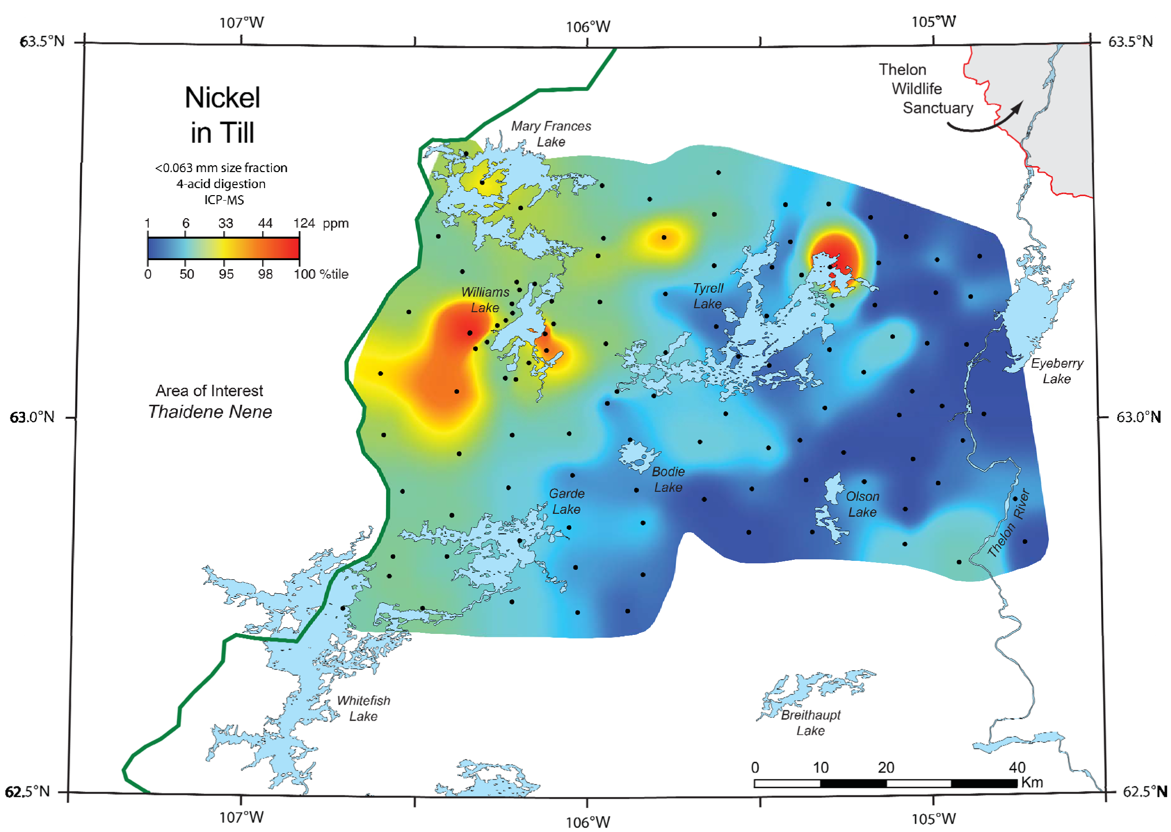


Figure 11. Single element map for nickel (Ni) by 4-acid digestion and ICP-MS analysis.

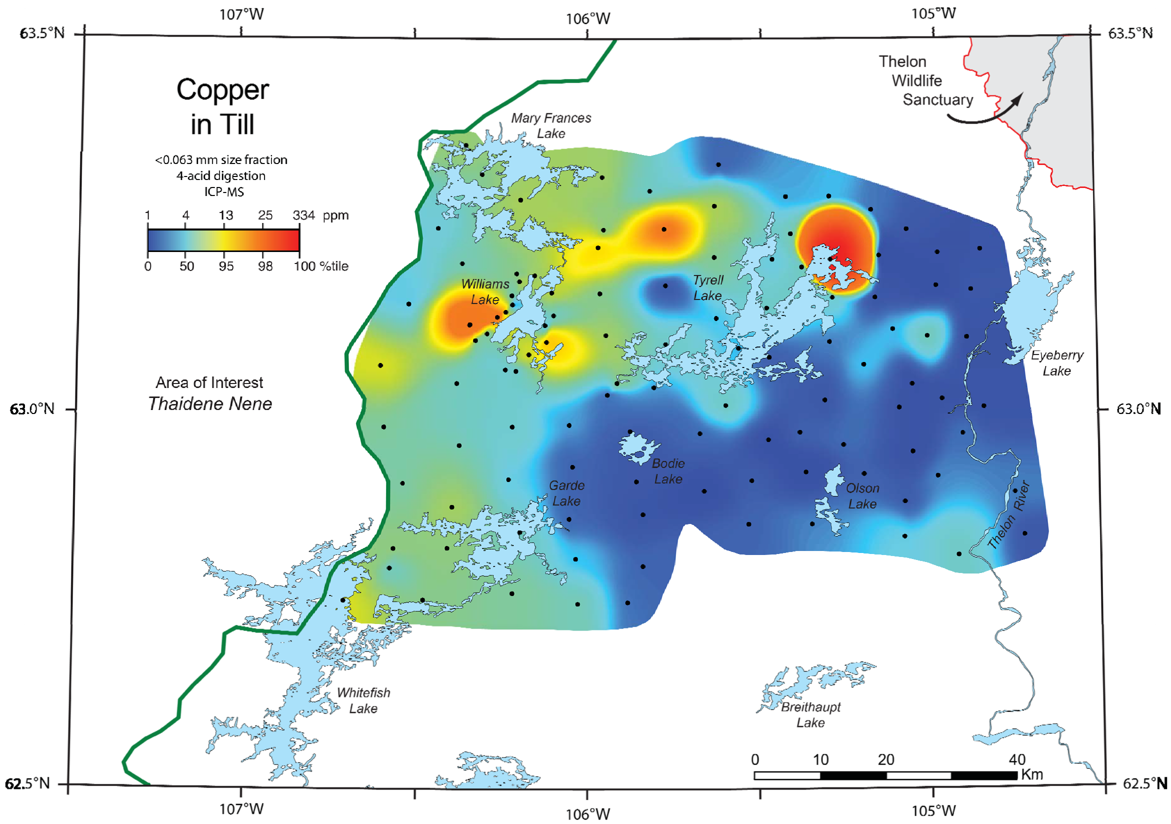


Figure 12. Single element map for copper (Cu) by 4-acid digestion and ICP-MS analysis.

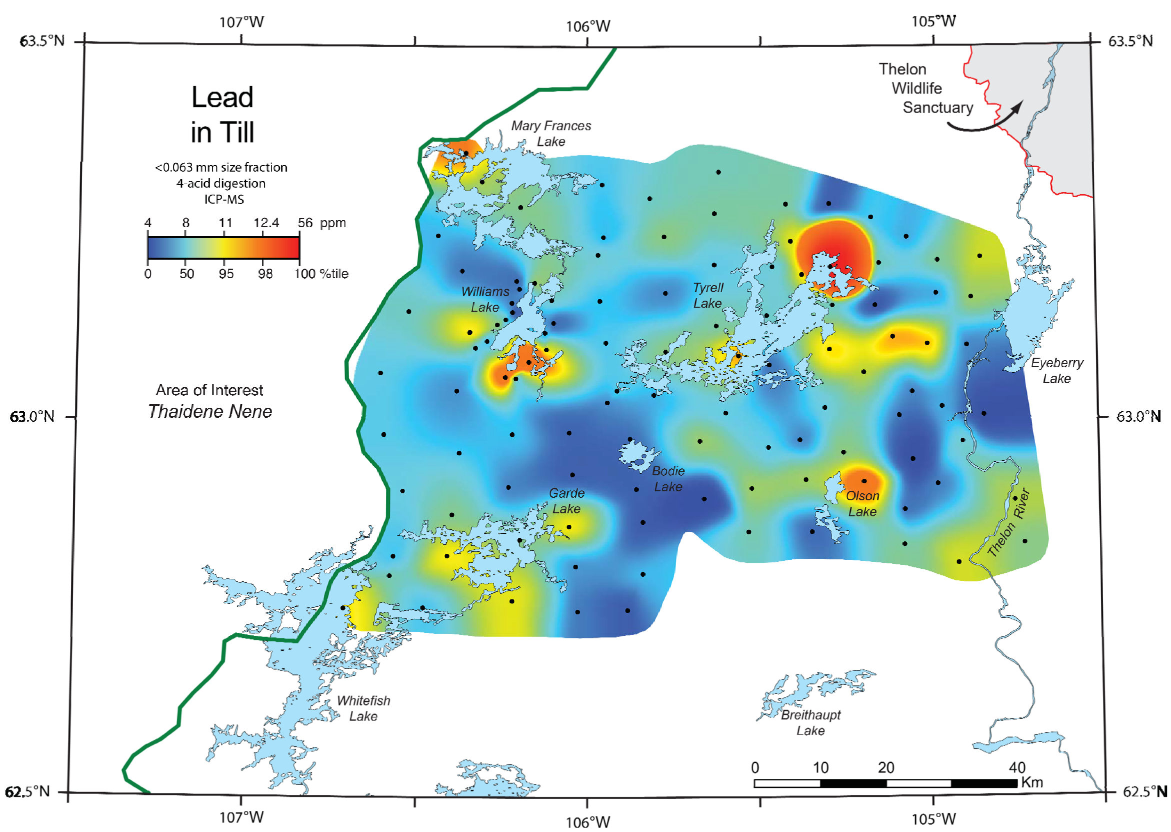


Figure 13. Single element map for lead (Pb) by 4-acid digestion and ICP-MS analysis.

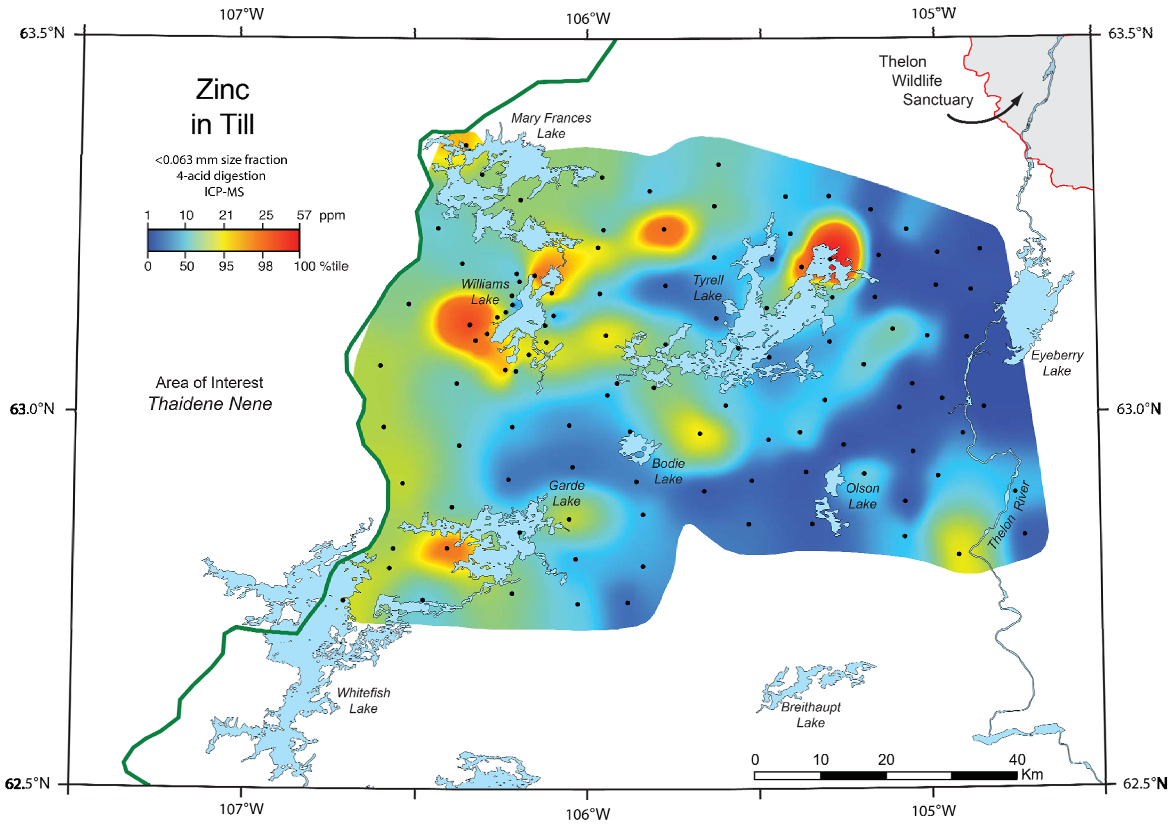


Figure 14. Single element map for zinc (Zn) by 4-acid digestion and ICP-MS analysis.

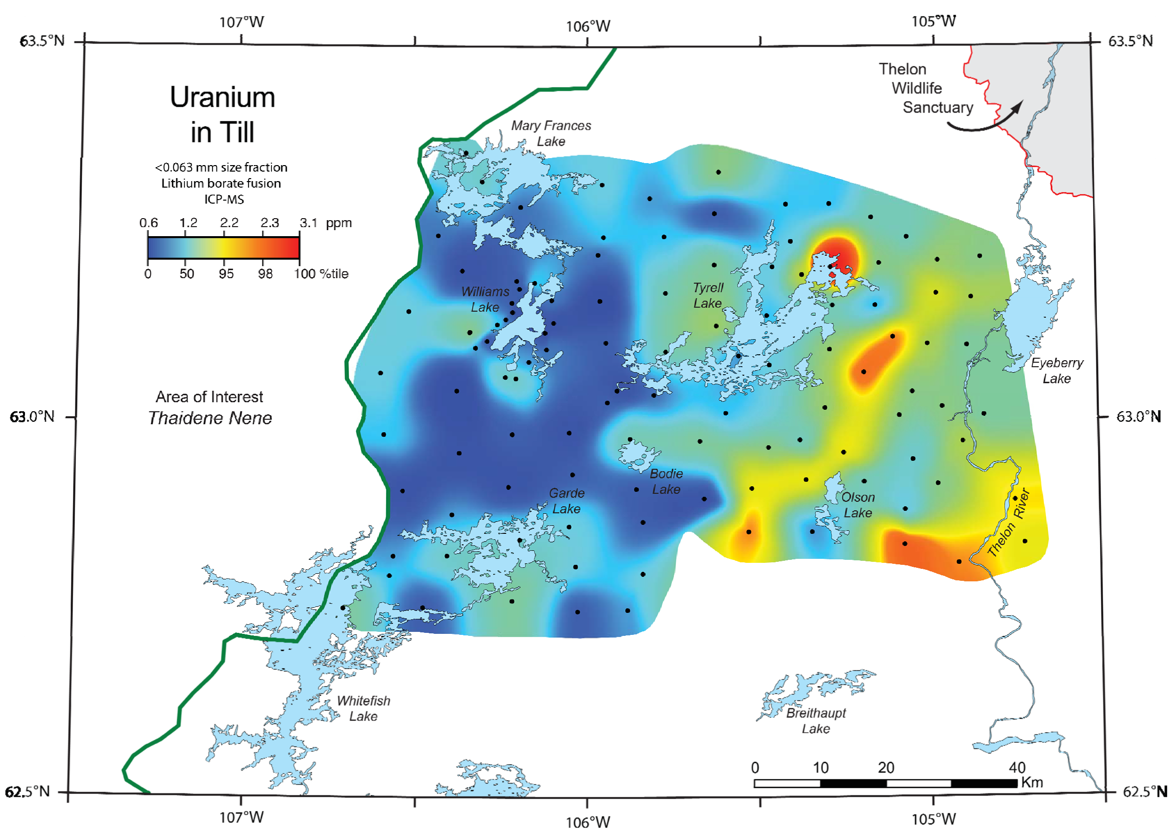


Figure 15. Single element map for uranium (U) by fusion digestion and ICP-MS analysis.

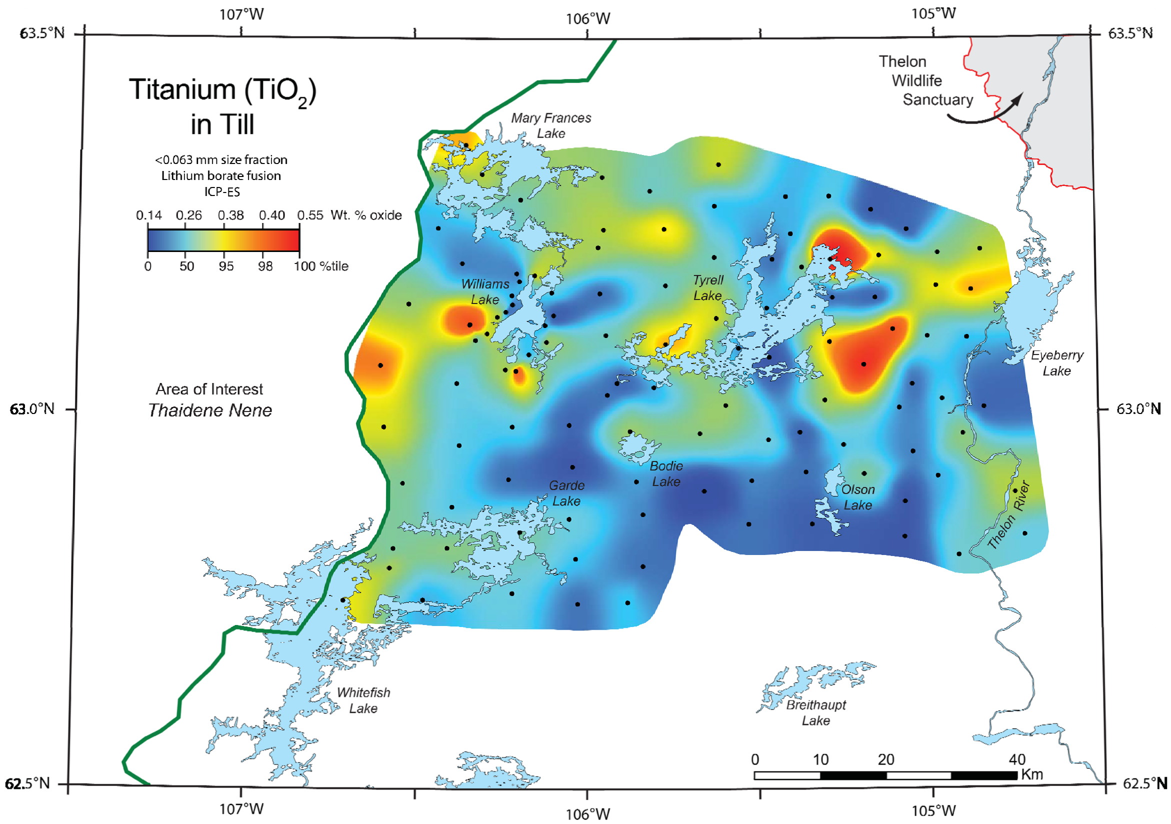


Figure 16. Single element map for titanium (Ti) as $TiO_2$ by fusion digestion and ICP-ES analysis.

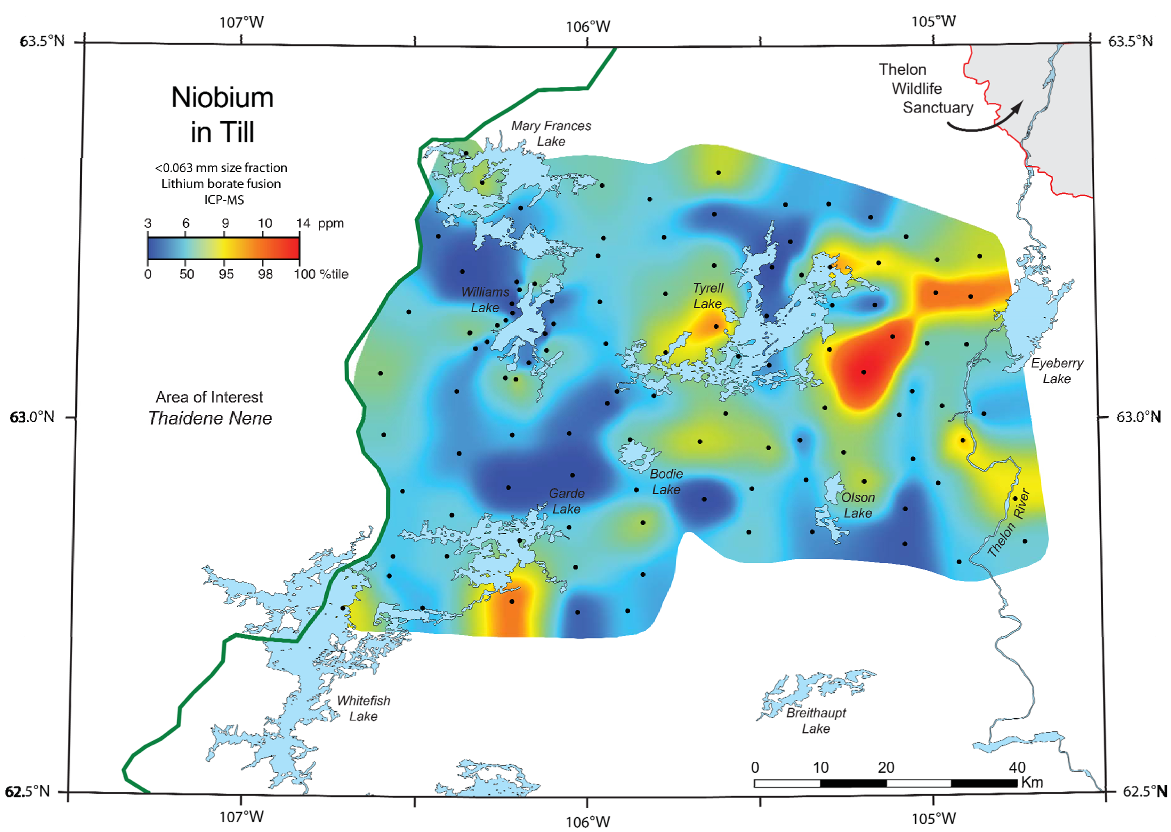


Figure 17. Single element map for niobium (Nb) by fusion digestion and ICP-MS analysis.

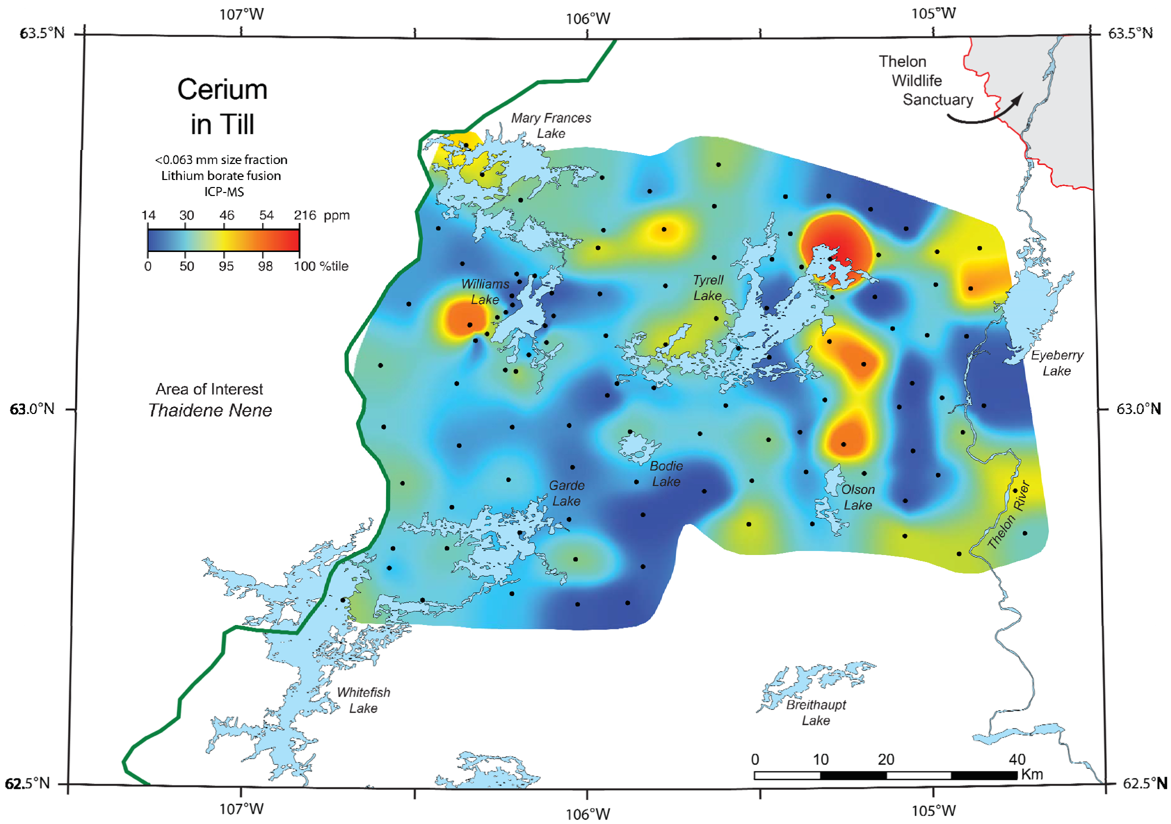


Figure 18. Single element map for cerium (Ce) by fusion digestion and ICP-MS analysis.

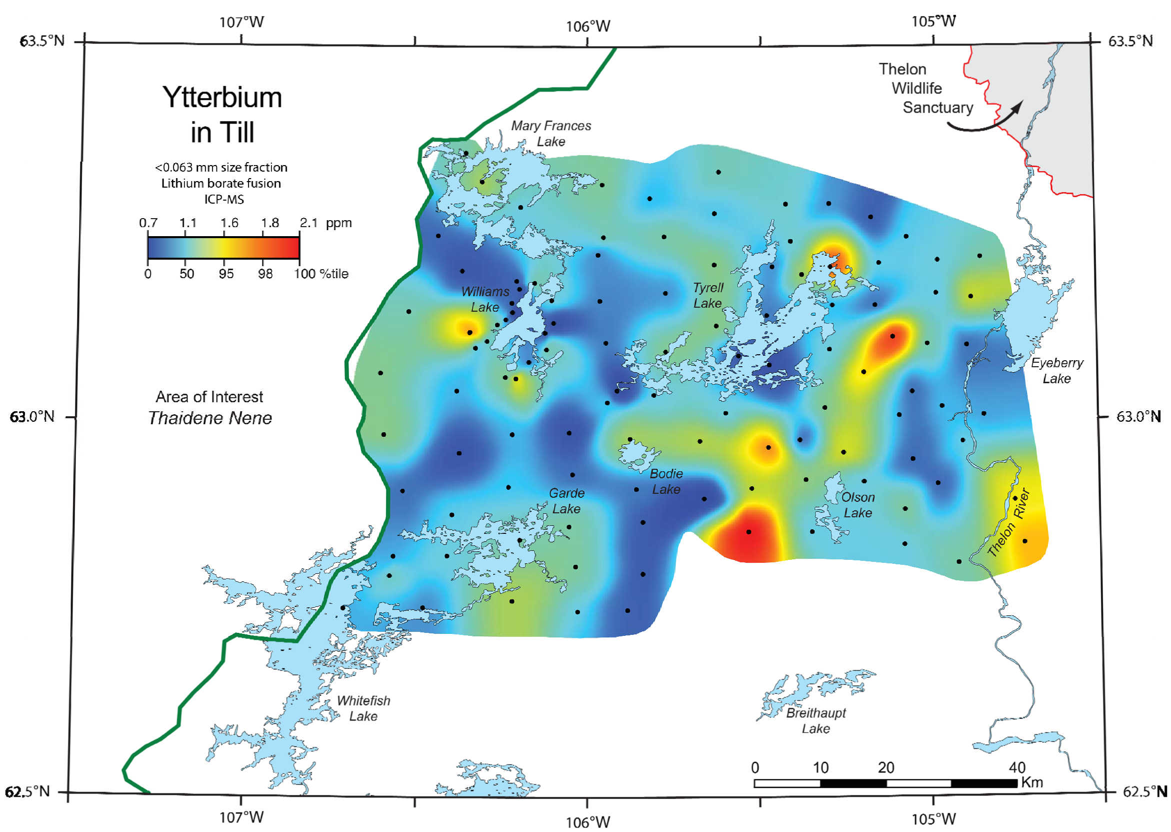


Figure 19. Single element map for Ytterbium (Yb) by fusion digestion and ICP-MS analysis.

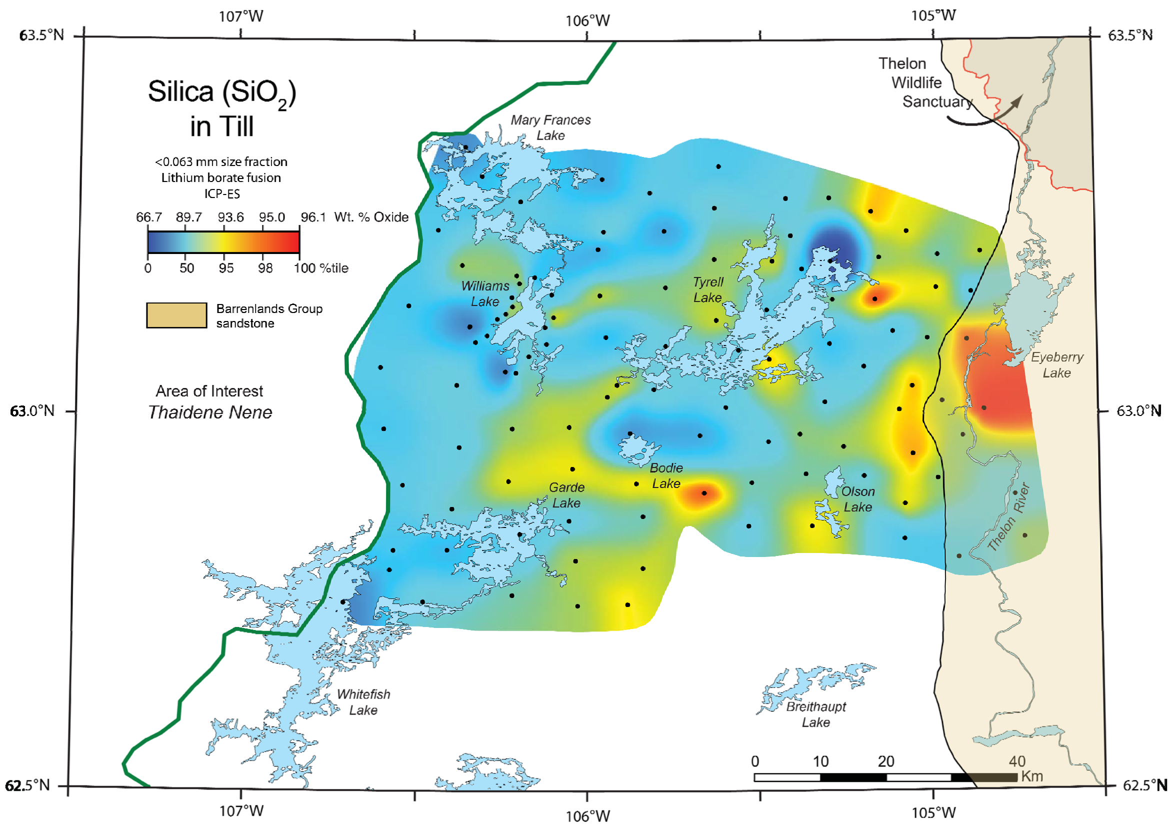


Figure 20. Single element map for silica ($SiO_2$) by fusion digestion and ICP-ES analysis. The known extent and western edge of the Thelon Basin (Barrenlands Group sandstone) shown as a light brown overlay.

## Till Geochemistry Anomalies

All single element maps where examined with respect to known mineralized occurrences to identify areas with unexplained anomalous metal concentrations. Note that samples that are anomalous, with respect to the study area, need to be rated (e.g., McCurdy et al., 2007). For this study, any individual sample is rated, with respect to sample concentration divided by the arithmetic mean of a large sample set from the region (this sample set plus the East Arm sample set of Kjarsgaard et al., 2013a). Ratings are as follows: very weak, 1.1 – 2 times the mean; weak, 2.1 – 3 times the mean; moderate, 3.1 – 5 times the mean; strong, 5.1 – 10 times the mean; very strong, greater than 10.1 times the mean. Although the study area is of limited areal extent, the anomalies noted below are anomalous with respect to the study area as well as known geochemical responses in till over a much more significant area to the east (Kjarsgaard et al., 2013a).

A number of till samples have anomalous geochemical responses (Table 2) that cannot be explained by the two known mineralized areas (to the north and south of the present study area; see Figs. 2 and 21), with respect to transport distance and direction. Till sample S006-T, adjacent to the NE arm of Tyrrell Lake exhibits a very strong response for copper (Cu), silver (Ag) and cobalt (Co) coupled with a strong response for arsenic (As), nickel (Ni) and light rare earth

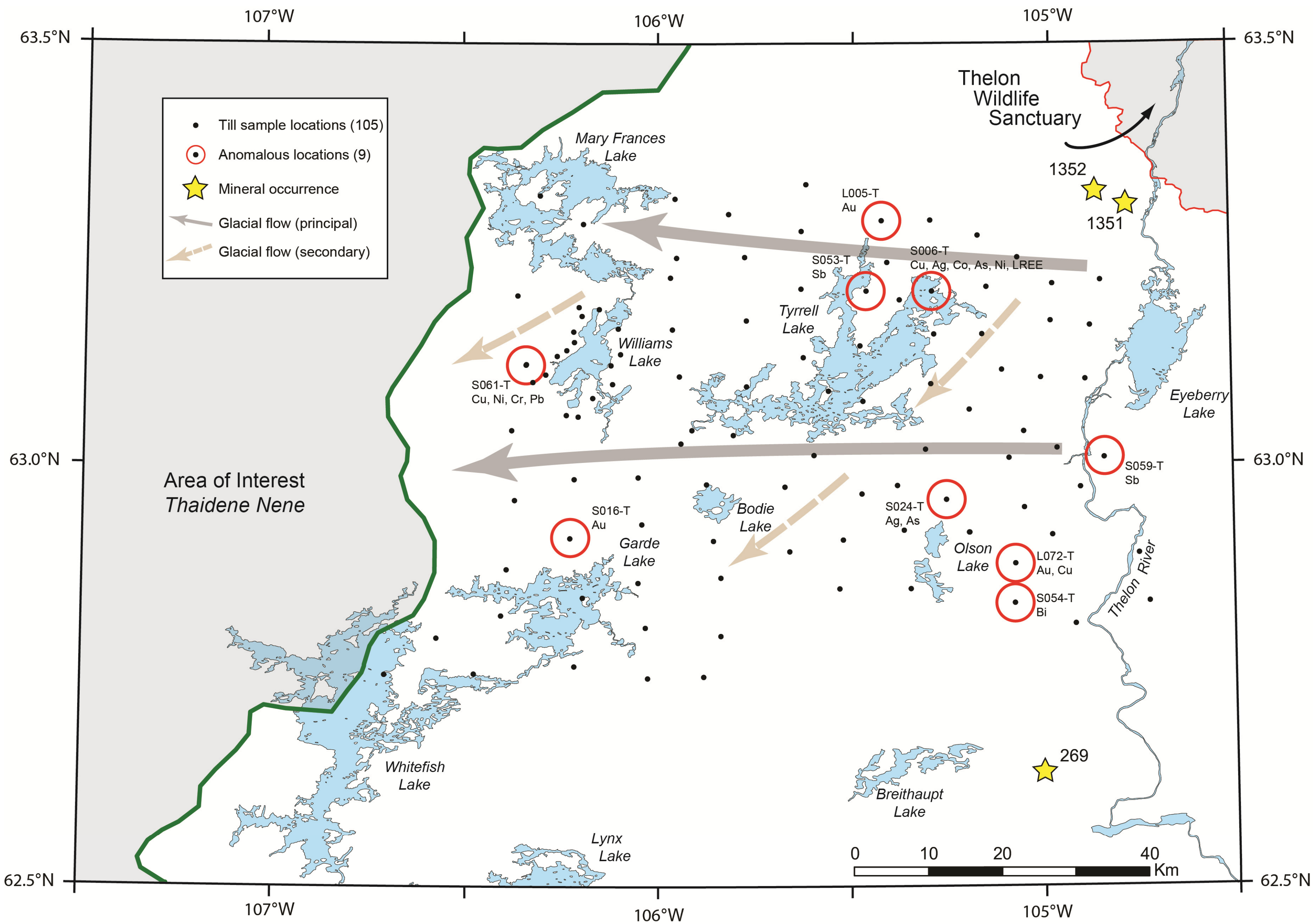


Figure 21. Map showing the locations of till samples with anomalous concentrations of element(s), with respect to the location of known mineral occurrences, and ice flow direction, in the study area. Data source for mineral occurrences from NORMIN.DB (Northwest Territories Geoscience Office, Yellowknife).

elements (LREE; Fig. 21). Anomalous and very strong responses for gold (Au) are observed at sample sites L005-T north of Tyrrell Lake, S016-T north of Garde Lake, and L072-T (that also has a strong Cu response) east southeast of Olson Lake (Fig. 21). A strong Cu, Ni, chromium (Cr) response (with moderate lead [Pb] response) is observed at sample site S061-T west of Williams Lake (Fig. 21). A strong Ag, As anomaly is observed at sample site S024-T north of Olson Lake (Fig. 21). Single element anomalies with very strong responses are observed at sample sites S059-T and S053-T for antimony (Sb) adjacent to and east and west of the Thelon River, repectively, and bismuth (Bi) at site S053-T adjacent to the northwest arm of Tyrrell Lake (Fig. 21).

| **Station ID** | **Anomalous Elements** |
|---|---|
| S006-T | Cu (40), Ag (19), Co (10), As (9), Ni (6), LREE (5) |
| S061-T | Cu (8), Ni (8), Cr (5), Pb (4) |
| L072-T | Au (10), Cu (8) |
| L005-T | Au (27) |
| S016-T | Au (22) |
| S024-T | Ag (6), As (5) |
| S059-T | Sb (81) |
| S053-T | Sb (22) |
| S054-T | Bi (11) |

Table 2. Summary of till samples with anomalous geochemical responses, and the element(s) of interest in those samples. The number in brackets after the element represents sample concentration divided by the arithmetic mean of the sample set (present study plus East Arm data sets; see text).

Of additional interest in terms of mineralization and economic potential of the study area is the exceptionally high concentration of silica (>93 wt% $SiO_2$) observed at a number of till sample sites (Fig. 20). While high silica concentrations are to be expected for samples overlying and immediately west of quartz- and feldspar-rich sandstone of the Thelon Basin (i.e., immediately adjacent to the Thelon River in Fig. 20), there are three areas further to the west worthy of note. This includes the area southeast of Bodie Lake, and areas to the east and northeast of Tyrrell Lake. Potentially, buried outliers of Thelon Basin sandstone occur in these areas, which is of interest with respect to unconformity style uranium mineralization. The visual observation of distinct areas with exceptionally high concentrations of white quartz sandstone pebbles in tills (i.e., from Thelon Basin) in the study area also supports this notion.

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