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Cover photo: Till sampling site at Kasmere Lake, northwestern Manitoba.

Abstract

Thirty-nine samples of surface tills in northernmost Manitoba have been analyzed for a suite of 35 elements and kimberlite-indicator minerals. The till-sample results presented in this report may prove useful for mineral exploration, especially where bedrock exposures are scarce, as extensive areas in northern Manitoba are covered with till, postglacial lake and marine sediments, and peat. The till-sample data provide estimates of background geochemistry, and may identify anomalous element concentrations and the presence of indicator minerals of economic interest.

The till samples were collected by the Manitoba Geological Survey at approximately 5 km spacing at Nejanilini Lake in 2005 and Kasmere and Putahow lakes in 2006. The report interprets the geographic distribution of elements and indicates sites of interest for understanding the geology of the area or for mineral exploration. Integrated with public, regional-scale till-survey data, the analytical results provide geochemical values characteristic of the larger project areas. In order to assess the glacial transport distances of the till materials, pebble lithology of the till samples is compared with the bedrock geology of the study areas.

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[1] Also available to download free of charge at http://www2.gov.mb.ca/itm-cat/freedownloads.htm, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Science, Technology, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, MB R3G 3P2, Canada.

Introduction

This open file report presents and briefly describes the results of geochemical and kimberlite-indicator-mineral (KIM) analyses of 39 till samples collected by the Manitoba Geological Survey (MGS) during the 2005 Nejanilini Lake project (Anderson et al., 2005; Anderson and Böhm, 2005; Matile, 2005) and the 2006 Kasmere and Putahow lakes projects (Anderson and Böhm, 2006; Böhm and Anderson, 2006a, b; Matile, 2006a, b) in Manitoba's far north. The till samples were collected from the uppermost and possibly only till sheet, at approximately 5 km spacing, and were analyzed for a suite of 35 elements and KIMs. The analytical results provide estimates of background values characteristic of the larger project areas, and are integrated with regional till datasets (e.g., Dredge and Pehrsson, 2006). The till-sample results may prove useful for mineral exploration, especially where bedrock exposures are scarce, as extensive areas in northern Manitoba are covered with till, postglacial lake and marine sediments, and peat.

Included in this open file are the following:

- this report (OF2008-13.pdf), which includes introductions to the bedrock and surficial geology of Manitoba north of 58°N; explanations of the till-sampling methodology, processing and geochemical analysis, and KIM analysis; a guide describing the methodology for data collection and presentation; map figures illustrating the till-sample locations (Figures 1 and 2) and pebble compositions in till samples (Figure 3); and an appendix of map figures illustrating element distributions from a selection of the till geochemical data (Figures 4–30)
- an accompanying Data Repository Item (DRI2008001.xls)[2] containing the data or other information sources used to compile this report; DRI2008001 consists of an Excel® spreadsheet with till-sample locations and till geochemical data (34 trace elements plus Au; Table 1), till-pebble counts and classification (Table 2), visual summaries of KIMs in the till samples (Table 3), and KIM microprobe analytical data (Table 4)

Regional bedrock geology

The northernmost part of Manitoba forms the southeastern flank of the Hearne Province of the Archean Rae-Hearne craton (Figure 1). In this area, the Archean continental crust

[2] Also available to download free of charge at http://www2.gov.mb.ca/itm-cat/freedownloads.htm, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Science, Technology, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, MB R3G 3P2, Canada.

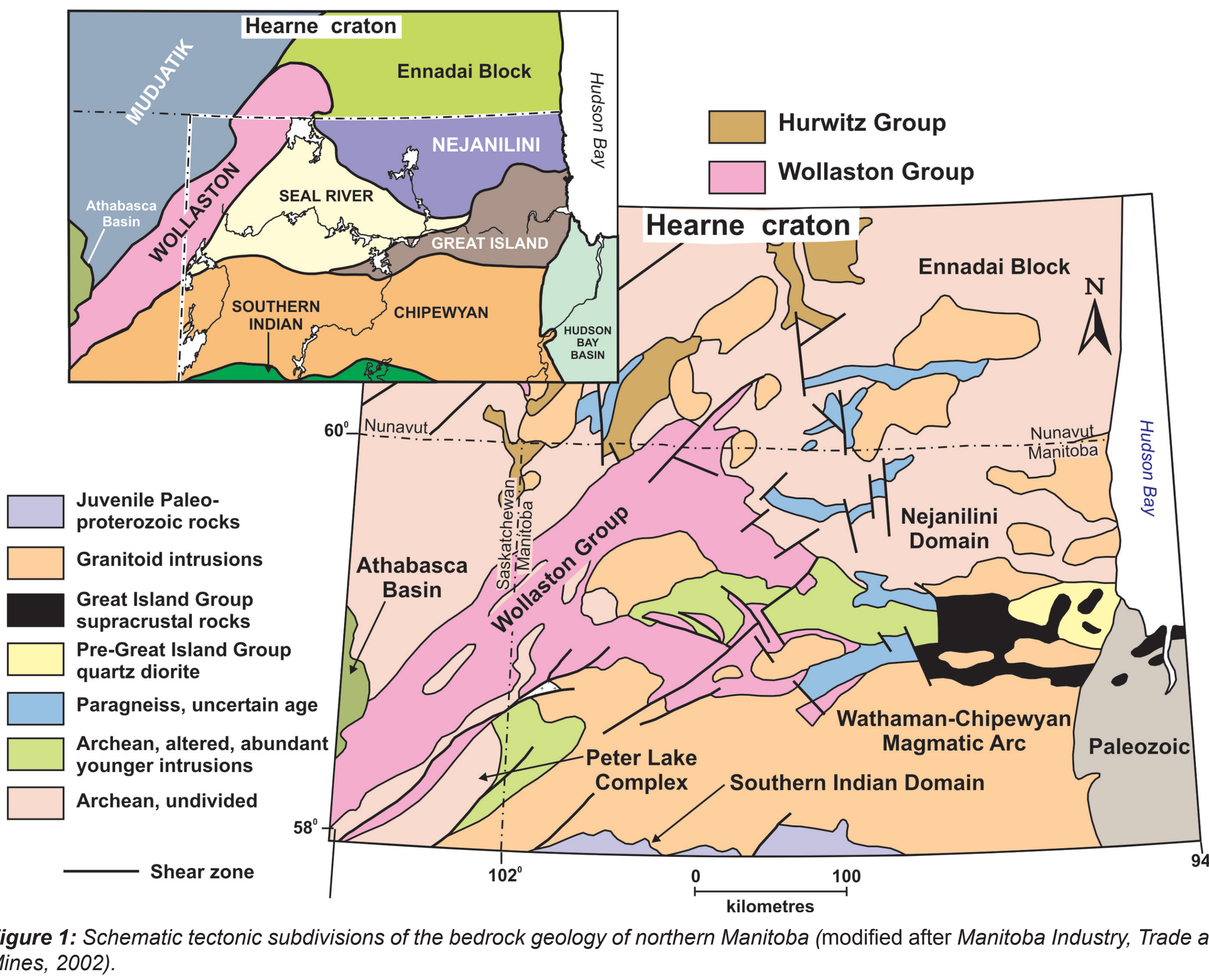


***Figure 1:** Schematic tectonic subdivisions of the bedrock geology of northern Manitoba* (modified after *Manitoba Industry, Trade and Mines, 2002).*

of the Hearne craton is overlain by Paleoproterozoic sedimentary cover rocks, and both have undergone variable degrees of thermotectonism during the Paleoproterozoic Trans-Hudson Orogeny (Lewry et al., 1978; Lewry and Sibbald, 1980). The bedrock geology of the study area is subdivided into the Mudjatik, Wollaston, Seal River and Nejanilini domains, which are distinguished by their cover rocks, the proportion or absence of basement rocks and their dominant structural trends.

The Mudjatik and Nejanilini domains consist mainly of previously undivided plutonic rocks of probable Archean age, with subordinate belts of high-grade metasedimentary rocks, whereas the Wollaston and Seal River domains consist mainly of metasedimentary rocks, possibly with rare inliers of Archean basement (Schledewitz, 1986; Manitoba Industry, Trade and Mines; 2000, 2002). The metasedimentary rocks are thought to record Paleoproterozoic deposition in an active continental-margin setting and, together with their basement, are intruded by voluminous granitoid batholiths and plutons associated with Paleoproterozoic continental-arc magmatism on the north flank of the Wathaman-Chipewyan plutonic complex, and later thermotectonism associated with the terminal phase of the Trans-Hudson Orogeny (Corrigan et al., 2007). To the south, the Wathaman-Chipewyan complex separates the Seal River Domain from a series of accreted juvenile Paleoproterozoic terranes (Halden et al., 1990; Meyer et al., 1992; Corrigan et al., 2007).

Field mapping of the bedrock geology of Manitoba's far north was undertaken by D.C.P. Schledewitz and colleagues at the MGS in the 1970s and 1980s (Schledewitz, 1986), and this mapping provides the basis for regional-scale (1:250 000) bedrock compilation maps (Manitoba Industry, Trade and Mines, 2000, 2001, 2002). As part of a current program to update the knowledge base of Manitoba's far north, revisions of the bedrock geology are available for the Nejanilini Lake area and the Kasmere and Putahow lakes areas (Anderson and Böhm, 2005, 2006; Böhm and Anderson, 2006b).

The Kasmere Lake and Putahow Lake study areas straddle the Mudjatik-Wollaston boundary, whereas the Nejanilini Lake study area occurs wholly within the Nejanilini Domain. The following sections summarize the bedrock geology to provide a framework for the interpretation of the till samples collected in the three areas.

Nejanilini Lake area

The Nejanilini Domain is composed mainly of amphibolite- to granulite-facies granitoid rocks that are thought to represent the Archean continental crust of the Hearne craton (Figures 1 and 2). Orthogneiss is typically orthopyroxene-bearing granodiorite to monzogranite (opdalite to monzocharnockite), which shows varying degrees of alkali metasomatism and contains widely scattered, discontinuous inclusions of pyroxene-bearing, intermediate to mafic gneiss. West of Nejanilini Lake, the domain comprises a foliated grey tonalite to granodiorite gneiss that extends into Nunavut, where it is considered to be equivalent to the Archean Kasba grey gneiss of the Ennadai Domain (Eade, 1973; Loveridge et al., 1988; van Breemen et al., 2007). In Nunavut, a composite sample of the Kasba grey gneiss yielded U-Pb zircon ages of 3.27 and 2.78 Ga (Loveridge et al., 1988), indicating that the grey tonalite was emplaced ca. 2.78 Ga and contains ca. 3.27 Ga zircon inheritance, or that the Kasba grey gneiss represents a composite of Archean rocks of more than one age. In northwestern Saskatchewan, a tonalitic migmatite contains zircons that yielded ages of ca. 2.82 and 3.11 Ga, again providing evidence for the existence of older basement in the area (van Breemen et al., 2007). At Nejanilini Lake, orthogneiss contains enclaves of migmatized metasedimentary rocks that consist mainly of pelitic to semipelitic paragneiss, with discontinuous units of quartzite and calcsilicate. A ca. 2.8 Ga Nd model age of a metapelite from Nejanilini Lake suggests a Neoarchean average sediment provenance, likely from the Hearne basement (Böhm et al., 2004), which suggests that the Nejanilini Lake metasedimentary rocks could be related to the Paleoproterozoic Hurwitz and/or Wollaston Group rocks to the north and west, respectively.

The supracrustal rocks are intruded by voluminous granitoid plutons of presumed Paleoproterozoic age that are present throughout the Nejanilini Domain and form discrete intrusions with broad K-feldspar alteration haloes (Clark and Schledewitz, 1988). Neodymium (crustal residence) model ages of a variety of granitoid samples, which include rock types mapped as possible granulite-grade Archean basement and Proterozoic granitoid intrusions, cluster in the tight range 3.0–3.2 Ga (Böhm et al., 2004), suggesting that they inherited their Nd isotope composition from Meso- to Neoarchean basement. Geochronology of felsic-intrusive basement samples collected during the 2005 Nejanilini Lake project yielded U-Pb igneous zircon ages of around 2.70, 2.66 and 2.58 Ga, with minor ca. 2.8 Ga zircon inheritance (Böhm, unpublished data, 2006), similar to tonalite and granite in the Phelps Lake area of northeastern Saskatchewan (van Breemen et al., 2007). Overlying quartzite at Nejanilini Lake appears to be derived mainly from Neoarchean basement of similar age (Böhm and Anderson, 2007). The youngest detrital zircons in the quartzite are ca. 2.50 Ga, comparable to quartz-rich sedimentary rocks of the lower Hurwitz Group in Nunavut (Davis et al., 2005). A smaller amount of Mesoarchean zircon detritus in the quartzite may reflect the presence of recycling of Hearne proto-crust. Semipelitic paragneiss at Nejanilini Lake, in comparison, yielded ca. 1.9–2.0 Ga detrital zircons (Böhm and Anderson, 2007; Böhm, unpublished data, 2006), similar to semipelitic paragneiss from the Wollaston Supergroup in Saskatchewan (Yeo and Delaney, 2007) and the upper Hurwitz Group in Nunavut (Davis et al., 2005).

Mineral assemblages in the Nejanilini Lake area indicate a regional metamorphic peak in the granulite facies, as is evidenced by the widespread and pervasive occurrence of mobilizate layers and patches. A sample of cordierite-garnet–rich mobilizate in paragneiss at Nejanilini Lake contains ca. 1813 Ma metamorphic zircon (Böhm, unpublished data, 2006), marking the peak Trans-Hudsonian thermal event. The structural grain is mainly east-west and appears to be defined by upright, tight to isoclinal macroscopic folds that may be doubly plunging on a regional scale.

Kasmere and Putahow lakes areas

The Kasmere and Putahow lakes areas lie largely within the Wollaston Domain and straddle the adjacent Mudjatik Domain to the northwest (Figure 1). No examples of Archean basement

Sample Overview

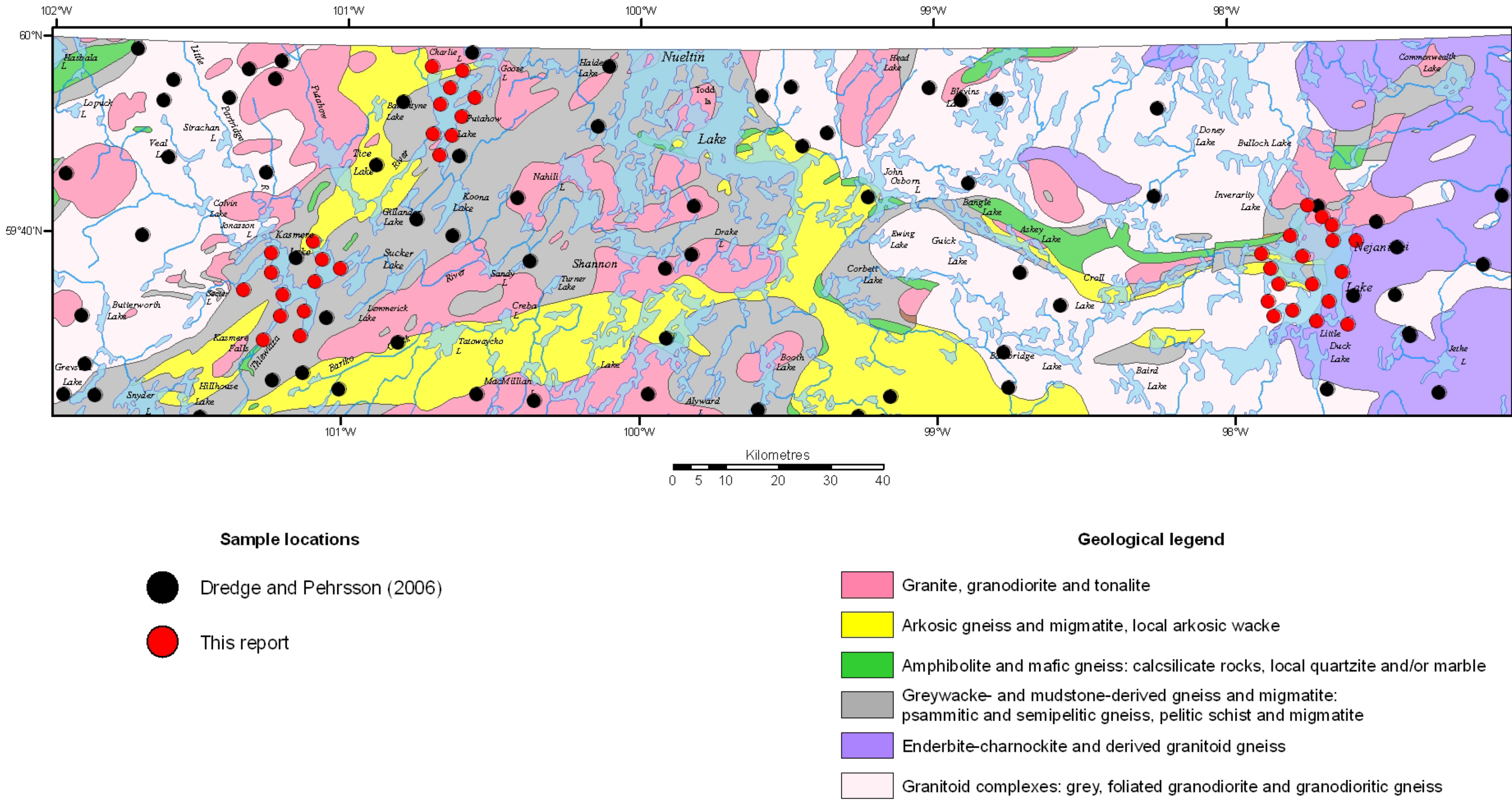


Figure 2: *Locations of new till samples (red circles) collected in the Nejanilini Lake area (Anderson and Böhm, 2005) and the Kasmere and Putahow lakes areas (Böhm and Anderson, 2006b; Anderson and Böhm, 2006). Black circles show locations of till samples reported by Dredge and Pehrsson (2006) and used in this report for regional data comparison. Schematic bedrock geology is simplified after Manitoba Industry, Trade and Mines (2000, 2001, 2002).*

rocks are documented in the area, and the geology is interpreted to consist predominantly of Paleoproterozoic metasedimentary rocks of the Wollaston Supergroup, with subordinate granitoid intrusions of probable Paleoproterozoic age (Weber et al., 1975a, b). In the adjacent Mudjatik Domain of northeastern Saskatchewan, however, apparently weakly deformed, leucocratic granitoid intrusions have yielded Neoarchean U-Pb zircon ages (ca. 2.72 Ga, Harper et al., 2004; ca. 2.68–2.65 Ga, van Breemen et al., 2007).

The metasedimentary rocks at Kasmere and Putahow lakes consist of psammitic, pelitic and arkosic paragneiss, quartzite, and minor units of marble, calcsilicate and conglomerate, which are interpreted to represent a foreland-basin sequence similar to that described in the Saskatchewan portion of the Wollaston Domain (e.g., Harper and Slimmon, 2005; Harper et al., 2003, 2005a, b; Tran et al., 2003). Preliminary detrital zircon age data for a quartzite sample from Kasmere Lake indicate a dominant ca. 2.7 Ga zircon source, with fewer zircons as young as ca. 2.5 Ga (Böhm and Anderson, 2007), which is comparable to the Nejanilini Lake quartzite. Metasandstone samples from the Putahow-Goose lakes area northeast of Kasmere Lake, in comparison, have abundant ca. 2.1–1.9 Ga, minor 2.4–2.3 Ga and variable 2.7 and 2.6 Ga detrital zircons like those from the upper Hurwitz Group in the central Hearne craton of Nunavut (Davis et al., 2005). In Saskatchewan, a ca. 2.10 Ga minimum age for the Wollaston Supergroup is indicated by a U-Pb zircon age of 2076 ±3 Ma from a quartzofeldspathic gneiss in the Courtenay Lake Formation, which is interpreted to be an igneous crystallization age (Annesley et al., 1992). Courtenay Lake Formation conglomerate, arkose and quartzite are interlayered with mafic volcanic rocks that exhibit an affinity to within-plate magmatism, thus favouring emplacement in a continental-rift setting (Fossenier et al., 1995; MacNeil et al., 1997). These rocks are likely, at least in part, time equivalent to the ca. 2.1–1.9 Ga upper Hurwitz Group metasedimentary rocks of the Hearne craton (Patterson and Heaman, 1991; Heaman and LeCheminant, 1993; Davis et al., 2005) and those from Wollaston Supergroup sedimentary rocks in northeastern Saskatchewan, which, in addition, have abundant 1.90–1.88 Ga detrital and younger (metamorphic) zircons (Yeo and Delaney, 2007; C.T. Harper, pers. comm., 2007).

The Wollaston Supergroup is intruded by granitic rocks and pegmatite that yield ages ranging from 1.84 to 1.80 Ga (Annesley et al., 1992, 1997) in the Wollaston Domain in Saskatchewan, which corresponds to the main period of Hudsonian granite emplacement throughout the western Churchill Province (Peterson et al., 2000, 2002).

Mineral assemblages in the Kasmere Lake area indicate a regional metamorphic peak in the upper amphibolite facies. The structural grain is mainly northeast-southwest and the supracrustal rocks appear to occupy elongate dome-and-basin structures that define upright, tight to isoclinal macroscopic folds that are doubly plunging on a regional scale. The western boundary of the Wollaston Domain is defined by a pronounced geophysical lineament that is traceable from the Manitoba-Saskatchewan border northeasterly to the Nunavut border. This boundary is considered to be structural in origin and is likely similar in age to the crustal-scale Needle Falls Shear Zone (1855–1800 Ma; Stauffer and Lewry, 1993) that forms the eastern boundary of the Wollaston Domain in Saskatchewan.

Quaternary geology

Permafrost, soil and terrain morphology

Most of the Nejanilini Lake area is north of the treeline, whereas the Kasmere and Putahow lakes areas are situated south of the treeline in an area of discontinuous permafrost (Natural Resources Canada, 2005). Permafrost, and permafrost features such as patterned ground and mud boils, are more common in the Nejanilini Lake area. Permafrost is encountered as shallow as 20 cm below surface in peatlands and as deep as 2 m in better drained sediments. Felsenmeer is widespread in both sample areas.

In both areas, the A and B soil horizons are typically a total of 10–30 cm thick. Local relief tends to be around 10–15 m. The larger eskers are typically 30 m in height. The largest ridges are up to 80 m high and are likely cored with durable bedrock.

Glacial setting and stratigraphy

The surficial geology of the study areas was previously mapped in the late 1970s by the Geological Survey of Canada. The results were published as a series of 1:250 000 scale preliminary maps by Dredge and Nixon (1981) and Dredge et al. (1982), and as a 1:500 000 scale final map by Dredge et al. (1985). More recently, the surficial geology and Quaternary stratigraphy of the Nejanilini Lake area and the Kasmere and Putahow lakes areas were investigated at a limited number of natural exposures and hand-dug pits (Anderson et al., 2005; Matile, 2005; Matile, 2006a, b).

The area is situated within the Keewatin sector of the Laurentide Ice Sheet. Glacial ice flowed southward over Precambrian rocks, producing a glacial till (diamict) with a very sandy matrix. The area was deglaciated between 7000 and 8000 years BP (Thorleifson, 1996; Matile and Keller, 2007). The pristine nature of the landforms and the general lack of sediment overlying the till suggest that Glacial Lake Agassiz did not extend into the Nejanilini Lake area and the Kasmere and Putahow lakes areas.

Glacial till is the most abundant surface material, followed by organic wetlands and glaciofluvial sediments such as eskers. In the Nejanilini Lake area, the glacial stratigraphy comprises >5 m of stratified sand (base of sand unit not exposed), overlain by a discontinuous cover of glacial till with an average thickness of 1 m that is characterized by a highly variable pebble content and numerous sand seams. In the Kasmere and Putahow lakes areas, the light grey to light brownish grey till (Munsell Color, 1975) appears to be several metres thick (base of till not exposed). The till is generally noncompacted and noncalcareous with a fine sand matrix. The till in both areas is locally overlain by esker sediments.

Numerous south-trending eskers are typically found within meandering tunnel channels, and are made up of several interconnected ridges composed of sand to pebbly sand, locally covered by gravel and/or subrounded to rounded boulders. The eskers are commonly flanked by sandy fans and boulder deposits, as well as areas of bedrock outcrop with scattered subrounded boulders.

Boulders and pebbles on eskers were found to contain significant quantities of exotic rock types transported long distances (from >10 to 20 km) down ice from outside the map areas (Anderson et al., 2005). Ubiquitous surface boulders, in comparison, are surprisingly consistent lithologically in any particular location and the lithology changes rapidly from area to area, presumably mimicking the local bedrock. Similarly, pebble counts from the till samples suggest short transport distances (Figure 3; Anderson et al., 2005), estimated to be between 1 and 5 km by Dredge (1981).

In Figure 3, counts and lithological classification of pebbles from till samples at Kasmere, Putahow and Nejanilini lakes (DRI2008001, Table 2) are graphically compared to the local bedrock geology. Because quartz veins are generally not sizable enough to be mapped, vein quartz pebbles are not included in Figure 3. The pie charts for pebble populations from till samples are colour coded based on the proportional pebble lithology. As shown in Figure 3, the pebble lithology largely matches the local bedrock geology, with only minor or no exotic pebbles observed. These observations provide further evidence that till in the study areas is locally derived and may thus be used to trace mineral anomalies in the local bedrock. Few pebbles are exotic compared to rock types exposed in the map areas; in the Kasmere and Putahow lakes areas, exotic pebbles are volcanic porphyritic, whereas exotic pebbles at Nejanilini Lake include volcanic porphyritic, chert iron formation and red bed rock types (DRI2008001, Table 2).

Bedrock outcrop is typically strongly weathered and, as a result, there are very few measurable glacial striations. Striations range from 160° to 180° in the Nejanilini Lake area, and from 190° to 200° in the Kasmere and Putahow lakes areas, providing approximate glacial transport directions and evidence of a single glaciation.

The till surface is intensely streamlined and is interpreted to have been eroded by turbulent subglacial meltwater (Rampton, 2000; Campbell, 2002; Brennand and Shaw, 1994; Matile, 2006a). The orientation of these landforms is highly variable and only loosely parallels the ice-flow direction as determined by glacial-striation measurements. Individual landform types, such as spindle drumlins, crescentic drumlins, Rogen moraines, tunnel channels and eskers, are typically found in clusters or grouped in curvilinear corridors. Although the orientation of narrow spindle drumlins appears to closely mimic the southerly ice-flow direction, other landforms, such as broader crescentic drumlins, Rogen moraines, tunnel channels and eskers, are highly variable in orientation. These landforms are believed to be derived from either erosional or depositional processes associated with turbulent subglacial meltwater flow and thus do not directly reflect the orientation of glacial-ice flow, but complicate the interpretation of the source of anomalies in till.

Methods

Till sampling

Eighteen glacial till (diamict) samples in the Nejanilini area and twenty-one in the Kasmere and Putahow lakes areas were collected from hand-dug pits and natural exposures (Anderson et al., 2005; Matile, 2006a, b). The till-sample sites were generally within 100 m of the lakeshore with a fairly uniform spacing of approximately 5 km (Figure 2). The samples were taken from the C horizon, 10–20 cm below an abrupt decrease in soil oxidation. Between 50 and 100 pebbles (1–4 cm along b-axis) per sample were collected separately, washed and classified based on the regional bedrock geology (DRI2008001, Table 2; Figure 3).

Till-sample processing and analysis

In the MGS sample-preparation facility, the entire till sample (10 L or ~20 kg) was laid out for drying and then split (pie-piece method) into a representative sample of ~1–2 kg for geochemical analyses. The remaining material for each sample was submitted for indicator-mineral analysis.

The silt (<63 µm, approx. 230 mesh) and clay (<2 µm) fractions of the ~1–2 kg till sample splits were prepared for geochemical analysis by dry-sieving and centrifugation at the MGS facility. Approximately 30 g of the resulting <63 µm silt fraction and 0.5–1.5 g of the <2 µm clay fraction were sent to Activation Laboratories Ltd. in Ancaster, Ontario for aqua-regia extraction and instrumental neutron activation analysis (INAA; Hoffman, 1992) for 34 trace elements plus gold. The analytical results are presented in Table 1 of DRI2008001. Quality control on these data was done by including six duplicate till samples (three for each size fraction), one MGS internal till standard ('STEF') for the <2 mm size fraction and one certified reference standard ('TILL-2'; CANMET Mining and Minerals Sciences Laboratories, Ottawa, Ontario; http://www.nrcan-rncan.gc.ca/mms/canmet-mtb/mmsl-lmsm/ccrmp/certificates/tills.htm) for the <63 mm size fraction.

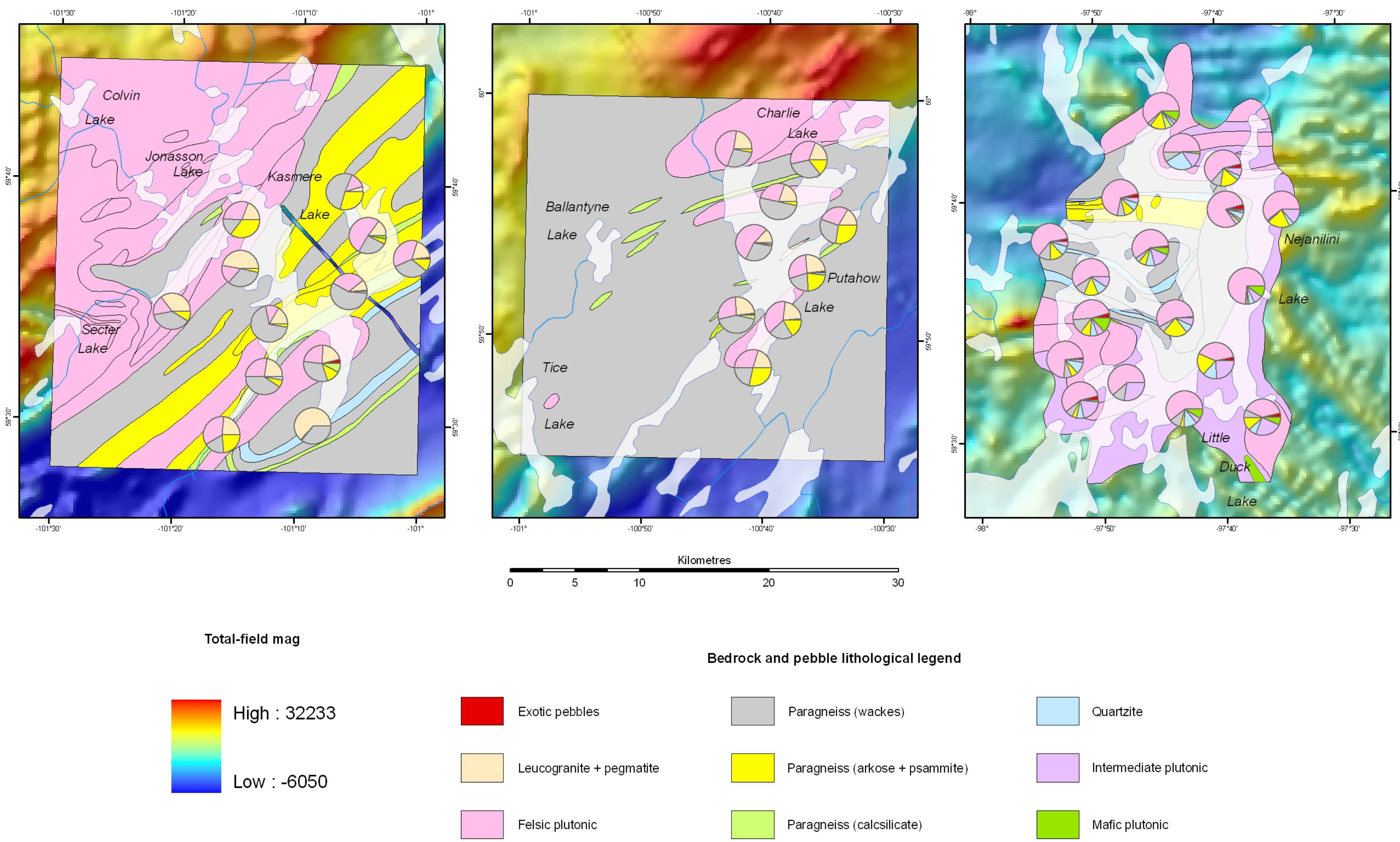
Separate samples of the 1–4 cm size fraction (pebbles) were collected for each till sample. The lithology and percentages of pebbles (DRI2008001, Table 2; Figure 3) were determined in the field camp.

Till-sample processing for KIMs was conducted by De Beers Canada Exploration Inc. at their sample-processing facility in Sudbury, Ontario, where samples were screened into +1.0 mm, 0.3–1.0 mm and –0.3 mm fractions. Heavy minerals in the –1.0 mm size fractions were concentrated by standard magnetic- and density-separation methods optimized for recovery of KIMs. Heavy-mineral aliquots (50 g of 0.5–1.0 mm, 30 g of 0.3–0.5 mm) were shipped to De Beers sorting lab in Toronto, Ontario, where the two size fractions were hand picked for visual KIMs, including garnet (peridotitic and eclogitic), ilmenite, clinopyroxene (chrome diopside), spinel (chromite) and others (e.g., diamond, olivine). In addition to kimberlitic indicator minerals, the presence of gold grains was noted. Selected indicator minerals were further classified as 'doubtful', 'ambiguous/questionable' or 'kimberlitic', based on visual criteria (DRI2008001, Table 3). The selected indicator-mineral grains were then sent for microprobe analysis to De Beers Analytical Services in Johannesburg, South Africa. Microprobe geochemical results for 24 individual mineral grains are listed in Table 4 of DRI2008001 and included in the Manitoba Kimberlite Indicator Mineral Database (Keller et al, 2004).

ArcGIS® data presentation

The resulting analytical data are presented in Figures 4–30 (Appendix 1), which were constructed using ArcGIS®. In creating these diagrams, element-concentration distributions

Pebble Counts



Pie-chart colours are coded to match bedrock geology.

Figure 3: *Pebble counts on till samples from the Nejanilini Lake area and the Kasmere and Putahow lakes areas. Bedrock geology is simplified after Anderson and Böhm (2005), Böhm and Anderson (2006b) and Anderson and Böhm (2006). Pie charts represent proportional pebble compositions, colour-coded according to bedrock lithology. Map background depicts total magnetic field.*

were used to separate the data into classes, with class breaks selected to best group similar values and maximize the differences between classes.

Interpretation of the till geochemical results and application for mineral exploration

Trace-element geochemical analysis of the <63 μm (silt) till fraction (DRI2008001, Table 1; Appendix 1, Figures 4–12) is interpreted to best reflect the regional geology (provenance) and thus provide an indication of the mineral potential of the region. The <63 μm till fraction contains very diluted clay and heavy-mineral information. In comparison, the <2 μm (clay) till fraction (DRI2008001, Table 1; Appendix 1, Figures 13–21) represents a concentrate of minerals (improved signal/noise ratio) whose composition may be indicative of a variety of mineralization types (e.g., precious and base metals, uranium, rare earth elements).

Regional distributions

In order to integrate the till-sample data from the Nejanilini Lake area and the Kasmere and Putahow lakes areas into the regional geology of Manitoba's far north, geochemical results for the <2 μm (clay) till fraction from the 39 new samples were compared with geochemical results from regional till-sample data by Dredge and Pehrsson (2006, Figure 2). Figures 22–30 (Appendix 1) show element concentrations for till samples from the combined dataset. Comparison of variations of element concentrations between the tighter spaced, local dataset (this report) and the wider spaced, regional data (Dredge and Pehrsson, 2006) allows a first-order evaluation of the regional (background) means, identification of local anomalous values and identification of areas that have multi-element anomalies (Dredge and Pehrsson, 2006). For example, the Wollaston metasedimentary basin and its interface with older basement (e.g., Mudjatik Domain) and younger intrusions (e.g., Nueltin and Hudson granite suites) appear to host anomalously high amounts of U, Fe, Ni, Cr, Mo, REE, Au, and possibly Zn and Cu (DRI2008001, Table 1; Appendix 1, Figures 23–30).

Other areas with multi-element anomalies outside the Nejanilini Lake area and the Kasmere and Putahow lakes areas include (Dredge and Pehrsson, 2006)

- southwest of Baralzon Lake and northwest of Nejanilini Lake near Hutton Lake (Co-Cr-Zn-Ni-Cu-Mn anomalies);
- Great Island–Seal River area, including areas east, west and south of Great Island (Au-As-Fe-Cu-Co and possibly U); and
- northeast of Caribou and Long lakes (various base-metal anomalies).

Kimberlite-indicator-mineral results

Table 3 summarizes the visual kimberlitic-indicator-mineral (KIM) results from the 39 till samples collected at Nejanilini, Kasmere and Putahow lakes. To further assess a kimberlitic affinity, the composition of the 25 visual KIM grains reported was determined by electron-microprobe analysis (Table 4). The following is a summarized interpretation of the data:

- Garnets that have an empirically strong affinity with diamond are low-Ca and high-Cr (G10) garnets from peridotitic mantle sources and low-Cr and high-Ca (G3) garnets from possible eclogitic mantle sources (e.g., Gurney, 1984; Grütter et al., 2004). Four analyzed garnets have variable CaO concentrations but very low to absent Cr_2O_3, characteristic of crustal rather than kimberlitic garnets.
- Even though there is considerable compositional overlap between spinels in a variety of mantle and crustal source rocks, Cr-rich spinel (chromite) from chromite harzburgite can be associated with diamond if the chromites have high Cr content (>60 wt. %, pressure dependent), together with relatively high Mg and low Ti. Analyzed spinels have moderate levels of Cr_2O_3 (~42-57 wt. %) and strongly variable MgO (~0-13 wt. %) concentrations. One analyzed spinel is high in TiO_2 (7.3 wt. %; Table 4, KML10, grain #4, Table 4) but lacks the high Cr content characteristic of the Cr-Ti chromites of lamproite and kimberlite.
- Analyzed ilmenite grains have very low MgO and Cr_2O_3 concentrations and thus plot outside the kimberlitic fields of Mg-ilmenite as defined by Wyatt et al. (2004).
- A clinopyroxene grain from Nejanilini Lake (Table 4, GM060, grain #55) has very low Al_2O_3 and moderate to low Cr_2O_3, compared to kimberlitic Cr-diopsides derived from garnet peridotite or spinel lherzolite mantle sources (Ramsay and Tompkins, 1994).

The small number of till samples analyzed in this study, their low yield of KIMs, and the lack of additional, public KIM data from Manitoba's far north (Keller et al., 2004) significantly limit the interpretation of these data.

Mineral potential

Combined with the regional geological setting and the results of past and present exploration, the till-geochemical and, to a lesser extent, the indicator-mineral data summarized in this report indicate that several areas in Manitoba's far north have potential for the identification of economic deposits of U, Au, base metals (Zn-Pb ±Cu, Ni-Cu, ±Pt, Pd) and possibly diamonds.

Past and present U exploration has been focused mainly on the northeastern extension of the Wollaston sedimentary basin in the Kasmere Lake area, where broad zones of U enrichment were delineated during the Uranium Reconnaissance Program (URP; Soonawala et al., 1979; Soonawala, 1980). Between Snyder Lake and Kasmere Lake, this program revealed a chain of lake-sediment anomalies, trains of radiometric anomalies and relatively higher ratios of U to Th. Some of these anomalies can be related to boulders and rare outcrops of leucogranite, pegmatite, calcsilicate and graphitic pelitic rocks that contain anomalous to high-grade concentrations of U, Mo, Co, Ni, Cu and/or Au. Rare examples of flat-lying, low-grade sedimentary rocks in the adjacent areas of Saskatchewan, which are interpreted to represent outliers of the Athabasca Basin, indicate that the Kasmere Lake area was likely situated not far below the Mesoproterozoic unconformity. Similarly flat-lying, low-grade sedimentary rocks were identified by Schledewitz (1986) in the Great Island area, and appear to unconformably overlie older, strongly tectonometamorphosed supracrustal sequences.

Coupled with the regional geological setting, these factors are interpreted to indicate a regional potential for high-grade, basement-hosted, unconformity-type U deposits, as well as low-grade, leucogranite pegmatite (i.e., alaskite)–hosted magmatic U deposits. In addition to elevated U, the late porphyritic and pegmatitic intrusions also exhibit potential for lithophile-element mineralization (e.g., Sn-W-Ta-Nb, REE).

As noted previously, the Wollaston Supergroup is tentatively interpreted to represent a platform cover sequence deposited on top of the Archean Hearne craton, either along the passive southeastern margin of the craton or within intracratonic basin settings. In either scenario, deposition of the cover sequence presumably records the onset of crustal subsidence in response to continental extension (e.g., Aspler and Bursey, 1990; Patterson and Heaman, 1991). In such settings, basin initiation is often accompanied by mafic-ultramafic magmatism, high heat flow and resultant hydrothermal circulation, which have the potential to produce significant hydrothermal (i.e., sedimentary exhalative Zn-Pb-Ag sulphide) and magmatic (i.e., magmatic Ni-Cu-PGE) ore deposits. The rocks of the Courtenay Lake–Cairns Lake fold belt, which lie along the eastern edge of the Wollaston Supergroup in Saskatchewan, contain a number of base-metal occurrences interpreted to fit a sedimentary exhalative origin (Delaney et al., 1997). In addition, the widespread granitoid magmatism associated with Paleoproterozoic continental-arc and younger thermotectonism is considered to indicate good potential for intrusion-related Au-Cu (±U, REE) deposits (e.g., skarn or iron-oxide Cu-Au deposits).

The Archean high-grade rocks of the Nejanilini Domain form part of the stable crust of the Rae-Hearne craton, which appears to have developed a lithospheric keel that extended into the diamond stability field. Diamondiferous kimberlite intrusions are known to occur in the Nunavut portion of the Hearne craton, indicating that similar potential likely exists in Manitoba. Fundamental crustal boundaries, such as the southeastern margin of the Rae-Hearne craton in northern Manitoba, together with regional dike swarms, represent areas of enhanced potential for this deposit type, due to their propensity to control kimberlite emplacement on a regional scale.

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De Beers Canada Inc. generously provided till-sample processing and microprobe analysis of kimberlite-indicator minerals. The authors thank P. Lenton and M. Lavergne for helpful suggestions on the manuscript, and C. Steffano for desktop publishing. Scientific and technical discussions were stimulated by S. Pehrsson, H. Thorleifson, M. Fedikow, I. Girard and I. McMartin.

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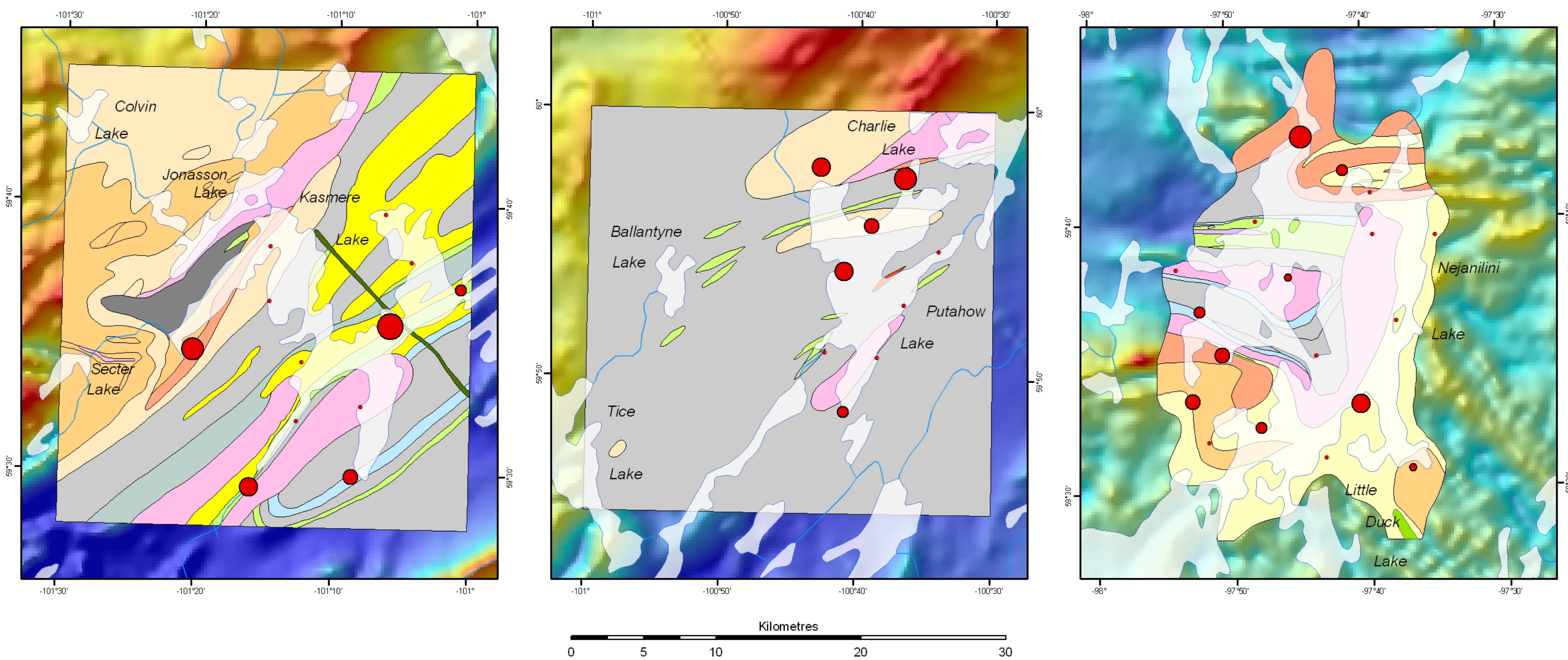
Appendix 1 — Distributions of selected elements in silt and clay fractions of till

As Distribution of arsenic in till (<63 µm fraction)



Arsenic (ppm)

- 1.0 - 1.1
- 1.2 - 1.3
- 1.4 - 1.6
- 1.7 - 2.3
- 2.4 - 2.5
- 2.6 - 8.0
- Below detection

Total-field mag

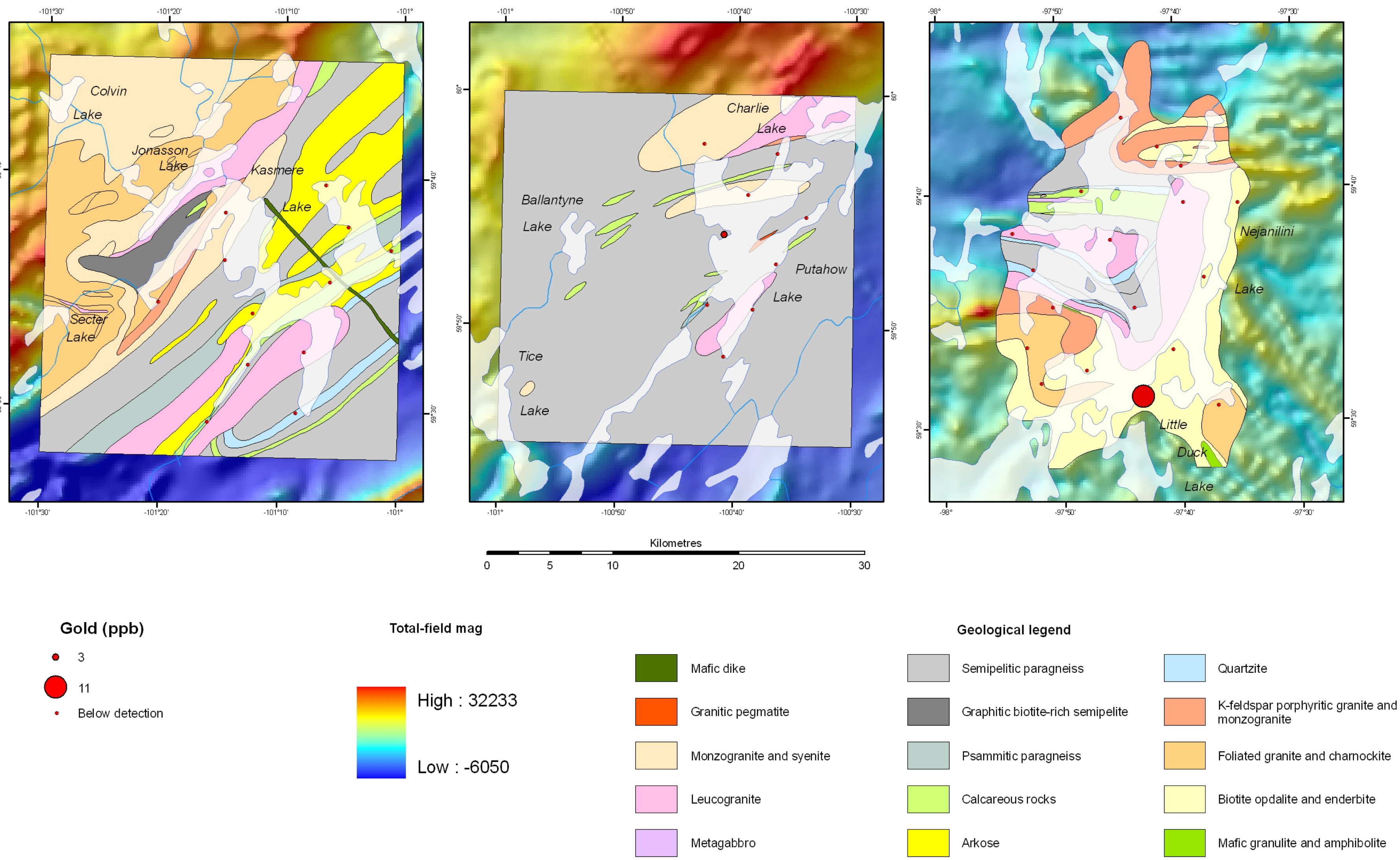
High : 32233

Low : -6050

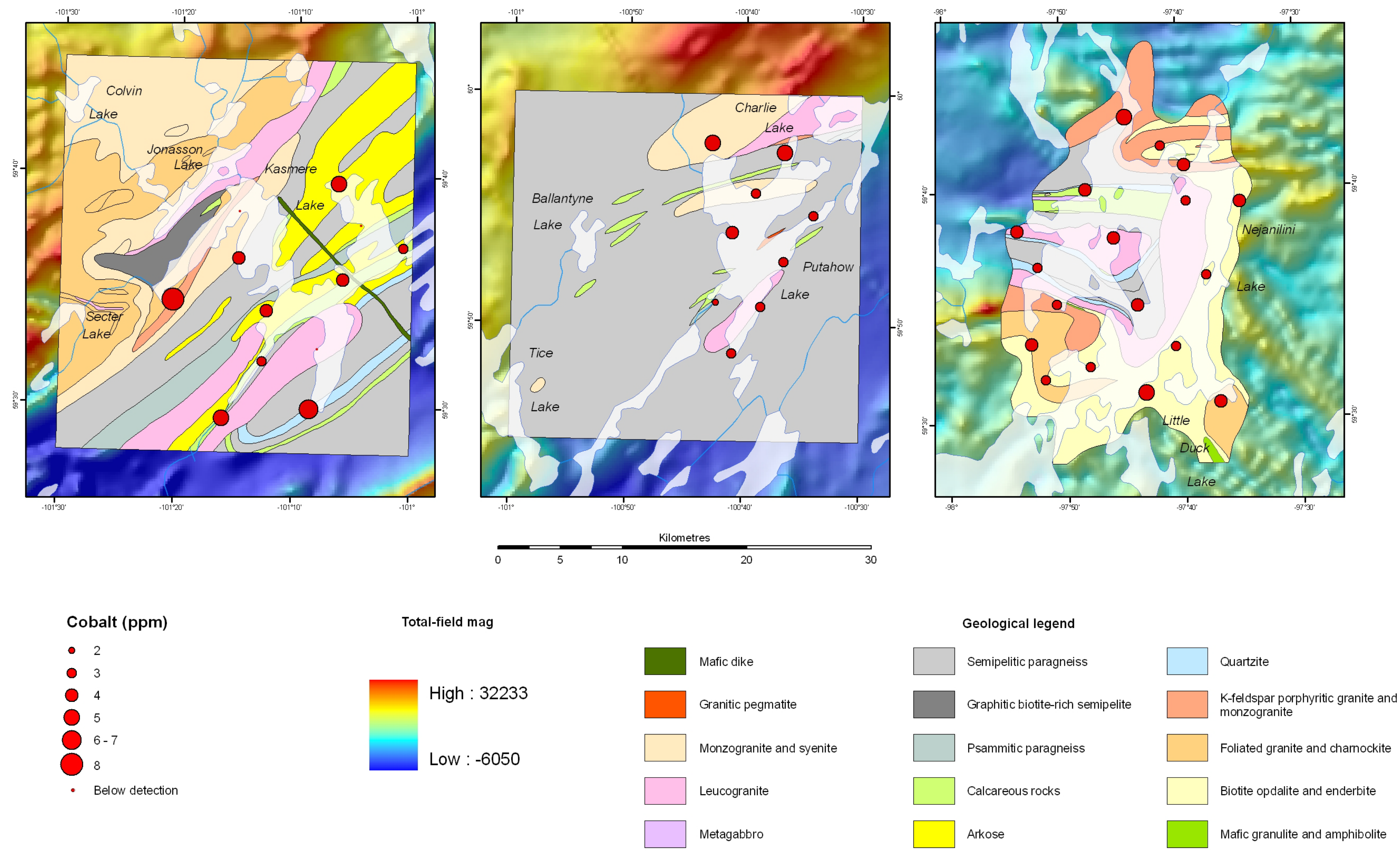
Geological legend

- Mafic dike
- Granitic pegmatite
- Monzogranite and syenite
- Leucogranite
- Metagabbro
- Semipelitic paragneiss
- Graphitic biotite-rich semipelite
- Psammitic paragneiss
- Calcareous rocks
- Arkose
- Quartzite
- K-feldspar porphyritic granite and monzogranite
- Foliated granite and charnockite
- Biotite opdalite and enderbite
- Mafic granulite and amphibolite

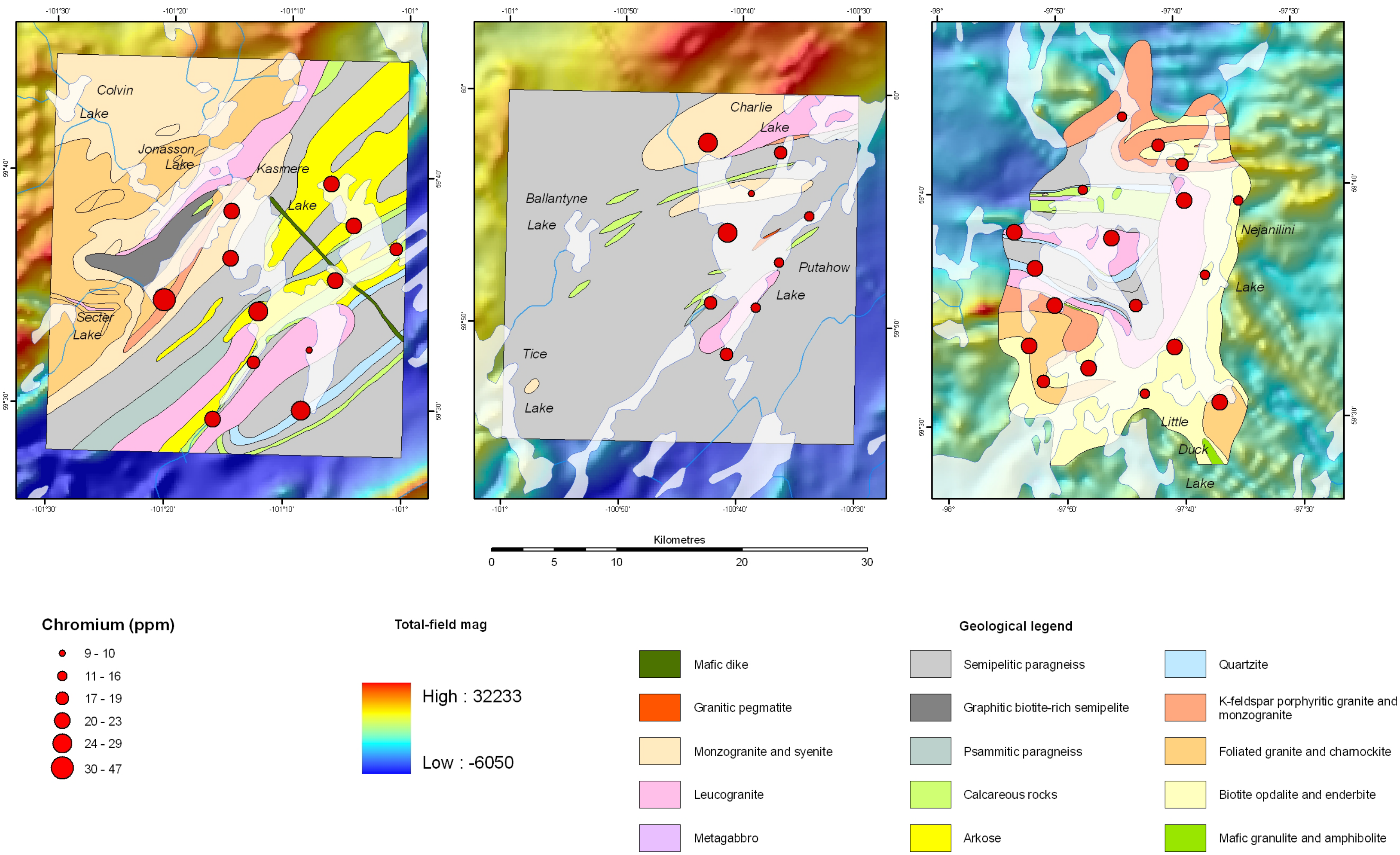
Au Distribution of gold in till (<63 µm fraction)



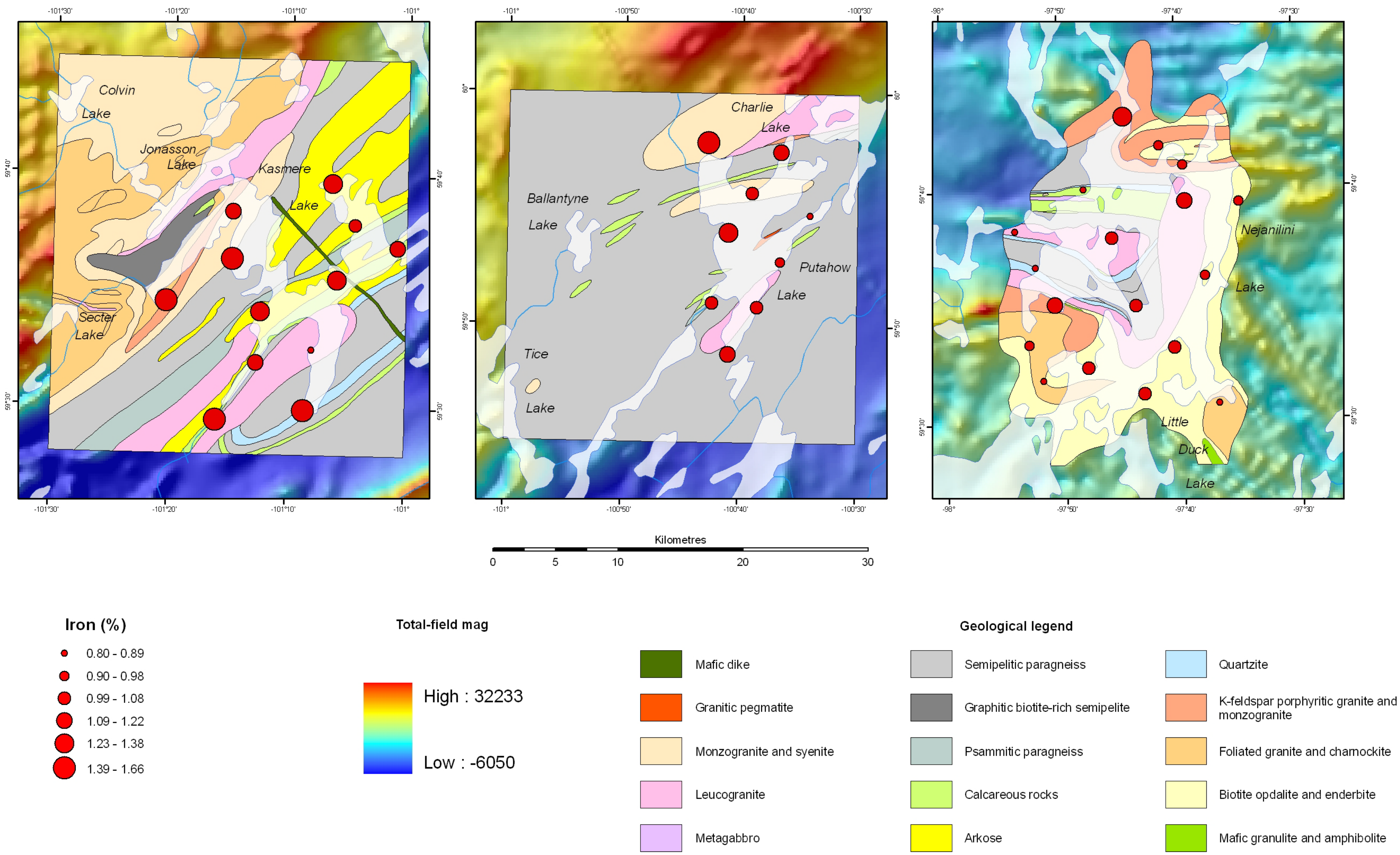
Co Distribution of cobalt in till (<63 µm fraction)



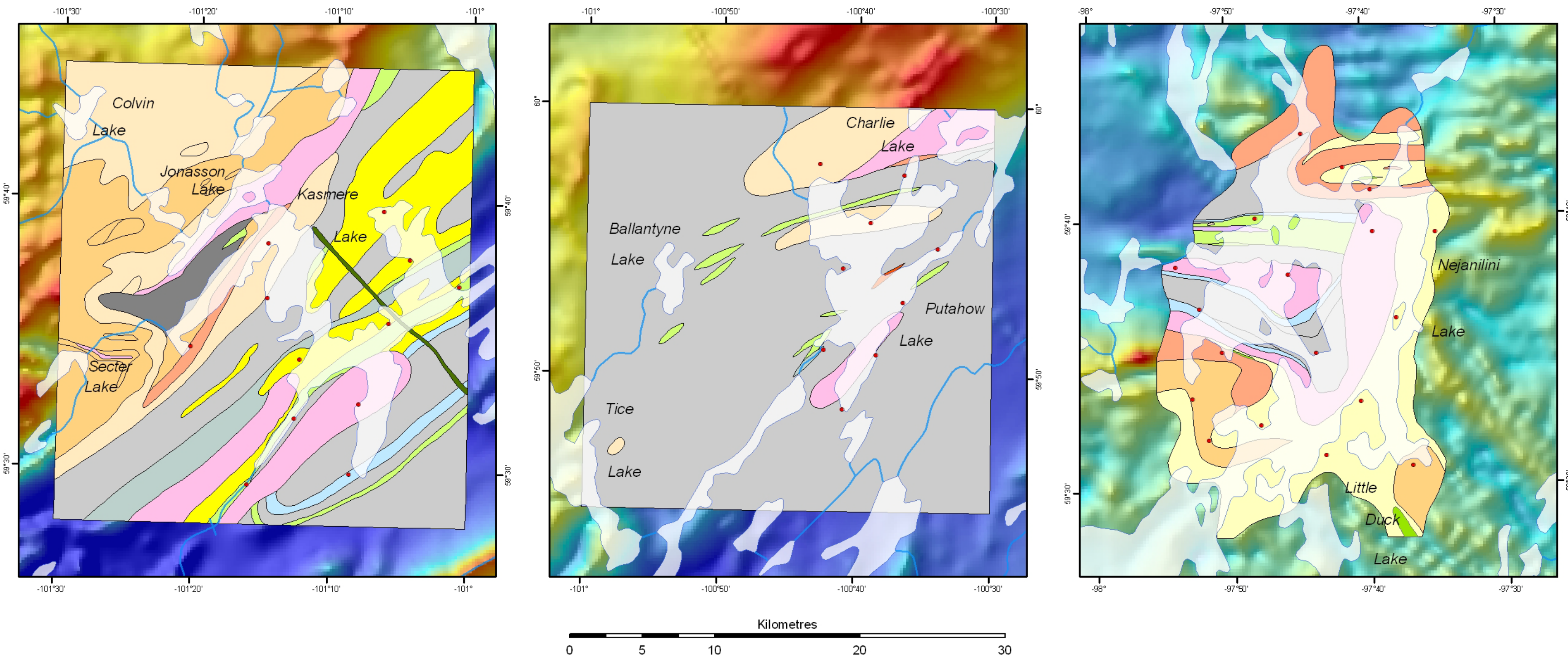
Cr Distribution of chromium in till (<63 µm fraction)



Fe Distribution of iron in till (<63 µm fraction)



Mo Distribution of molybdenum in till (<63 µm fraction)



Molybdenum (ppm)

• Below detection

Total-field mag

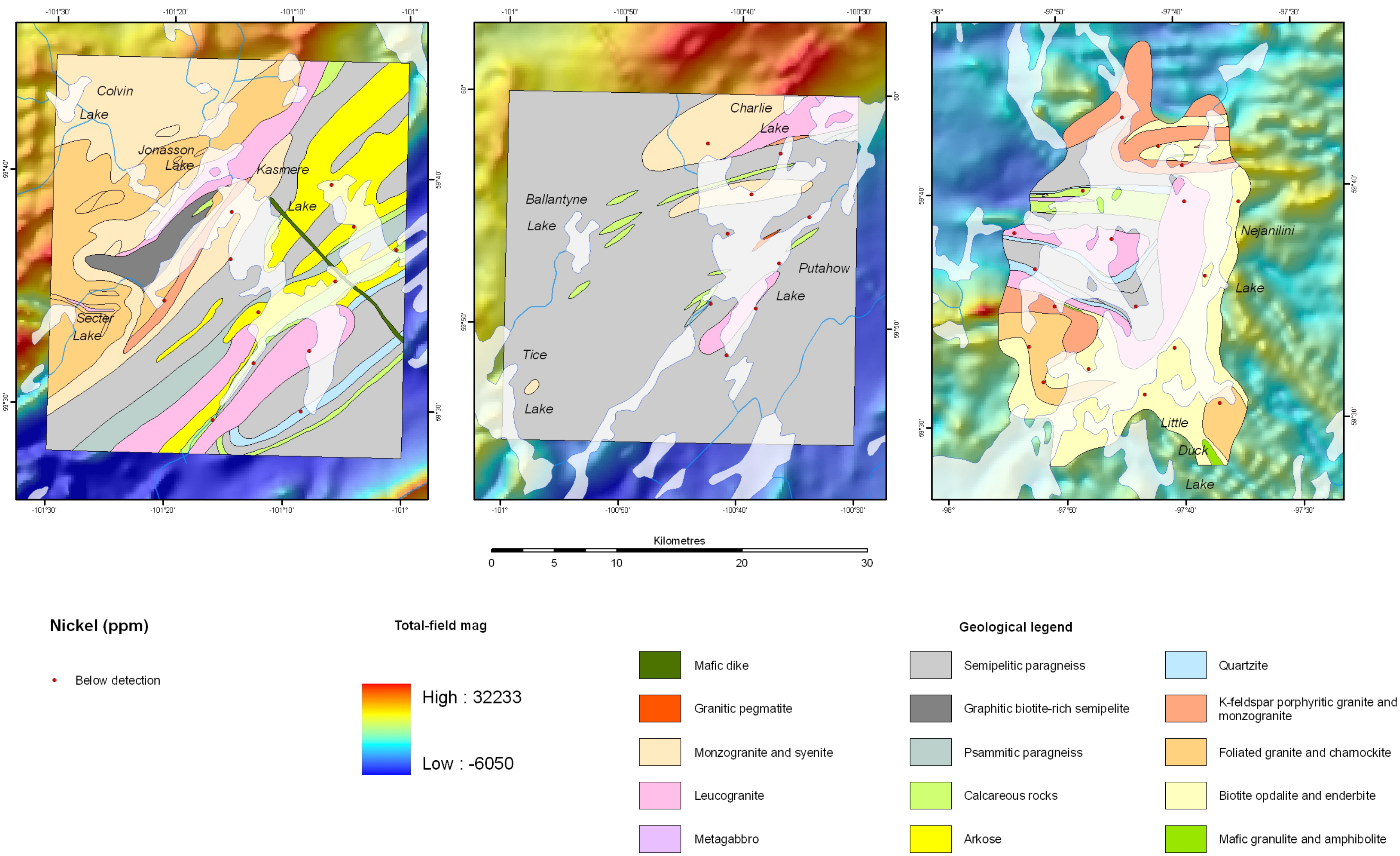
High : 32233

Low : -6050

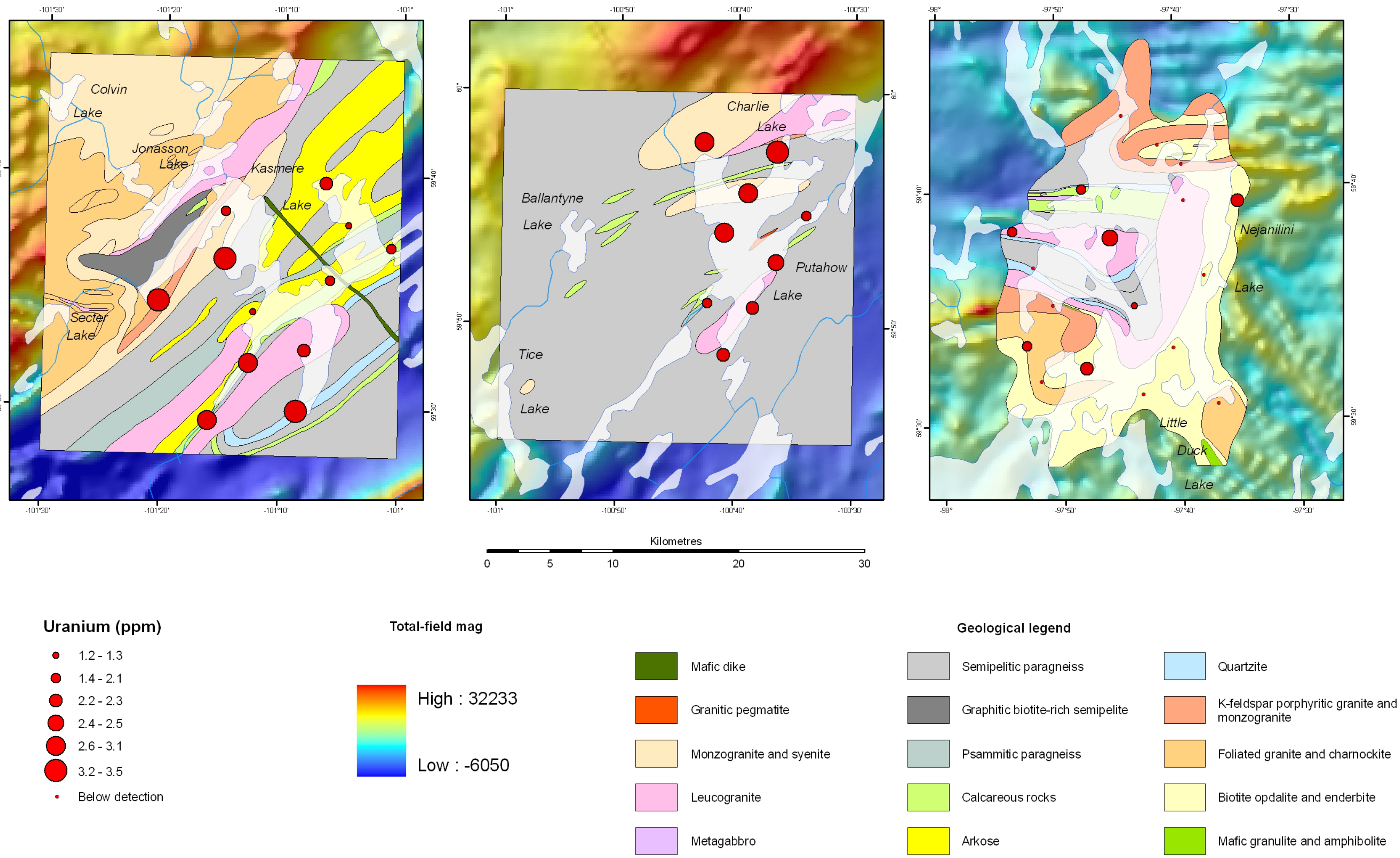
Geological legend

- Mafic dike
- Granitic pegmatite
- Monzogranite and syenite
- Leucogranite
- Metagabbro
- Semipelitic paragneiss
- Graphitic biotite-rich semipelite
- Psammitic paragneiss
- Calcareous rocks
- Arkose
- Quartzite
- K-feldspar porphyritic granite and monzogranite
- Foliated granite and charnockite
- Biotite opdalite and enderbite
- Mafic granulite and amphibolite

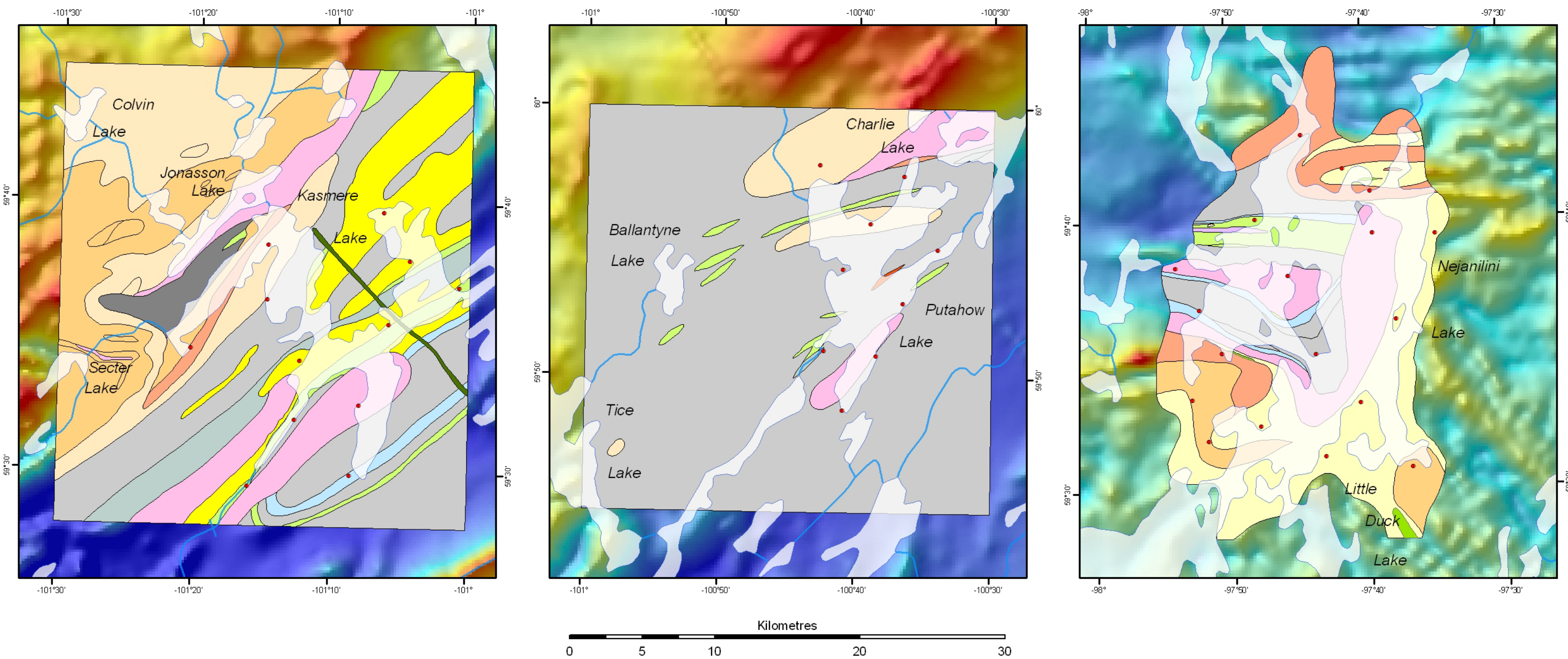
Ni Distribution of nickel in till (<63 µm fraction)



U Distribution of uranium in till (<63 µm fraction)



Zn Distribution of zinc in till (<63 µm fraction)



Zinc (ppm)

• Below detection

Total-field mag

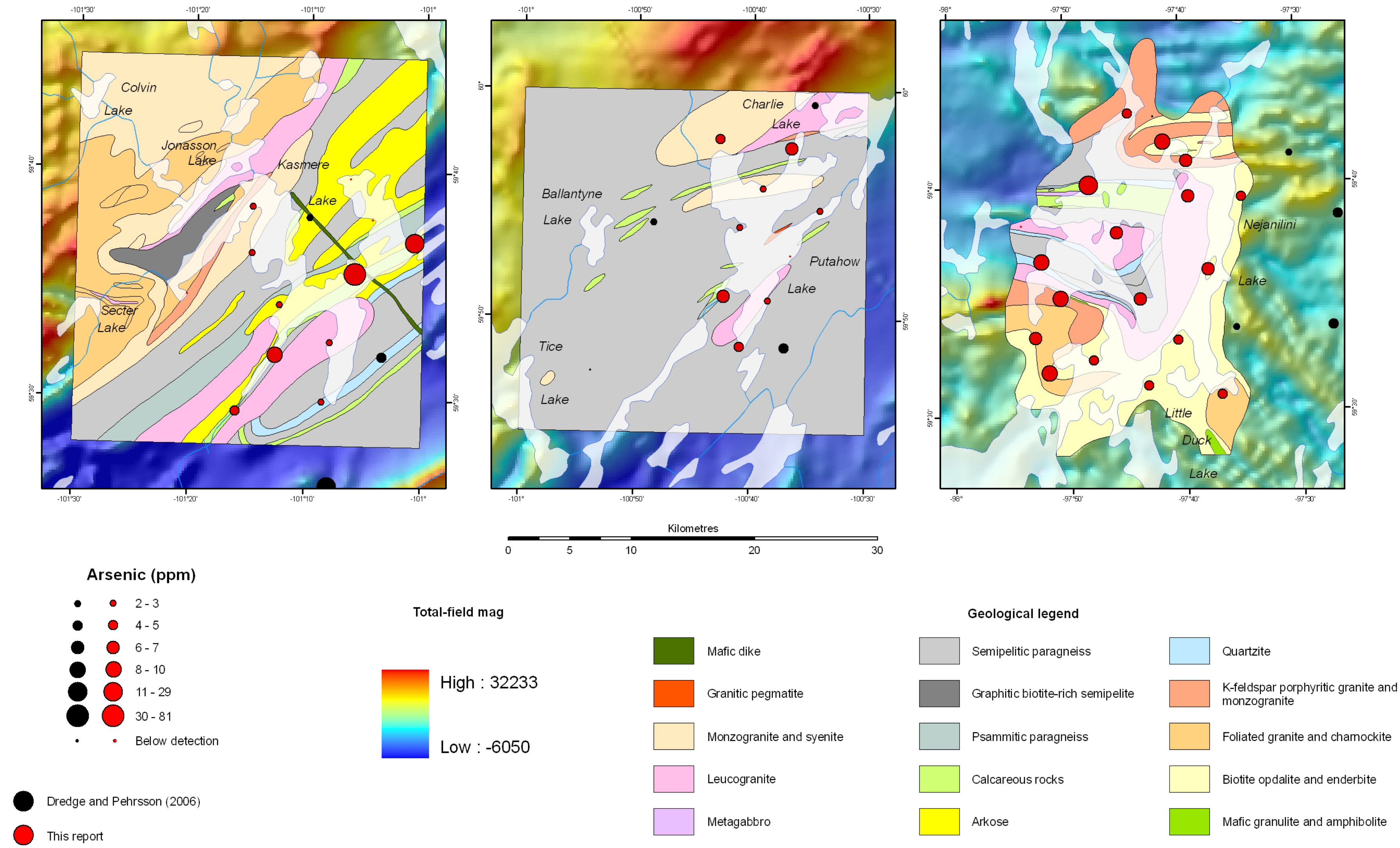
High : 32233

Low : -6050

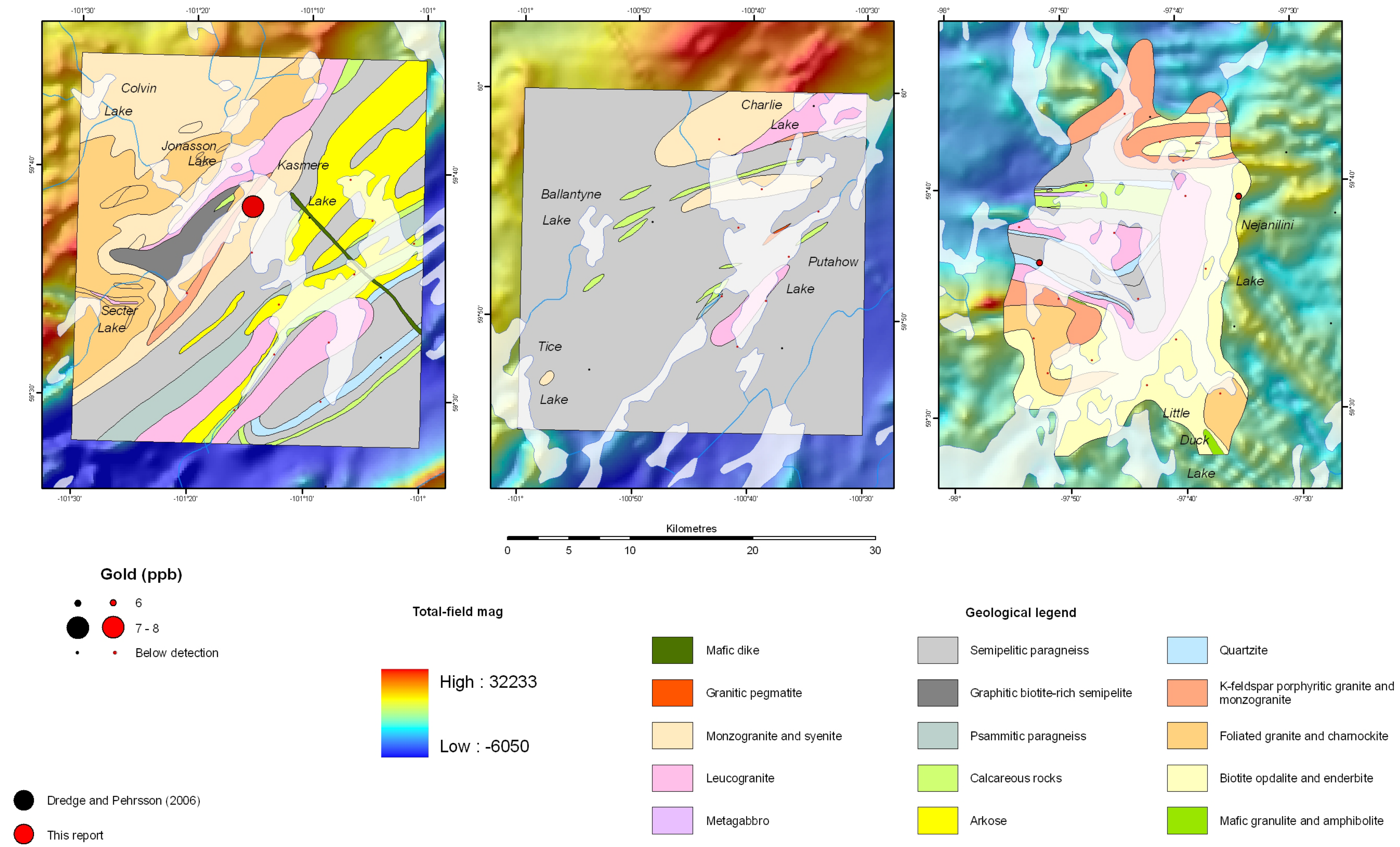
Geological legend

- Mafic dike
- Granitic pegmatite
- Monzogranite and syenite
- Leucogranite
- Metagabbro
- Semipelitic paragneiss
- Graphitic biotite-rich semipelite
- Psammitic paragneiss
- Calcareous rocks
- Arkose
- Quartzite
- K-feldspar porphyritic granite and monzogranite
- Foliated granite and charnockite
- Biotite opdalite and enderbite
- Mafic granulite and amphibolite

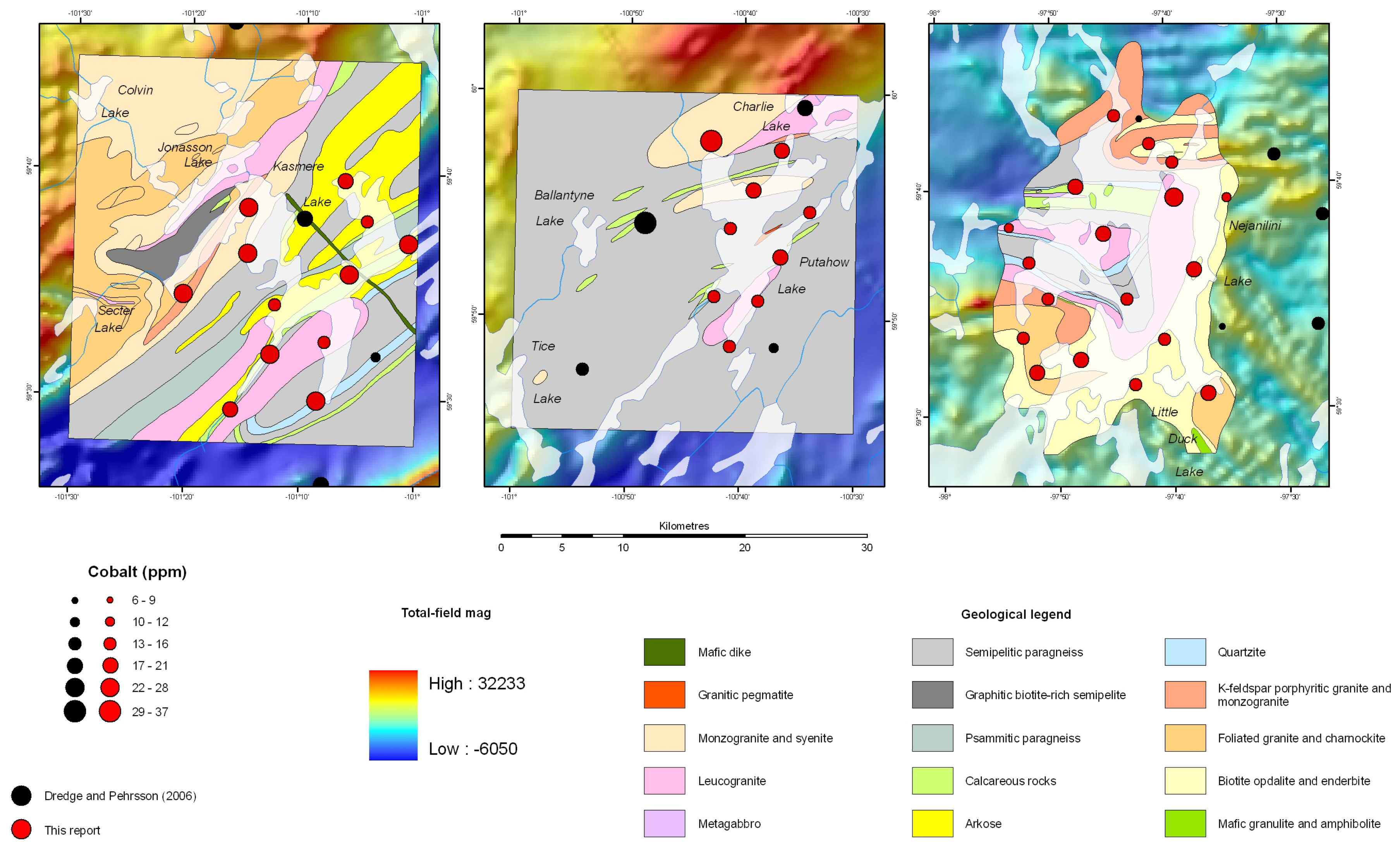
As Distribution of arsenic in till (<2 µm fraction)



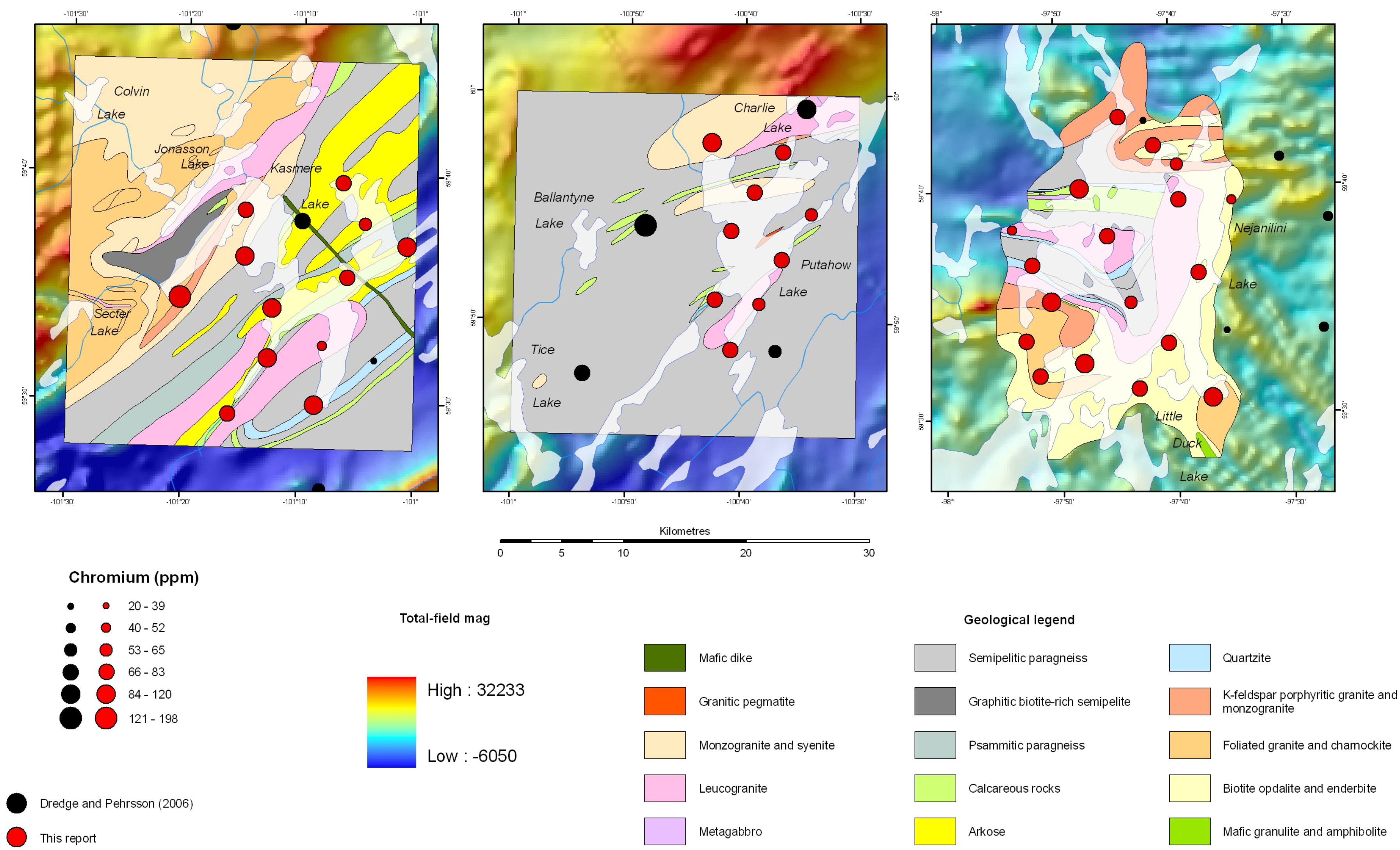
Au Distribution of gold in till (<2 µm fraction)



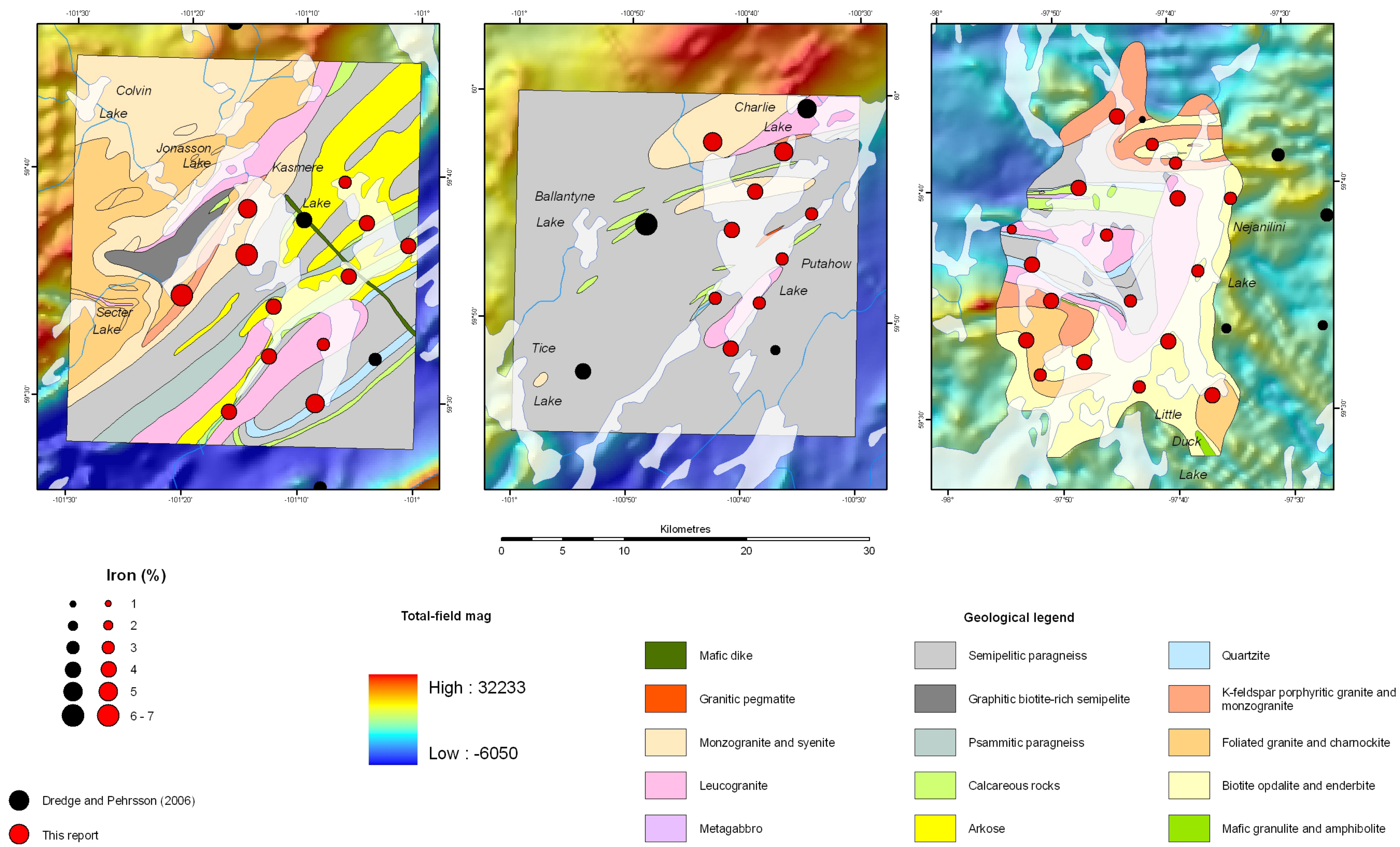
Co Distribution of cobalt in till (<2 µm fraction)



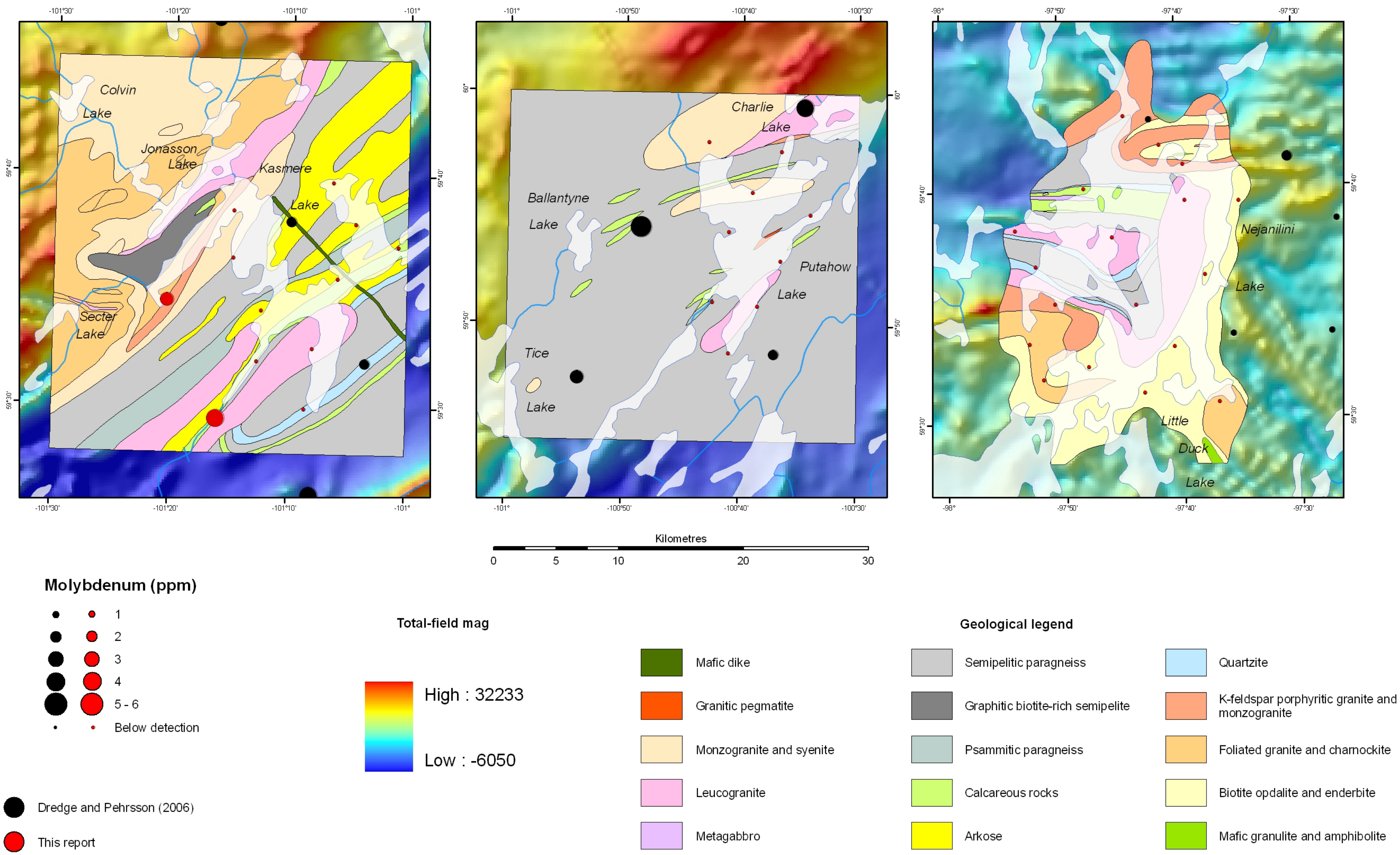
Cr Distribution of chromium in till (<2 µm fraction)



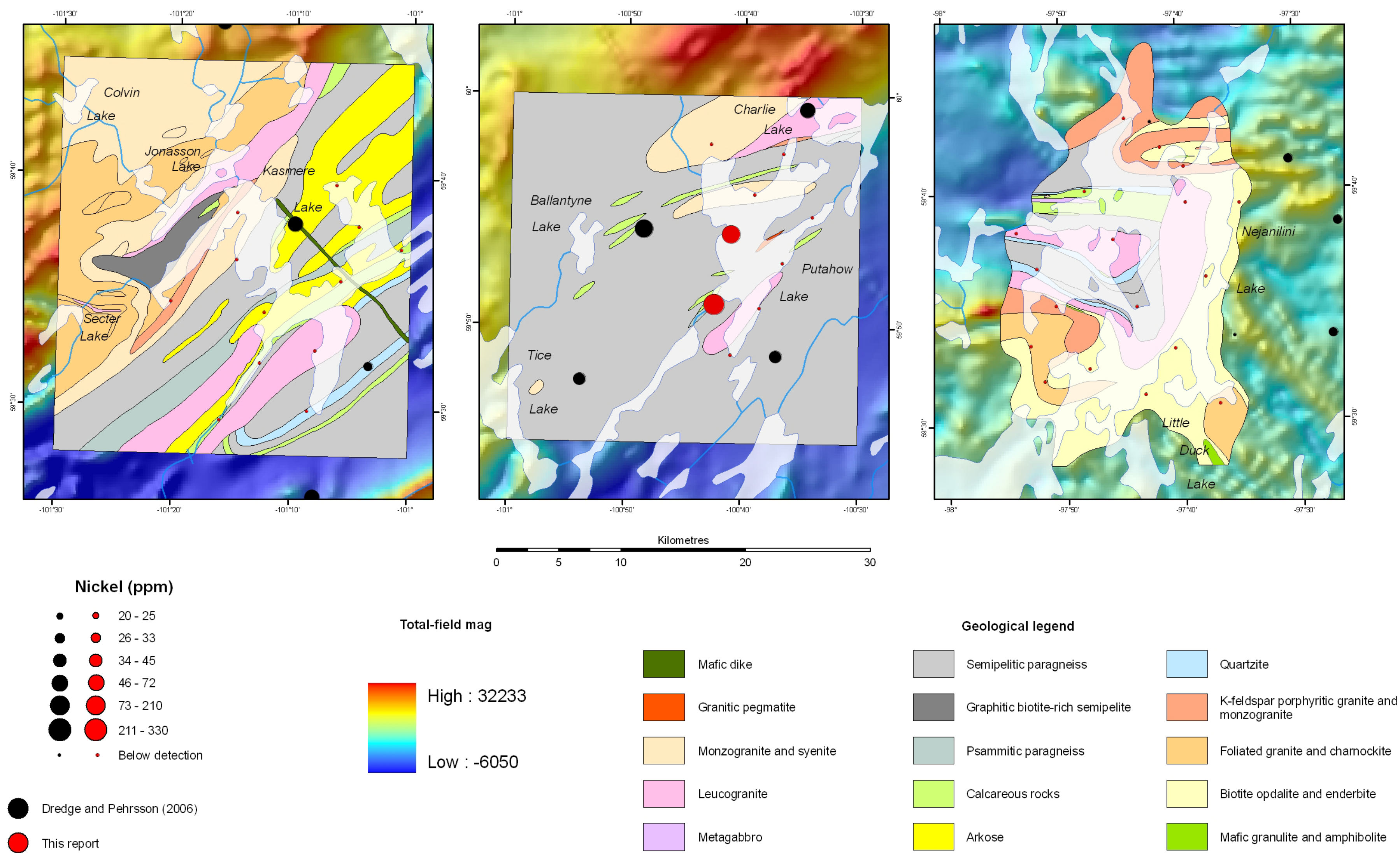
Fe Distribution of iron in till (<2 µm fraction)



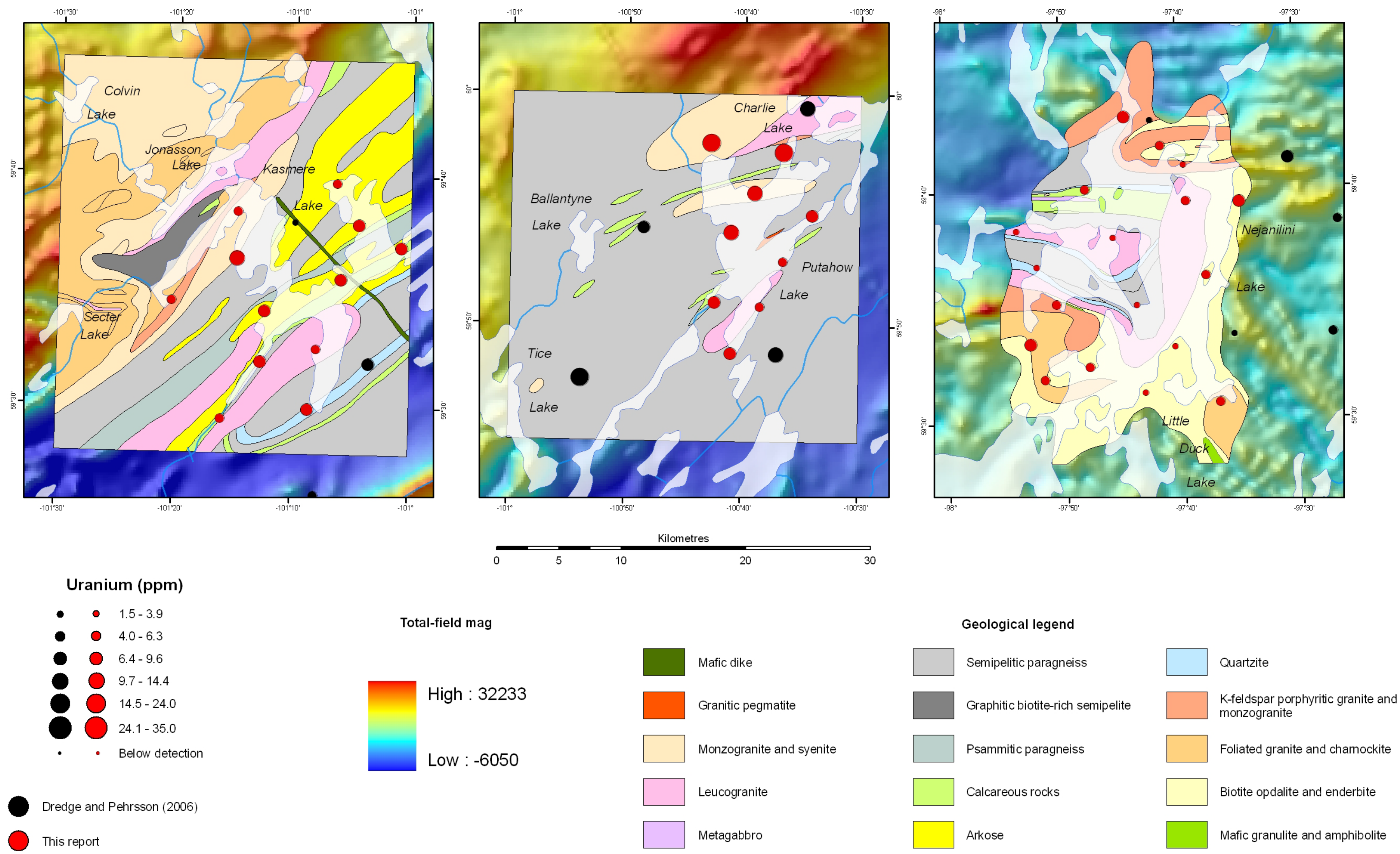
Mo Distribution of molybdenum in till (<2 μm fraction)



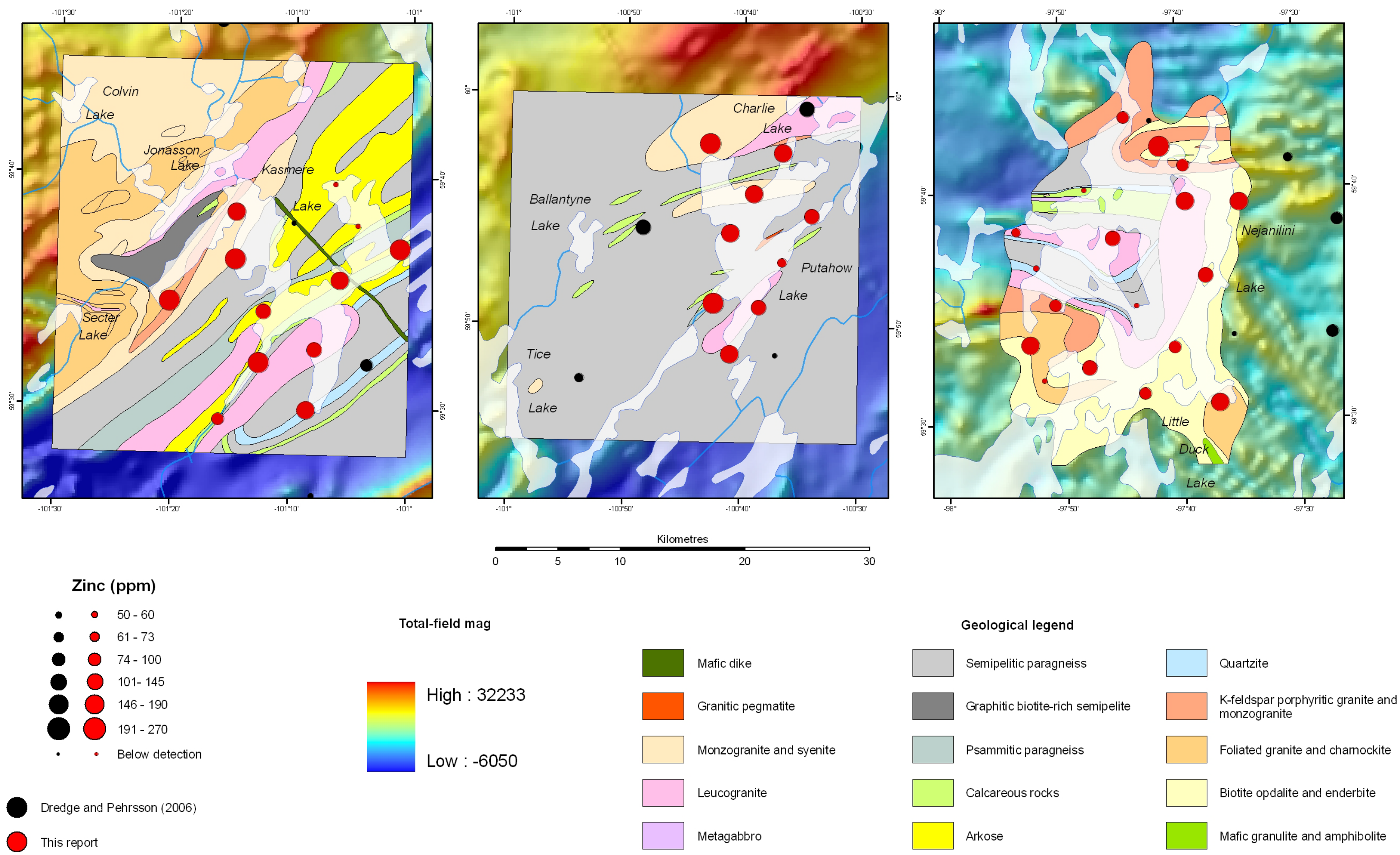
Ni Distribution of nickel in till (<2 µm fraction)



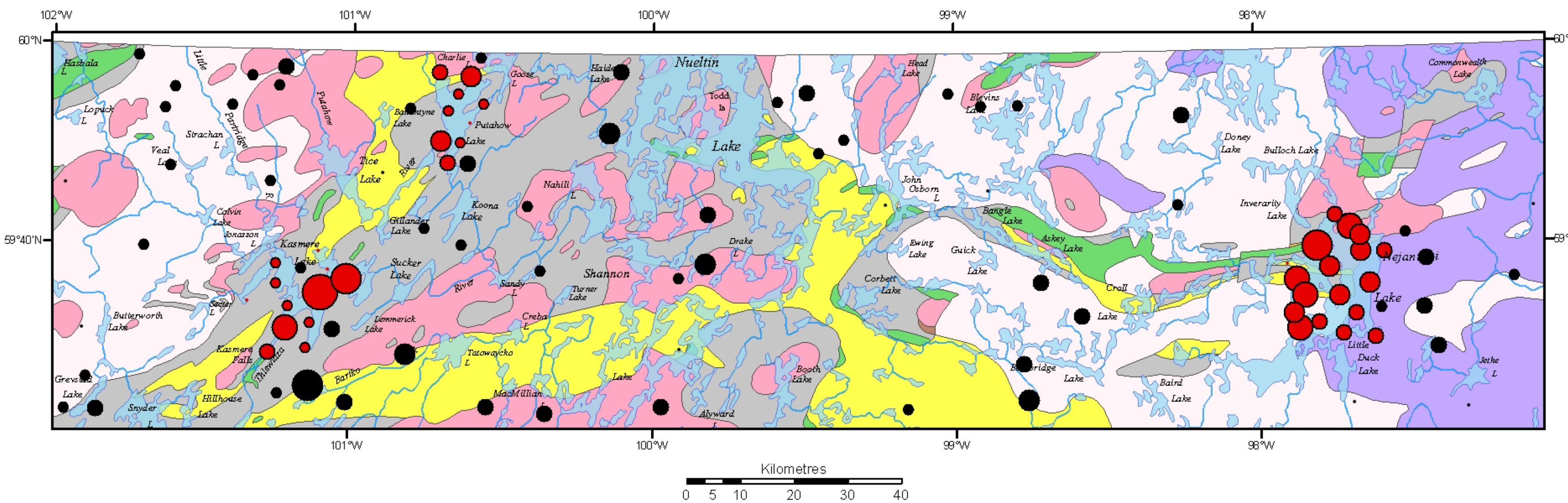
U Distribution of uranium in till (<2 µm fraction)



Zn Distribution of zinc in till (<2 µm fraction)



As Distribution of arsenic in till (<2 µm fraction)



Arsenic (ppm)

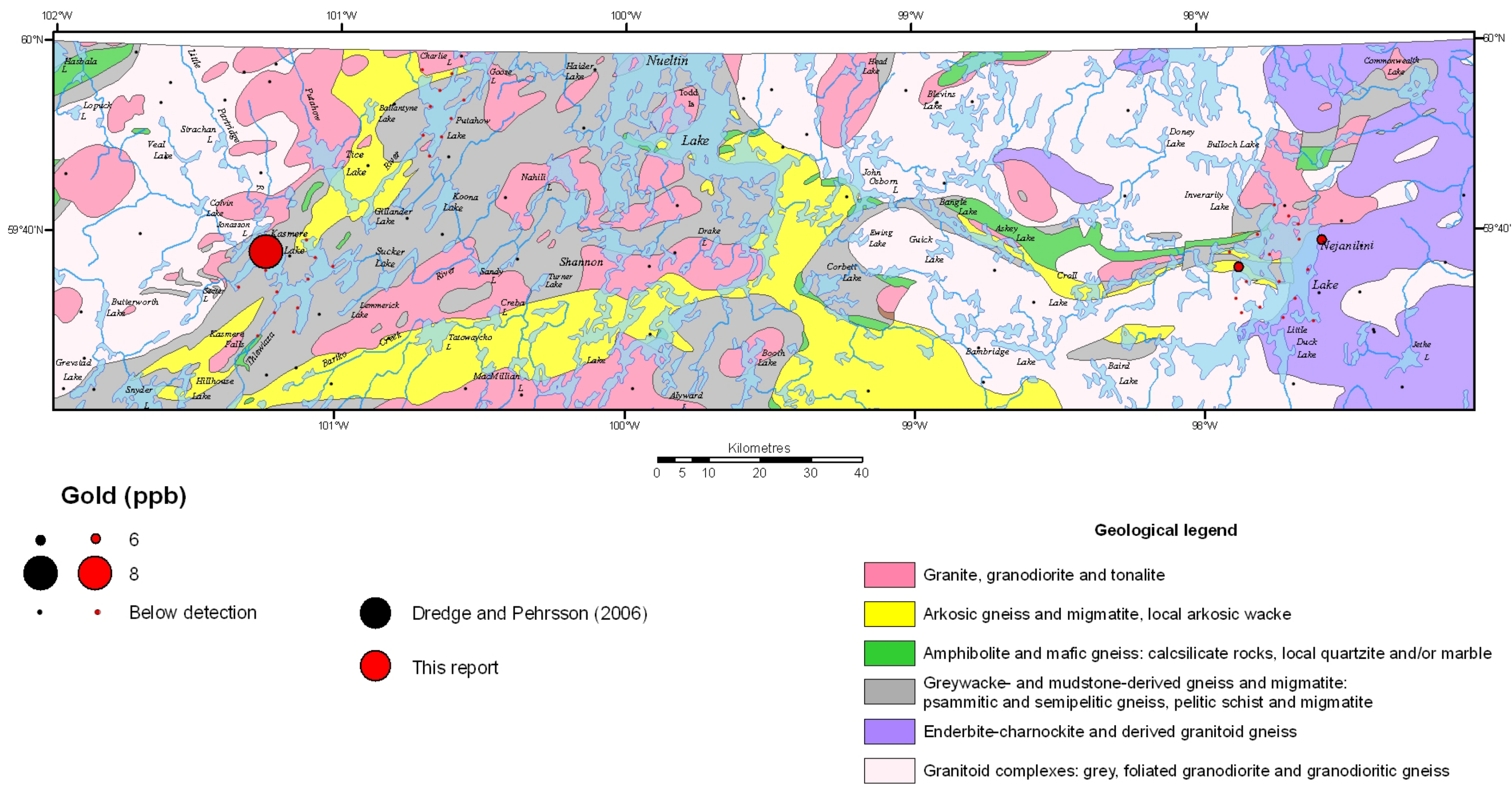
- 2 - 3
- 4 - 5
- 6 - 7
- 8 - 10
- 11 - 29
- 30 - 81
- Below detection

- Dredge and Pehrsson (2006)
- This report

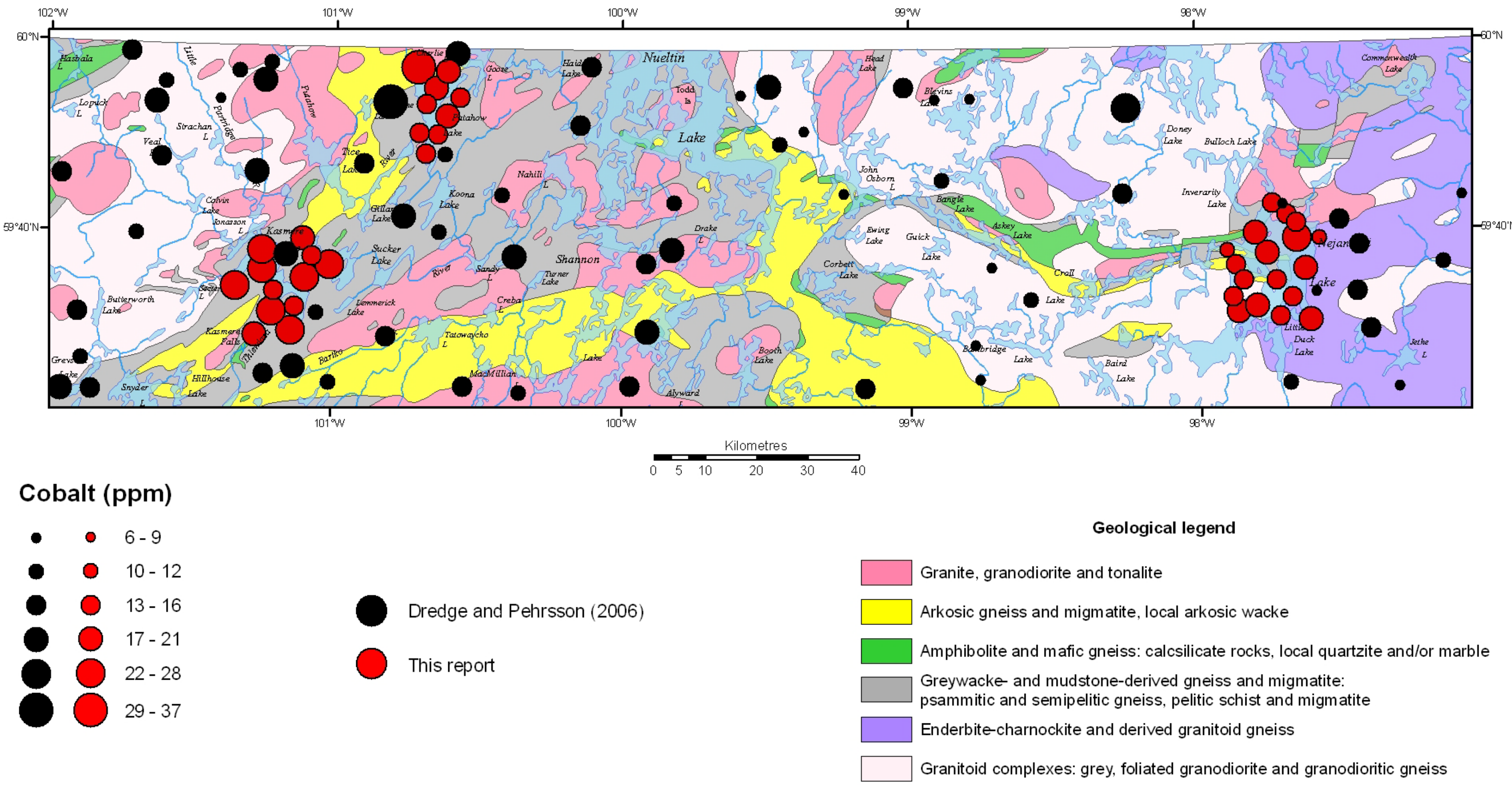
Geological legend

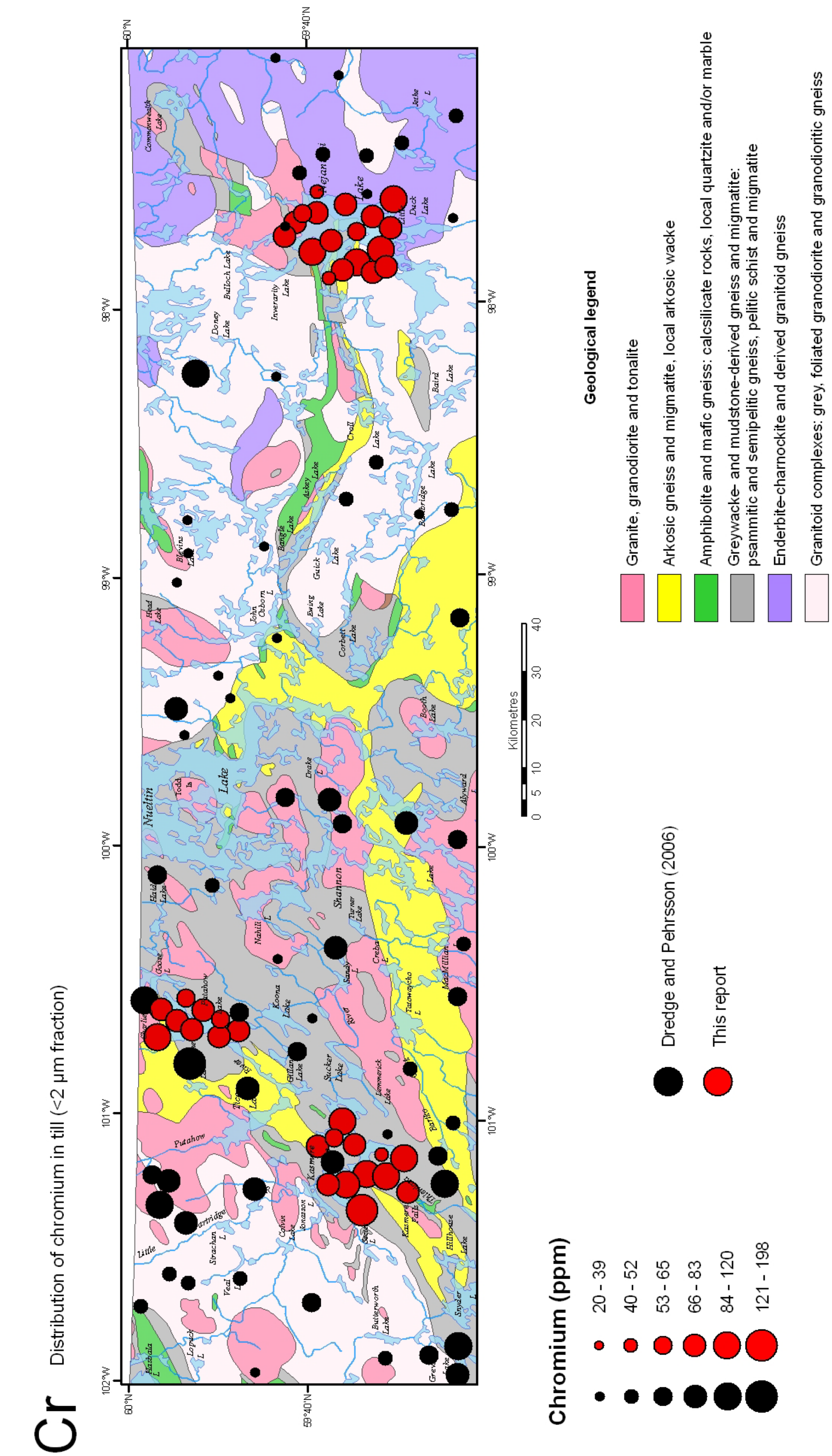
- Granite, granodiorite and tonalite
- Arkosic gneiss and migmatite, local arkosic wacke
- Amphibolite and mafic gneiss: calcsilicate rocks, local quartzite and/or marble
- Greywacke- and mudstone-derived gneiss and migmatite: psammitic and semipelitic gneiss, pelitic schist and migmatite
- Enderbite-charnockite and derived granitoid gneiss
- Granitoid complexes: grey, foliated granodiorite and granodioritic gneiss

Au Distribution of gold in till (<2 µm fraction)

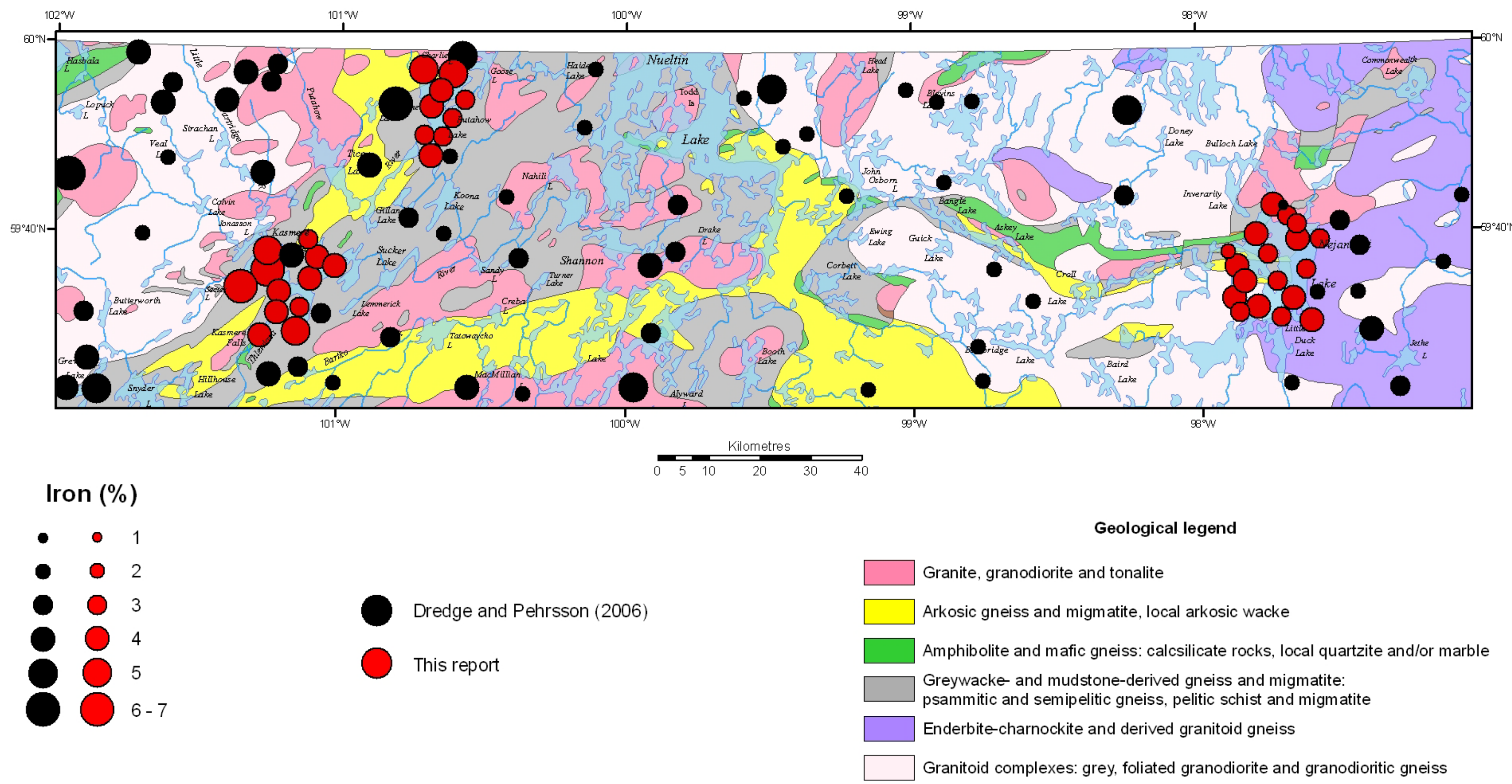


Co Distribution of cobalt in till (<2 µm fraction)

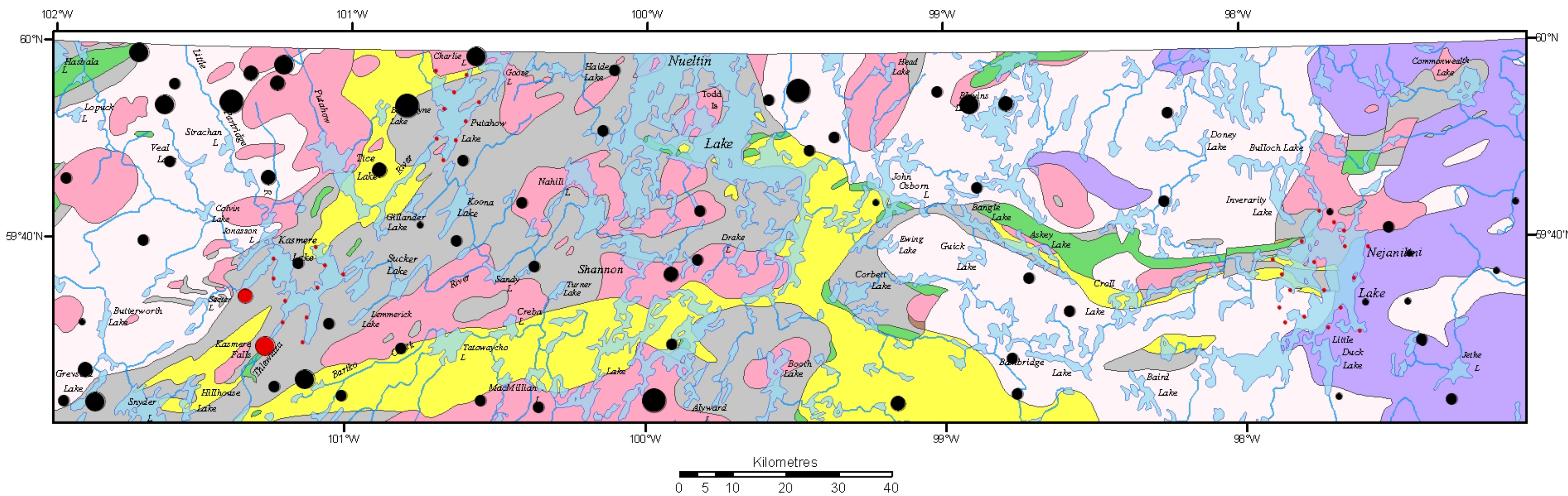



Cr
Distribution of chromium in till (<2 µm fraction)
Chromium (ppm)
20 - 39
40 - 52
53 - 65
66 - 83
84 - 120
121 - 198
Dredge and Pehrsson (2006)
This report
Kilometres
0 5 10 20 30 40
Geological legend
Granite, granodiorite and tonalite
Arkosic gneiss and migmatite, local arkosic wacke
Amphibolite and mafic gneiss: calcsilicate rocks, local quartzite and/or marble
Greywacke- and mudstone-derived gneiss and migmatite: psammitic and semipelitic gneiss, pelitic schist and migmatite
Enderbite-charnockite and derived granitoid gneiss
Granitoid complexes: grey, foliated granodiorite and granodioritic gneiss
102°W
101°W
100°W
99°W
98°W
60°N
59°40'N
Nueltin Lake
Shannon Lake

Fe Distribution of iron in till (<2 µm fraction)



Mo Distribution of molybdenum in till (<2 µm fraction)



Molybdenum (ppm)

- 1
- 2
- 3
- 4
- 5 - 6
- Below detection

- Dredge and Pehrsson (2006)
- This report

Geological legend

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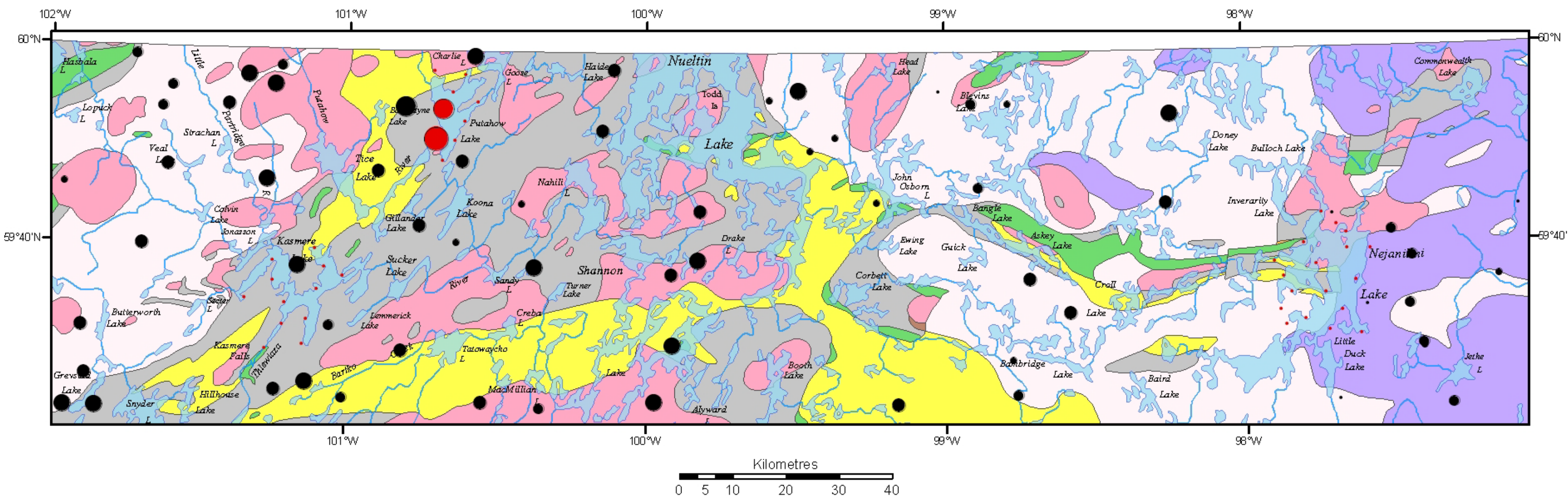
- Enderbite-charnockite and derived granitoid gneiss
- Granitoid complexes: grey, foliated granodiorite and granodioritic gneiss

Ni

Distribution of nickel in till (<2 µm fraction)



Nickel (ppm)

- 20 - 25
- 26 - 33
- 34 - 45
- 46 - 72
- 73 - 210
- 211 - 330
- Below detection

Dredge and Pehrsson (2006)

This report

Geological legend

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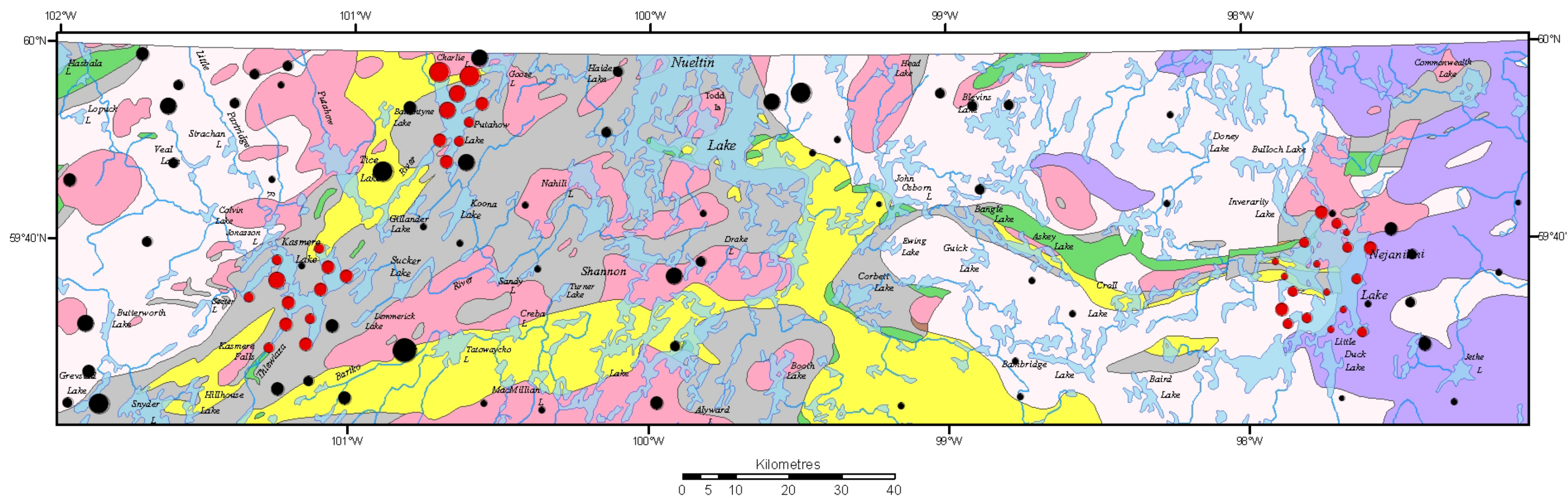
- Enderbite-charnockite and derived granitoid gneiss
- Granitoid complexes: grey, foliated granodiorite and granodioritic gneiss

U Distribution of uranium in till (<2 µm fraction)



Uranium (ppm)

- 1.5 - 3.9
- 4.0 - 6.3
- 6.4 - 9.6
- 9.7 - 14.4
- 14.5 - 24.0
- 24.1 - 35.0
- Below detection

- Dredge and Pehrsson (2006)
- This report

Geological legend

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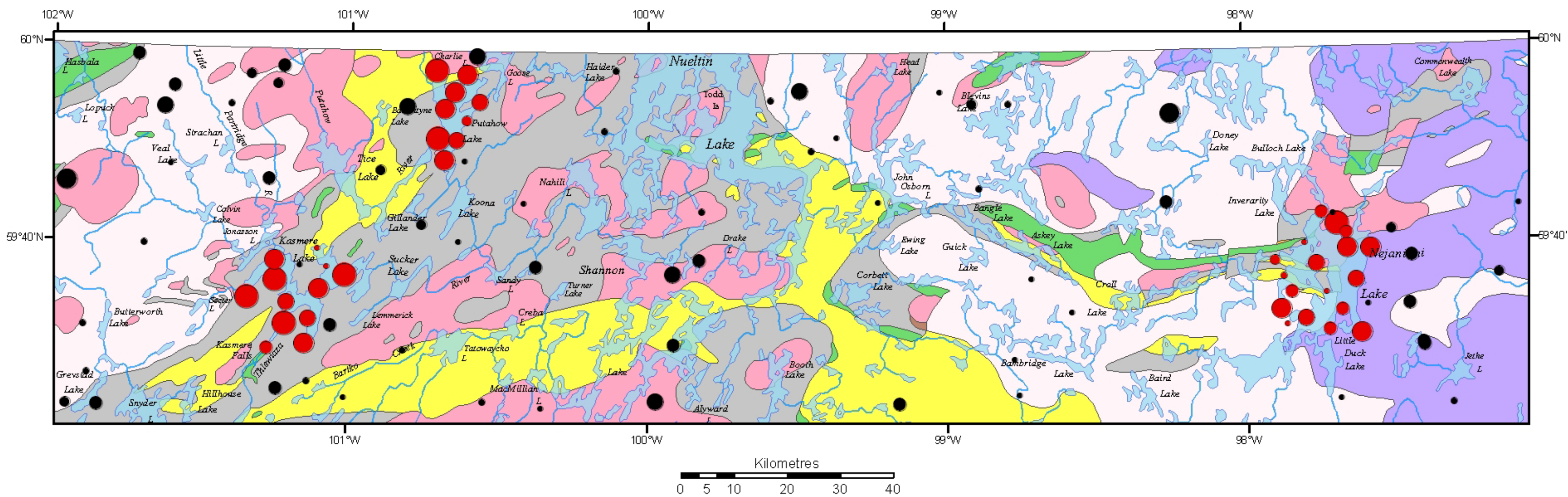
- Enderbite-charnockite and derived granitoid gneiss
- Granitoid complexes: grey, foliated granodiorite and granodioritic gneiss

Zn Distribution of zinc in till (<2 µm fraction)



Zinc (ppm)

- 50 - 60
- 61 - 73
- 74 - 100
- 101- 145
- 146 - 190
- 191 - 270
- Below detection

Black symbols: Dredge and Pehrsson (2006)

Red symbols: This report

Geological legend

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- Enderbite-charnockite and derived granitoid gneiss
- Granitoid complexes: grey, foliated granodiorite and granodioritic gneiss