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Ontario Geological Survey
Open File Report 6223

Till Signature of the Caribou Lake Greenstone Belt Area, Armstrong, Ontario

2008

Ontario

ONTARIO GEOLOGICAL SURVEY

Open File Report 6223

Till Signature of the Caribou Lake Greenstone Belt Area, Armstrong, Ontario

by

P.J. Barnett

2008

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Miscellaneous Release—Data 229 – Revised

Till Compositional Database: Investigation of the Overburden Signature of the Caribou Lake Greenstone Belt Area, Armstrong, Ontario, Canada

by P.J. Barnett

This digital data release, which accompanies Open File Report 6223, contains the results of laboratory analysis of till samples collected from north of Lake Nipigon and in the area east of Armstrong centred on the Caribou Lake greenstone belt. The results from heavy mineral concentration and mineral identification and heavy mineral and till matrix geochemistry (ICP–MS, ICP–OES and NiS-FA) are provided as spreadsheet (*.csv* format or Microsoft® Excel® *.xls* format) files, geographic information software (GIS) (*.shp* format) files and dot plots of selected results (*.tif* format). Digital data release MRD 229—Revised (replacing Miscellaneous Release—Data 229 (released December 11, 2007)), contains changes in the shape file “dp_norm_precious” and 2 associated dot plots, and unit of measure changes on 6 dot plots for NiS-FA analytical results (**ppb** (not ppm)). The data are available on 1 CD-ROM.

These data are available separately from the report.

Abstract

Surficial sediments in the area north of Lake Nipigon can be successfully used for mineral exploration and to determine the natural distribution of elements in the environment. Till, the ideal sediment for sampling, is widespread and commonly reflects local bedrock conditions in the area. Over 130 samples were collected for geochemical analysis and 92 samples were collected for heavy mineral analysis over an area of over 5000 km^2 centred on the Caribou Lake greenstone belt. The Caribou Lake greenstone belt ranges from 3 to 17 km wide and extends for nearly 100 km where it merges with the Onaman–Tashota greenstone belt. It consists primarily of massive to pillowed basalts, iron formation and komatiite with minor amounts of conglomerate. It is being explored for gold, molybdenum, copper-nickel-platinum group elements (PGE) and rare-element pegmatites.

The area has been subjected to multiple flow directions of the Laurentide Ice Sheet. Multiple directions of ice flow, recorded as glacial striae, occur at a few localities and are commonly located near end moraines, such as the Nipigon moraine. The oldest ice flows observed were toward the south followed by more westerly flow. The area can be divided into 3 main zones based on ice-flow sequences defined by the Nipigon moraine and the “Crescent Lake esker”. Only one visited site contained evidence of 2 tills deposited by different ice-flow directions. The till exposed at most sites was deposited by the last direction of ice flow. Surficial sediments can exceed 30 m in thickness and these sediments commonly occur within end moraines, such as the Nipigon moraine, eskers and abandoned lake plains adjacent to Lake Nipigon along the Pikitigushi and Little Jackfish rivers and within the drainage basin of Mojikit Lake.

The results of heavy mineral analysis and trace element geochemistry do indicate known areas of mineral potential and indicate additional areas that might be considered for future mineral exploration. There remains potential for finding additional rare-element pegmatites, volcanogenic massive sulphide copper-zinc, magmatic copper-nickel-PGE and gold mineralization in the region.

Till Signature of the Caribou Lake Greenstone Belt Area, Armstrong, Ontario

P.J. Barnett[1]

Ontario Geological Survey
Open File Report 6223
2008

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Introduction

The Caribou Lake greenstone belt, located approximately 15 km north of Lake Nipigon, is currently being explored for gold, copper-nickel-platinum group elements (PGE) and rare-element ["rare-metal"] pegmatites (Smyk et al. 2005). Its mineral potential has not yet been fully evaluated. At present, the "area has an under-appreciated potential for a variety of … mineral deposits … including lode gold, volcanogenic massive sulphide copper-zinc, orthomagmatic copper-nickel and rare metal-bearing pegmatites" (Smyk et al. 2005, p.26). A number of recently opened forest access roads into the area provide the opportunity to gain access to a large part of the greenstone belt to observe fresh exposures of bedrock and surficial sediments for mapping and sampling. The value of prospecting along newly opened forest access roads is emphasized by the discovery of the Kilometre 61 property (Smyk et al. 2005). "The discovery of the Cu-Mo-Au-Ag-mineralized porphyry was made by prospectors S. and M. Stares in 2002 in float boulders and outcrops along the newly constructed logging road" (Smyk et al. 2005, p.25). This example also emphasizes the contribution of drift prospecting to locating areas of mineralized bedrock.

Pye (1968, p.40) wrote, "Because of the general scarcity of outcrops throughout much of the map-area, conventional prospecting is difficult." Till, however, is generally well distributed in the study area and is commonly thick enough to obtain C-horizon samples. There are, however, a few areas of thick glaciofluvial and glaciolacustrine sediments within the study area that hinder the collection of till samples. However, these are commonly located over the area of granitic and granodioritic rocks located south of the Caribou Lake greenstone belt.

The current project involves regional mapping of the surficial geology and till sampling for heavy mineral indicator and geochemical analysis, over a part of the Caribou Lake greenstone belt located north of Lake Nipigon (Figure 1). The study area is portrayed on 4, 1:50 000-scale National Topographic System (NTS) maps: Pikitigushi Lake 52 I/07, Little Jackfish River 52 I/08, Mojikit Lake 52 I/09 and Linklater Lake 52 I/10. The results of this study provide guidance in the interpretation of results from overburden sampling programs in this area and regional information on the mineral potential of this part of the Caribou Lake greenstone belt. The area is a region of complex interplay between fluctuating glacial margins.

During the 2005 field season (Barnett 2005), till was sampled for heavy-mineral concentrate (HMC) analysis at 42 sites and samples sent to Overburden Drilling Management Ltd., Nepean, Ontario, for processing. C-horizon till matrix samples were collected at 80 sites for geochemical analysis by the Geoscience Laboratories (Geo Labs) at the Ministry of Northern Development and Mines. Pebbles were also collected at the till matrix sample sites for lithology identification to provide information on distance of glacial transport. An additional 50 samples were collected for HMC, matrix geochemistry and pebble lithology analysis in 2006. During both field seasons, sampling was extended eastward and westward from the study area along and beyond the Caribou Lake greenstone belt because of the availability of recently constructed forest access roads (Figure 2).

A lake sediment survey has been completed in the study area (Ontario Geological Survey 2000). The information from this survey is useful in determining the background levels of various elements within the natural environment as well as indicating areas that are naturally enriched in potentially hazardous elements such as arsenic (As). This information is also useful in mineral exploration. This study presented plots of selected trace elements and recommended 27 areas for potential follow-up work within the current area of interest. Anomalous elements determined in this study "include: Au, Pd, Pt, Cr, Cu, Zn, Pb, W and Mo" (Ontario Geological Survey 2000, p.19).

Geological Setting

LANDSCAPE

The study area consists of large areas of bedrock-controlled terrain separated by plains that are commonly underlain by thick, Quaternary stratified sediments. Regionally, the area straddles a broad topographic low connecting the Hudson Bay Lowland, via Lake Nipigon, to the Lake Superior basin (Figure 3a). This regional-scale low influenced glacial movement through time and in particular during the latter stages of deglaciation as the glacier thinned.

The region encompassing the study area, located on the Canadian Shield, is an irregular, subdued, gently rolling, bedrock-dominated terrain underlain by Precambrian igneous and metamorphic rocks (*see* Figure 3a). The area immediately north of Lake Nipigon, however, is not typical shield terrain (Figure 3b). This area has been referred to as the Nipigon Plain by Bostock (1970) and "is formed on nearly flat-lying Proterozoic gabbro sills and sediments surrounding Lake Nipigon" (Bostock 1970, p.16). Combined past tectonic activity, differential weathering and glacial and/or glacial meltwater erosion of the Proterozoic sills and Sibley Group metasedimentary rock surfaces has produced a unique landscape of

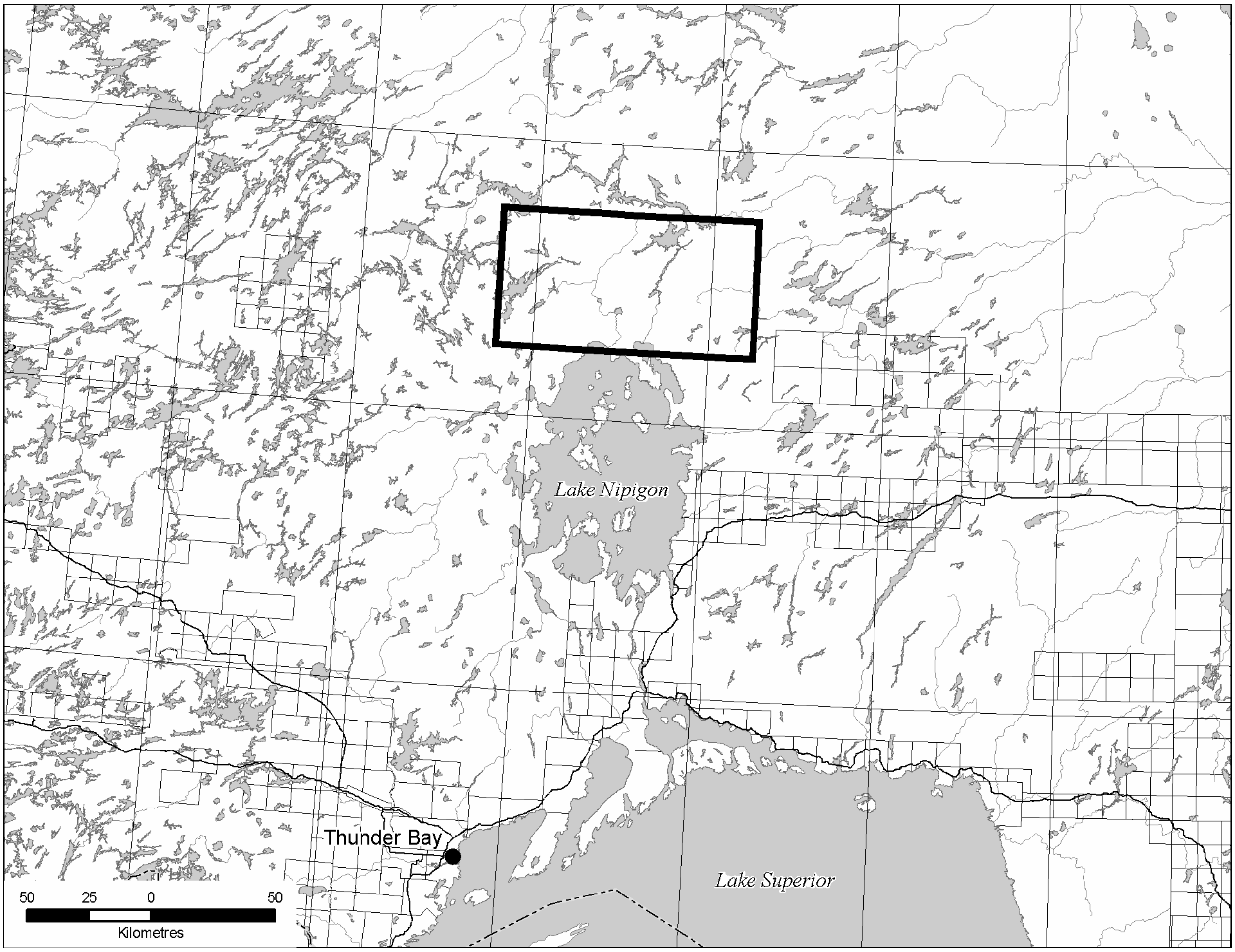

Figure 1. Location of the study area.

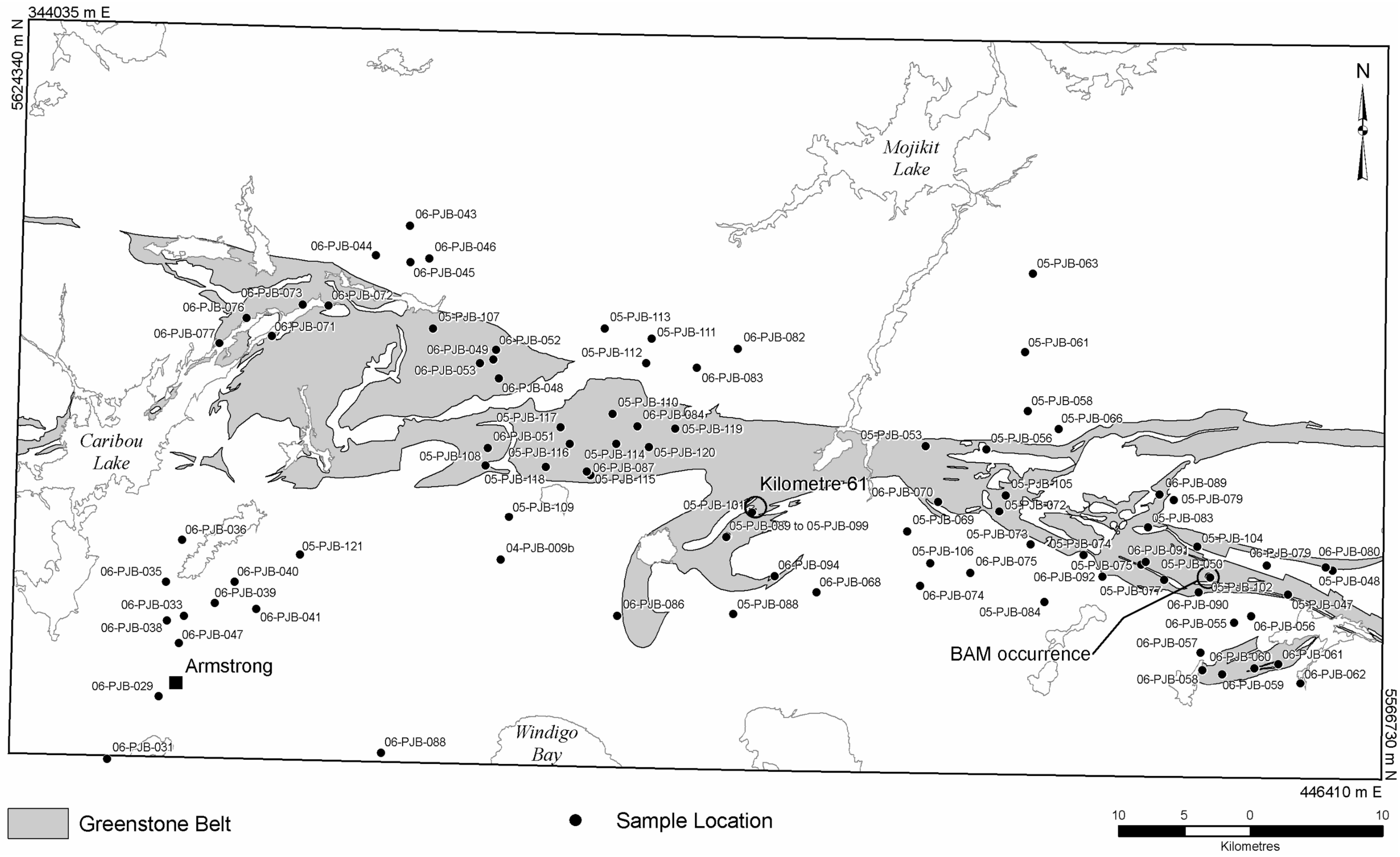

Figure 2. Location of samples.

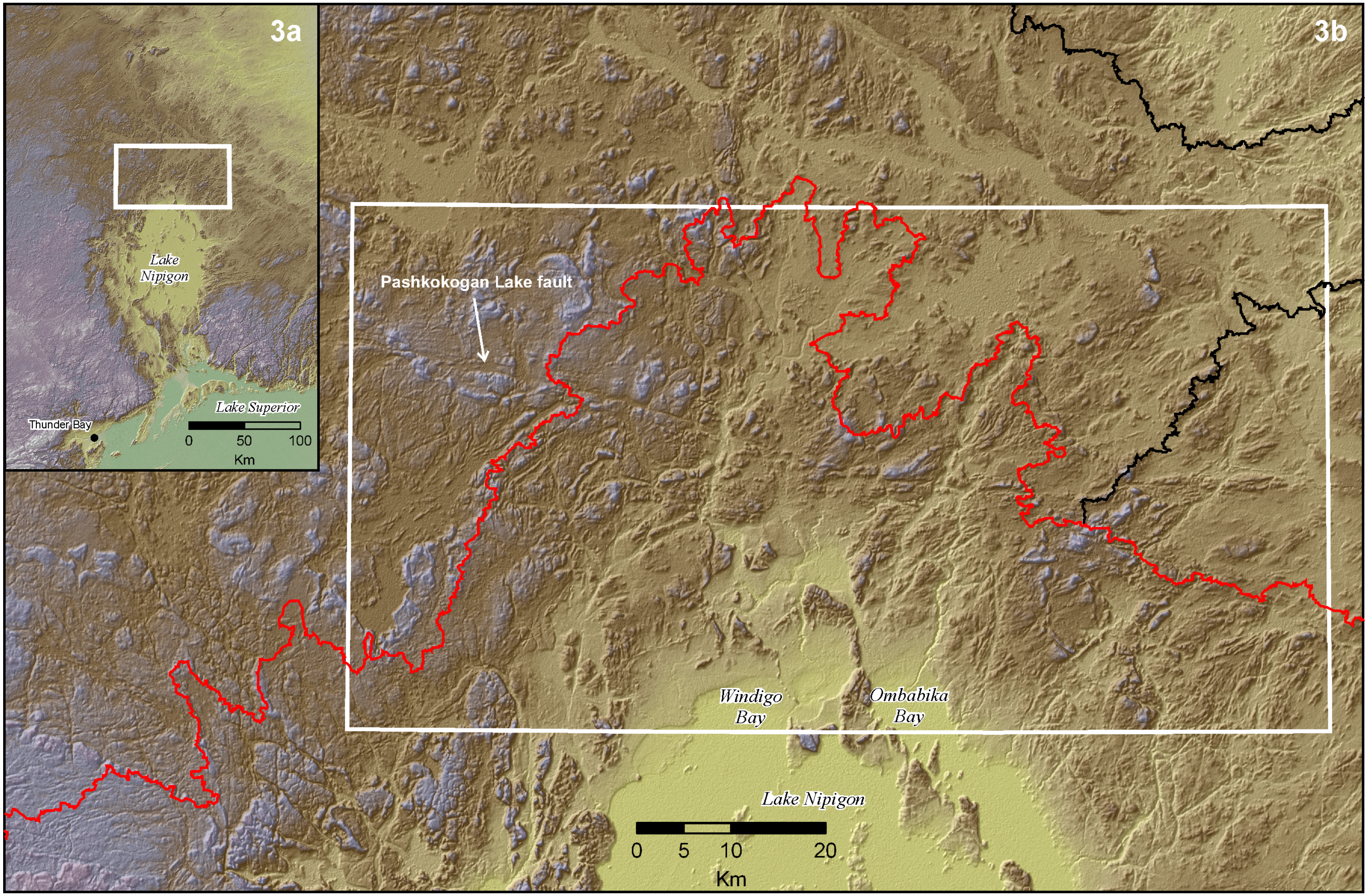

Figure 3. Shaded-relief image of a digital elevation model of a) the region, and b) the study area (data source: Shuttle RADAR Topographic Mission). Red line marks the Lake Nipigon drainage divide and the black lines outline the area of the Ogoki diversion..

buttes, mesas and steep-walled valleys along the margins of the Nipigon Plain. To the west and north, beyond the extent of the sills, in the area underlain by Archean igneous and metamorphic rocks more typical Shield terrain is prevalent (Severn Upland physiographic region of Bostock 1970). One of the most striking features in the area's topography (*see* Figure 3b) is the surface expression of the Pashkokogan Lake fault that separates Archean migmatitic metasedimentary rocks of the English River Subprovince from Archean supracrustal rocks of the Caribou Lake greenstone belt of the Wabigoon Subprovince. This fault crosses midway through the entire study area (*see* Figure 3b). The smooth plains on Figure 3b commonly correspond to areas with a thick cover of surficial sediments; predominantly glacial lake sand, silt and clay.

Total relief of the study area exceeds 310 m. Local relief in areas of Archean rocks is commonly between 15 and 45 m. Along the eroded edges of sills that surround the Nipigon Plain, relief can exceed 100 m.

The Great Lakes–Hudson Bay drainage divide bisects the study area (*see* red line on Figure 3b). Natural drainage southward into Lake Nipigon is via Minataree, Lamaune, Marten, Roaring, Slant, Seymore, Rapid, Kenna and Hoodoo creeks and the Little Jackfish, Pikitigushi and Whitesand rivers. Natural drainage northward toward Hudson Bay is via the Ottertail, Gurr, Raymond and Ogoki rivers. However, since the building of the Waboose Dam on the Ogoki River in 1942, the Ogoki Diversion Project, drainage of most of the study area is southward via the Little Jackfish River into Lake Nipigon. "This diversion increased maximum and average water flow in the Little Jackfish River by 8 and 30 times, respectively. Since 1943, when the diversion was constructed, these flow alterations have caused the erosion of 90 million cubic metres of sediment from the river, increasing turbidity, siltation, and sedimentation in Ombabika Bay" (Environment Canada 1997).

Regionally, during deglaciation, large, ice-contact glacier-fed lakes fronted parts of the ice margin (glacial lakes Agassiz, Minong, Kelvin and Nakina). The interactions of the glacier with these glacial lakes controlled depositional environments such that the distribution and types of landforms, origin (glacial, glaciofluvial or glaciolacustrine), material type and sediment distribution, particularly in low-lying areas were affected. The extensive plains surrounding the Pikitigushi River and Mojikit Lake are the products of glaciolacustrine sedimentation. Elsewhere, at higher elevations, the subglacial landscape is preserved across the region.

BEDROCK GEOLOGY

The study area straddles the boundary between the English River and Wabigoon subprovinces of the Superior Province (Figure 4). The Pashkokogan Lake fault, which marks this boundary, separates the Archean migmatitic metasedimentary diatexitic granite-granodioritic rocks of the English River Subprovince from Archean supracrustal rocks of the Caribou Lake greenstone belt and tonalitic plutons of the Wabigoon Subprovince (Percival et al. 2002; Stott et al. 2002).

The Caribou Lake greenstone belt ranges from 3 to 17 km wide and extends for nearly 100 km where it merges along strike with the Onaman–Tashota greenstone belt (Percival et al. 2002; Stott et al. 2002; MacDonald 2006). It consists primarily of massive to pillowed basalts, iron formation and komatiite with minor amounts of conglomerate (Percival et al. 2002). Proterozoic (Keweenawan) Nipigon diabase sills and Marathon gabbro dikes cut the Archean rocks in the study area.

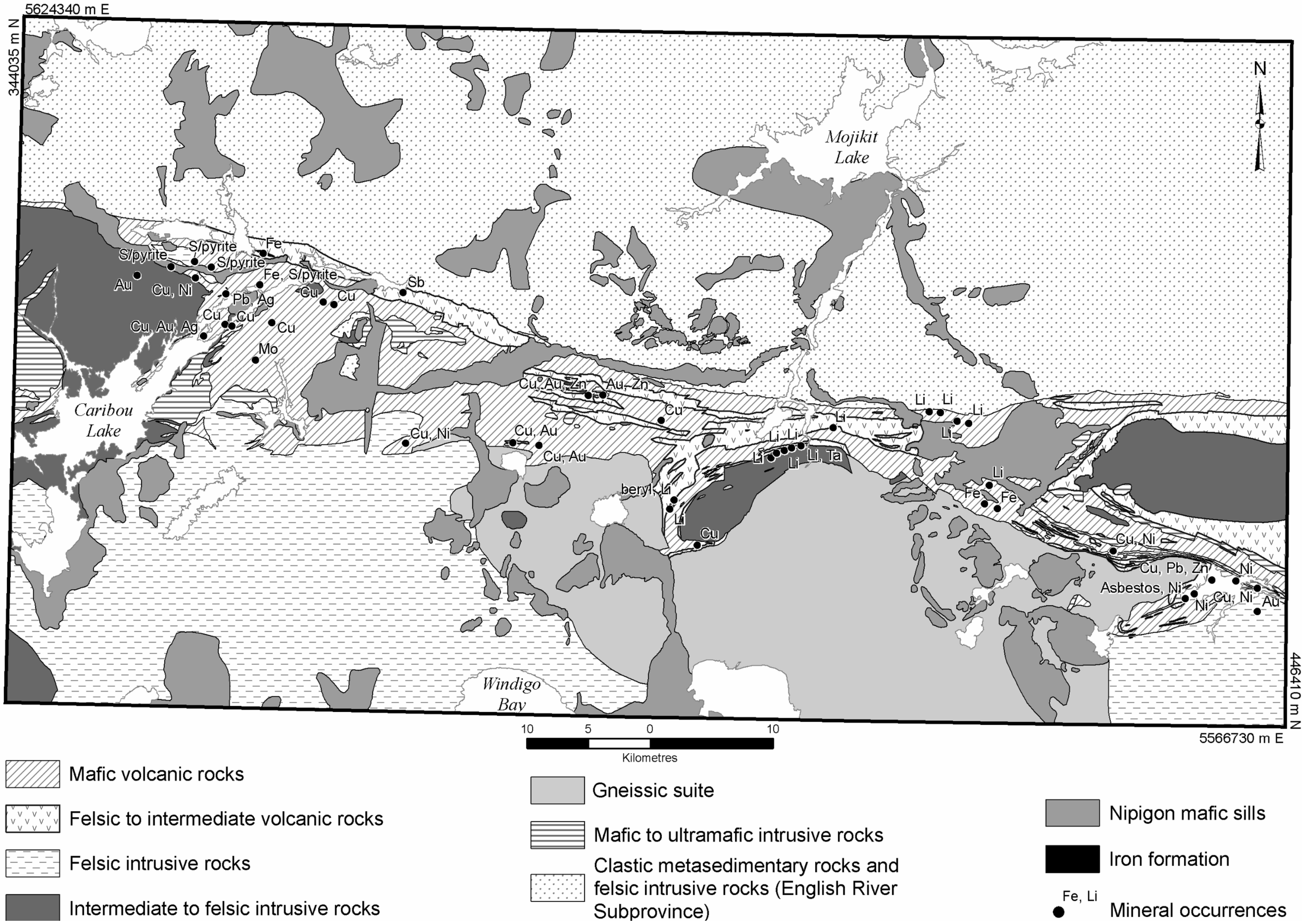

Figure 4. Generalized bedrock geology (*after* Percival et al. 2002; Stott et al. 2002) and mineral occurrences of the study area. Mineral occurrences (black dots) are from the Mineral Deposits Inventory (MDI) and current to 2004 (OGS 2004).

Very little mapping of the bedrock geology has been undertaken to date within the study area, due, in part, to the poor access and exposure. Gussow (1942) mapped the western part of the greenstone belt and Pye (1968) produced a map and report on the geology of the Crescent Lake area or the eastern part of the greenstone belt. More recently, reports and maps produced by Sutcliffe (1986, 1988) and Berger (1992) describe the geology in greater detail of smaller parts of the greenstone belt (Figure 5). And most recently, MacDonald (2006) mapped 1800 km^2 area in the central part of the belt. The southwestern corner of the study area, south of the Caribou Lake greenstone belt, was mapped by MacDonald (2004).

Smyk et al. (2005, 2006) summarizes the current knowledge of mineralization and recent exploration activity within the study area. In addition to the Cu-Mo-Au-Ag-mineralized porphyry at Kilometre 61 mentioned above, there is potential for Au and Cu-Ni-PGE mineralization in the area (Smyk et al. 2005, 2006). Pye (1968) describes some of the historic prospecting activity along the Caribou Lake greenstone belt and discusses occurrences of Cu, Au, Fe, Li, Mo, Ni, Zn and iron-sulphides. As well, Breaks, Selway and Tindle (2002) discuss the geology and mineral potential of fertile and peraluminous granites and related rare-element pegmatites that occur within the Caribou Lake greenstone belt.

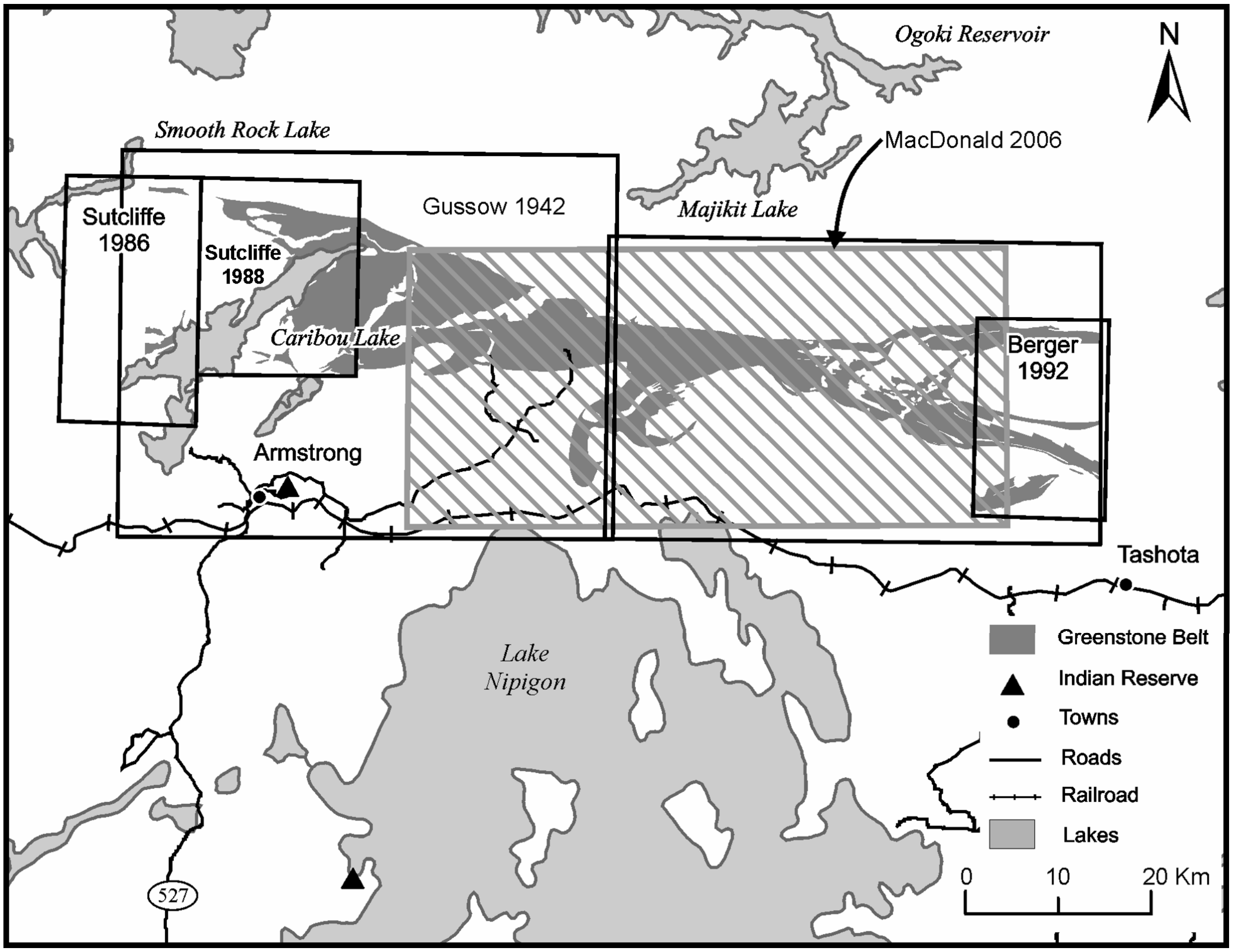

Figure 5. Areas covered by bedrock geology mapping (*after* MacDonald 2006).

GLACIAL GEOLOGY

Very few investigations of the surficial geology of the study area have been undertaken. Early work was completed in association with bedrock data collecting surveys. Dowling (1899) discussed a terrace of sand that occurred 100 feet above the lake and extended about 15 km up the Little Jackfish River. Park (1906, p.221A) suggested "clay along shoreline [Lake Nipigon north shore] would be suitable for the manufacturing of bricks and possibly would be of use for pottery". Burwash (1930) discussed the geology along the Little Jackfish River and created a profile along the river that contained information not only on the Precambrian geology, but also illustrated measured sections of the Quaternary sediments exposed along the riverbanks.

Pioneering map work by Zoltai (1965a, 1965b) describes the distribution and origin of the dominant landforms in the area. Northern Ontario Engineering Geology Terrain Study (NOEGTS) maps at a scale of 1:100 000 and reports (Cooper 1983a, 1983b; McQuay 1983a, 1983b; OGS–MNR 2005) describe the distribution of surficial materials, landforms, relief and drainage conditions within the study area.

The overall pattern of ice advance as recorded by glacial striae is displayed in Figure 6. Multiple directions of ice flow (striae) occur at a few localities located commonly near end moraines, such as the Nipigon moraine. The oldest ice flows observed were toward the south followed by more westerly flow. The area can be divided into 3 main zones based on ice-flow sequences defined by the Nipigon moraine and the Crescent Lake esker (formerly part of the Crescent Lake moraine, Zoltai 1965a, 1965b). West of the Nipigon moraine, ice flow was dominantly southward with minor late stage flow toward Lake Nipigon. East of this moraine and south of the Crescent Lake esker, ice flow was initially southward followed by ice flow toward the west-southwest and west-northwest in a splayed pattern on the east side of the Nipigon moraine. East of the Nipigon moraine and north of the Crescent Lake esker, ice flow is toward the southwest. Here, too, ice flow was likely southward at first; however, no record of this flow was observed on the ground.

Most deposits, particularly the till in the area, appear to be related to the last ice-flow event in each zone. Major glacial landforms in the study area include the Nipigon moraine, several small unnamed moraine segments, the Crescent Lake esker and a series of unnamed eskers, drumlins, rib or Rogen moraines and hummocky ground moraine. Figure 7 displays the distribution of surficial sediments and some of the major landforms in the area.

The till in the area is stony, poorly sorted with a slightly silty to silty sand matrix. The Folk's graphic mean (n = 129) for sand is 63.6%, silt 36% and clay 0.4% (Folk 1968). Carbonate content of the matrix is commonly below 3%; however, 4 samples contained between 3 and 10% and an additional 6 samples between 10 and 21% carbonate in their matrix (Figure 8).

Till is the dominant surficial sediment in areas of bedrock influence. It occurs as ground moraine, fluted ground moraine, in drumlins, rib or Rogen moraines and hummocky moraine. In most places, it has been deposited from the base of an actively flowing glacier and is, therefore, appropriate material to sample for mineral exploration (drift exploration). Exposures of till were plentiful particularly along forest access roads. The till, however, can be thick, exceeding 5 m in positive relief landforms such as drumlins, ribbed and hummocky ground moraine; sampling till from near the surface may not reflect bedrock immediately up-ice of the sampling location.

The end and recessional moraines, eskers and deltas are composed predominantly of ice-contact stratified sediments. Ice-contact proglacial lakes fronted the receding ice margin during deglaciation. Thick deposits of glaciofluvial and glaciolacustrine origin cover the bedrock and till surfaces, particularly in the valley of the Pikitigushi and Little Jackfish rivers. These sediments can obtain thicknesses exceeding 30 m and consist mainly of silt–clay rhythmites and sands (Lemoine 1989). They hinder mineral exploration by making it more difficult to collect till samples and more expensive if drilling is required to obtain till samples for mineral exploration.

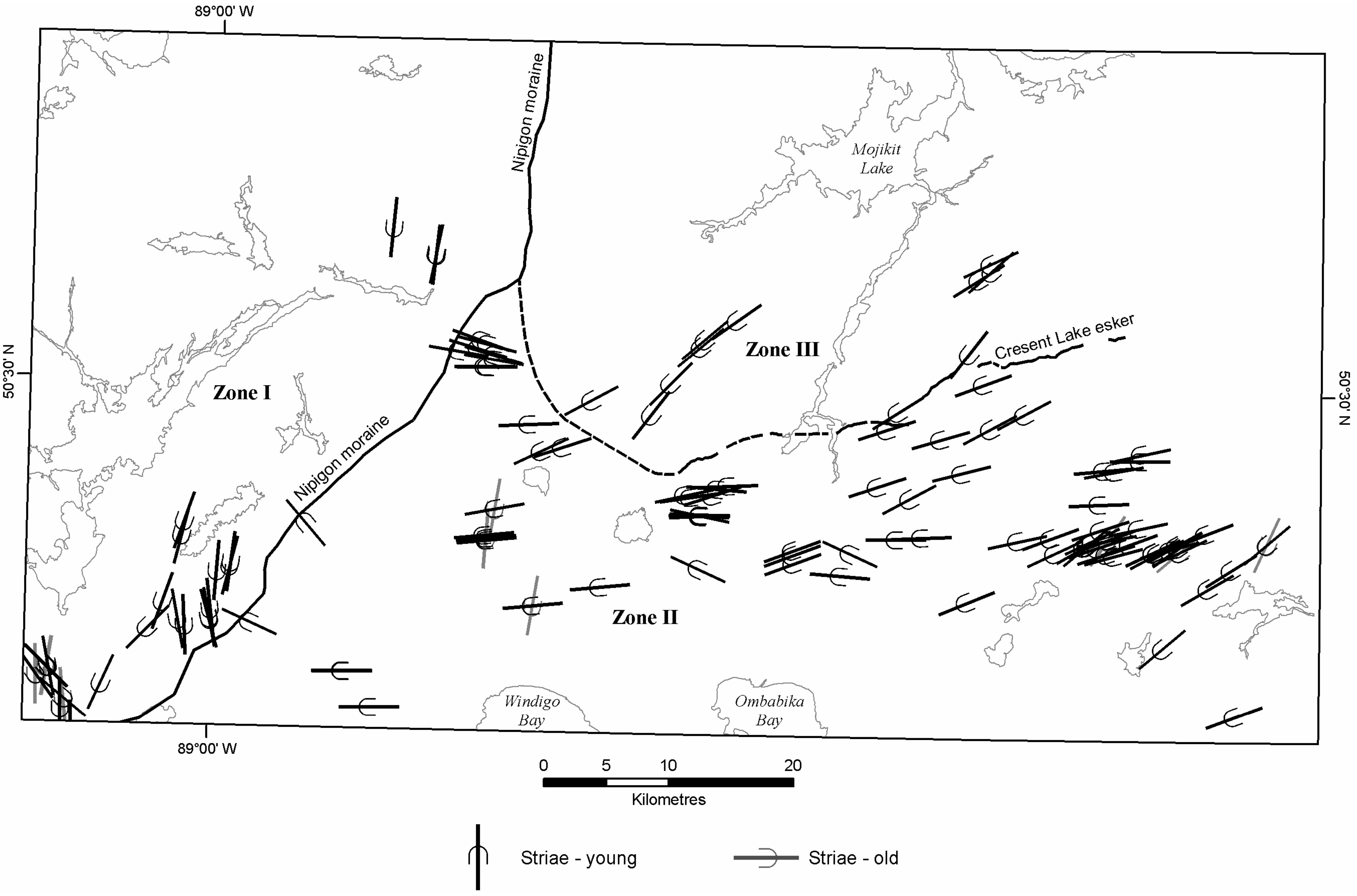

Figure 6. Distribution of measured glacial striae and the 3 main zones of ice flow sequences.

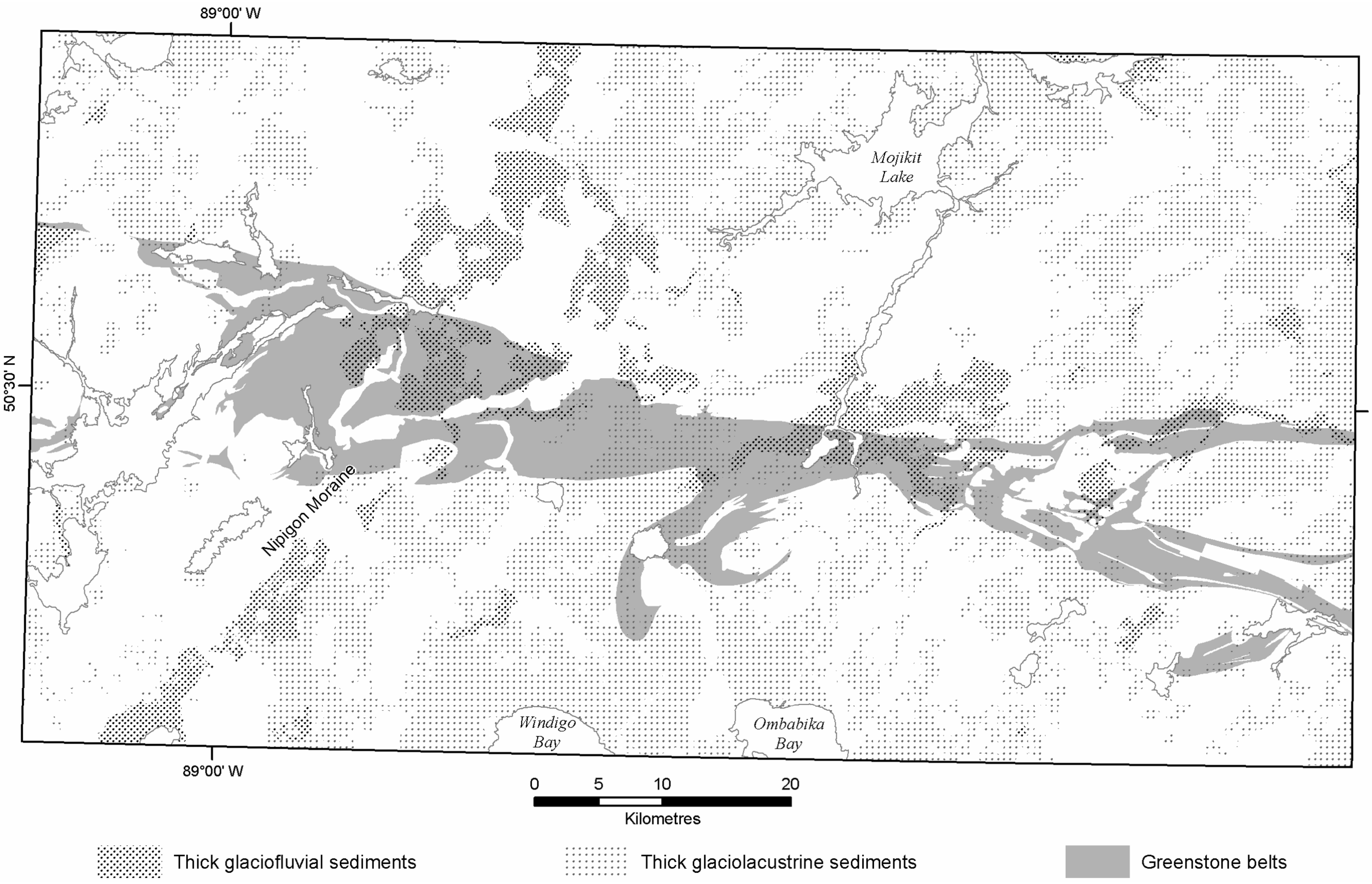

Figure 7. Areas of extensive cover of non-till sediments (*after* OGS–MNR 2005). Location of greenstone belts *after* Percival et al. (2002) and Stott et al. (2002).

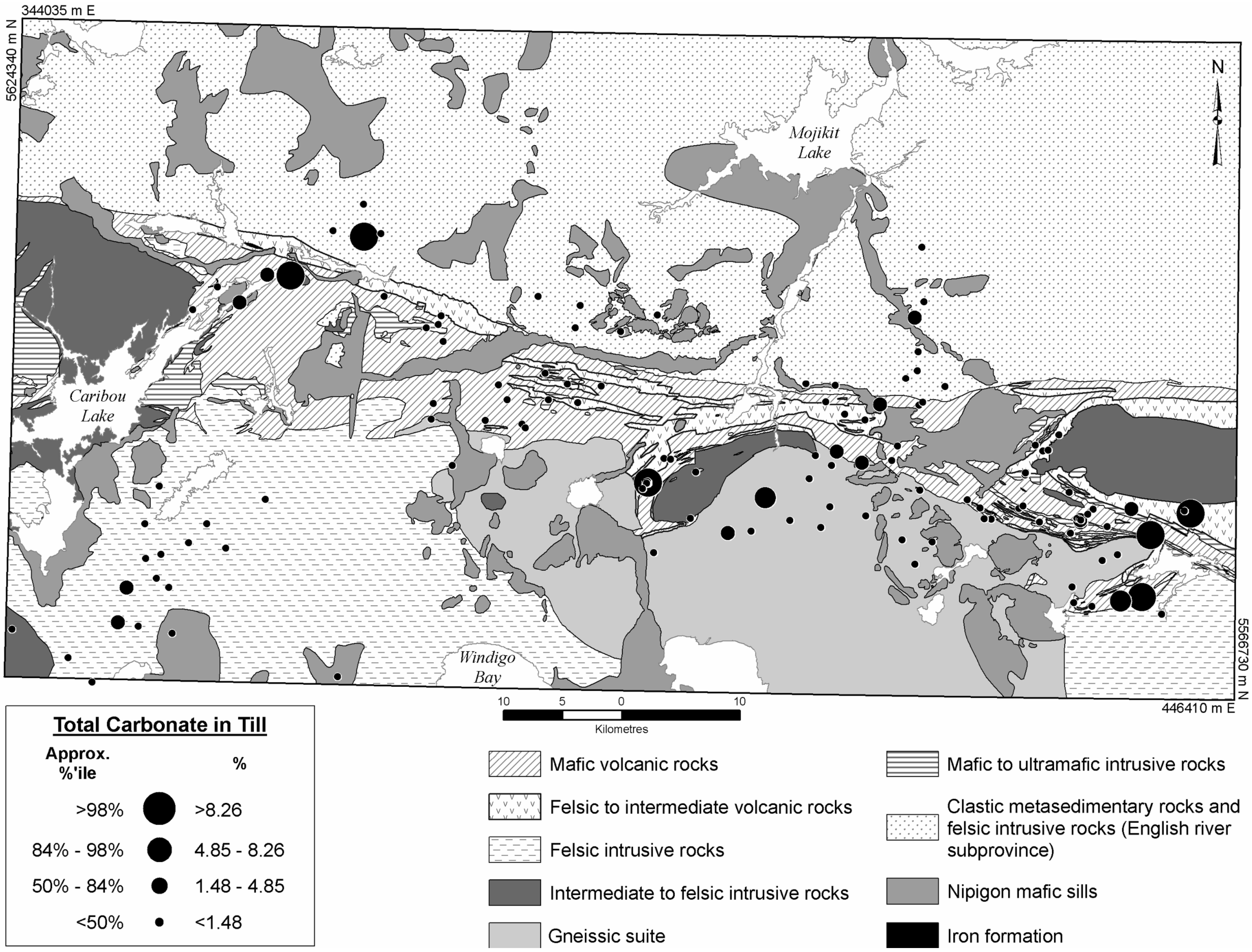

Figure 8. Total carbonate content of till samples.

Methods

The current project's goal was to determine the glacial dispersion of rock and mineral particles derived from the bedrock of the Caribou Lake greenstone belt. In order to accomplish this, it was imperative to sample subglacial till, the direct product of glacier erosion and deposition. At each sample site, either 2 or 3 samples were collected: a sample for particle size analysis and geochemistry of the till matrix; one for pebble lithology identification; and one for heavy mineral concentration and analysis. The sample for heavy mineral analysis was not always taken at each sample site.

A 10 to 15 kg sample of the <7 mm fraction of the till was collected for heavy mineral concentration and subsequent kimberlite indicator mineral (KIM), metamorphic/magmatic massive sulphide indicator mineral (MMSIM®[1]) and gold grain determinations by Overburden Drilling Management Limited (ODM), Nepean, Ontario. The following description of the heavy mineral concentration process used at ODM was provided by S. Averill, President, Overburden Drilling Management Limited: "Heavy mineral grains were separated from the <2 mm fraction of these samples by gravity tabling followed by heavy liquid refining using methylene iodide (S.G. = 3.2) and a magnetic separation to remove magnetite from the concentrate. This was followed by sieving of the nonferromagnetic heavies into 0.25 to 0.5 mm (medium textured sand), 0.5 to 1.0 mm (coarse textured sand) and 1.0 to 2.0 mm (very coarse textured sand) sizes and further electromagnetic sorting of the 0.25 to 0.5 mm minerals. The major (>15%) paramagnetic and nonparamagnetic minerals (i.e., the background mineral assemblage) in the 0.25 to 0.5 mm fraction of each sample were systematically observed and recorded in order of decreasing abundance using a binocular microscope, and the indicator minerals occurring in each size fraction were identified and put into vials. Energy dispersive X-ray spectrometry (EDS) analysis with a scanning electron microscope (SEM) was used to confirm visual mineral identification when required. During the tabling phase, a preliminary count of gold and/or platinum group mineral (PGM) grains was done and if any were observed, the finer (<0.25 mm) PGM and gold grains were micropanned from the table concentrates, measured and classified as to degree of wear during glacial transport." The processing methodology developed at ODM is described in greater detail in several other publications (Morris and Kaszycki 1997; Averill 2001; McMartin and McClenaghan 2001). Microprobe analysis, using a Cameca SX-50 EPMA, of picked mineral grains from ODM, primarily potential KIMs and MMSIM®s, was also undertaken by the Geo Labs.

A split of the heavy mineral grains for sample 05-pjb-058 was mounted and the chemistry analyzed using a Zeiss EVO®-50 scanning electron microscope (SEM) equipped with an Oxford Instruments energy dispersive spectrometer. From the resultant chemical information, mineral identification of each probed grain was determined and is summarized below (*see* "Geochemistry" "Heavy Mineral Fraction").

Samples of between 50 and 100 clasts from the >7 mm to 2.54 cm fraction of the till were collected for lithology identification. Samples of the till matrix were collected for particle size analysis and the –63 µm fraction isolated for geochemical determinations. The sample split for geochemical determinations was air dried, gently disaggregated, if necessary, and then sieved through a 250-mesh nylon sieve (63 µm). A 0.5 g sample of the –250-mesh fraction under went an aqua regia digestion and was analyzed using inductively coupled plasma mass spectrometry (ICP–MS) and inductively coupled plasma optical emission spectrometry (ICP–OES). Till matrix samples were also subjected to nickel sulphide–fire assay with inductively coupled plasma mass spectrometry (ICP–MS) finish. The –250 µm heavy mineral fraction of till samples was analyzed by ICP–MS and ICP–OES following an aqua regia digestion.

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[1] MMSIM is a registered trademark of Overburden Drilling Management Limited, Nepean, Ontario.

Results

Miscellaneous Release—Data 229 – Revised (MRD 229–Revised)[2], available separately, but designed to accompany this report, contains the results from the above analyses and information on data quality as determined by the insertion of duplicates and certified and non-certified reference materials. The results from heavy mineral concentration and mineral identification and heavy mineral and till matrix geochemistry (ICP–MS, ICP–OES and NiS-FA) are provided as spreadsheet files (*.xls* or *.csv* formats), GIS files (*.shp* format) and dot plots of selected results (*.tif* format). MRD 229–Revised contains 5 main folders: GeoLabs_data, HMC_grains, plot_data, base_data and dot_plots.

The original data from the Geo Labs are contained in 31 spreadsheet files of results and 15 quality control files (*.xls* or *.csv* format) in the "GeoLabs_data" folder. There are a few samples reported in these original spreadsheet files that were not collected in the study area and, therefore, their locations are not provided. The original results of samples collected for heavy mineral concentration and identification and their locations are contained in 3 spreadsheet files (*.xls* format) in a folder entitled "hmc_grains".

Results of the samples collected from within the study area are summarized in a series of 10 GIS files (*.shp* format) that are included in the folder entitled "plot data". A simplified compilation map of the bedrock geology and a map of important glacial features of the area are included as base information (*.tif* format, folder "base_data") to help in the user's interpretation of the "plot_data" files presented.

In addition, the folder "dot_plots" contains 54 examples of the study's results as elemental concentration dot plots or normalized grain counts superimposed on the bedrock compilation map (*.tif* format). For most of these plots, 4 sizes of dots were used: a small blue dot for values up to the mean (50th percentile), a larger blue dot for values between the mean and the mean plus 1 standard deviation (50th to ~ 84th percentile), a larger yellow dot for data between the mean plus 1 standard deviation and the mean plus 2 standard deviations (~84th to ~98th percentile) and larger red dots for values greater than the mean plus 2 standard deviations (greater than the ~98th percentile). For some elements, extreme values were removed prior to the calculation of the mean and standard deviation. The analysis of the chromium content of till samples produced results that formed 2 populations of data that were not taken into account in the dot plot presented (dp_icp-ms_till_Cr). In this Open File Report, only black and white versions of the diagrams are presented.

Interpretation of Results

INTRODUCTION

The results of analysis from till samples collected from various subglacial landforms in the area including ground moraine, drumlins, Rogen or ribbed moraine and hummocky ground moraine reflect changes in local bedrock conditions. Some examples include: gold grain content in till samples and gold determined by nickel sulphide–fire assay in till samples collected near Landore Resources BAM occurrence;

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[2] Digital data release MRD 229–Revised replaces Miscellaneous Release—Data 229 (released December 11, 2007). MRD 229–Revised contains changes in the shape file "dp_norm_precious" and 2 associated dot plots; and unit of measure changes on 6 dot plots for NiS-FA analytical results (**ppb** (not ppm)).

molybdenum in a till matrix sample immediately down-ice flow of the Kilometre 61 occurrence; and lithium and cesium in till matrix samples (ICP–MS) collected down-ice flow of the North Aubry and Falcon Lake pegmatites. Samples with anomalous results for various minerals and elements occur elsewhere and should be considered for follow-up work.

FLOAT

Four recovered float boulders were submitted for assay by Mark Smyk of the Resident Geologist Office in Thunder Bay. Two banded iron formation boulders, 05MLL-01 collected at Landore Resources BAM occurrence and 05MLL-02 collected less than 1 km from the southwest shore of Swole Lake, returned values of 204 ppm Cu and 132 ppm Zn and 459 ppm Cu and >3000 ppm Zn, respectively. A float boulder, a sulphidic metavolcanic, collected in 2006 approximately 3.5 km north of Toronto Lake (06MSL-01) returned 0.29 oz/ton Au, Ag not detected, 429 ppm Cu and 122 ppm Zn. A fourth boulder containing 2461 ppm Cu and 73 ppm Zn was collected 2.5 km south of Tape Lake. Ice flow in the area of the float boulders varies between southwest to almost westward (Figure 9).

HEAVY MINERALOGY CONCENTRATES

The heavy mineral concentrate of several collected samples are dominated by paramagnetic pigeonite derived from Nipigon diabase that occurs locally (Figure 10). The diabase contains up to 50% pigeonite (Larson and Mooers 2005). Consequently, the 0.25 to 2.0 mm till concentrates tend to be greatly oversized, often exceeding 100 g. The excessive pigeonite overwhelms and effectively masks the signature of any contained indicator elements if the concentrates are analyzed geochemically (Bajc 2000; Averill 2001; Larson and Mooers 2005), but the actual number of indicator mineral grains recovered for visual observation is unaffected. However, it is impractical to thoroughly examine concentrates >100 g for indicators. Therefore, some of the table concentrates were split; only 25 or 50% was refined and examined and the total number of indicators present was determined by extrapolation. In addition, the intensity of the electromagnetic separation was increased to cleanly separate the much smaller nonparamagnetic mineral fraction from the major paramagnetic pigeonite.

The samples most affected by the excessive pigeonite occur primarily in the central part of the Caribou Lake greenstone belt particularly north of Pikitigushi Lake and North Lamaune Lake (*see* Figure 10).

Precious Metals

GOLD GRAIN DATA

Gold grains in the heavy mineral fraction of till samples can be a direct indication of gold mineralization in the bedrock. The shape of the gold grains collected from till has been used to characterize transport history (Averill 1988; DiLabio 1990) and to provide insights into the size of the gold grains in the source mineralization. Gold grains are commonly classified into 3 classes based on their appearance: pristine, modified and reshaped.

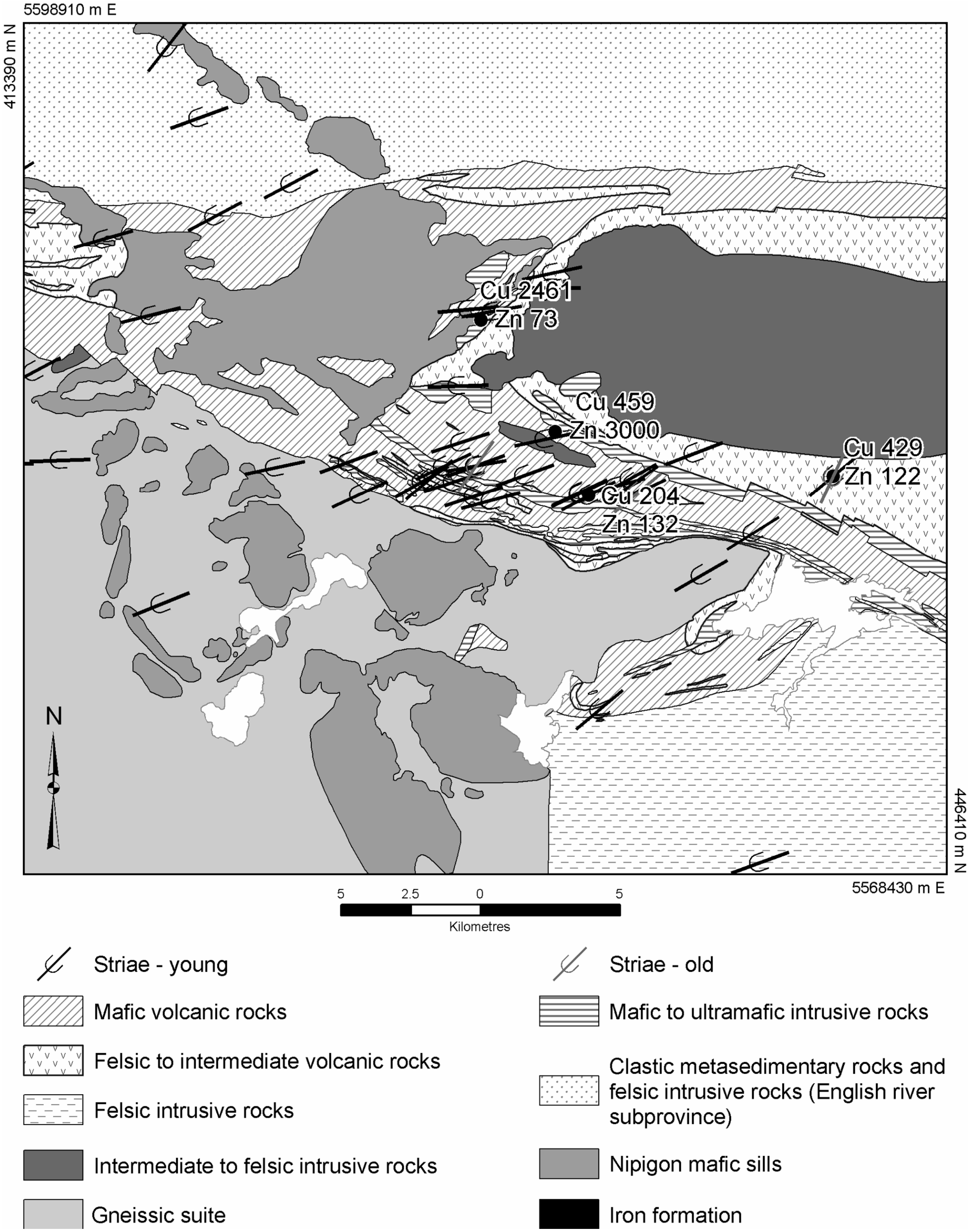

Figure 9. Distribution and copper and zinc content of float boulders sampled in the study area.

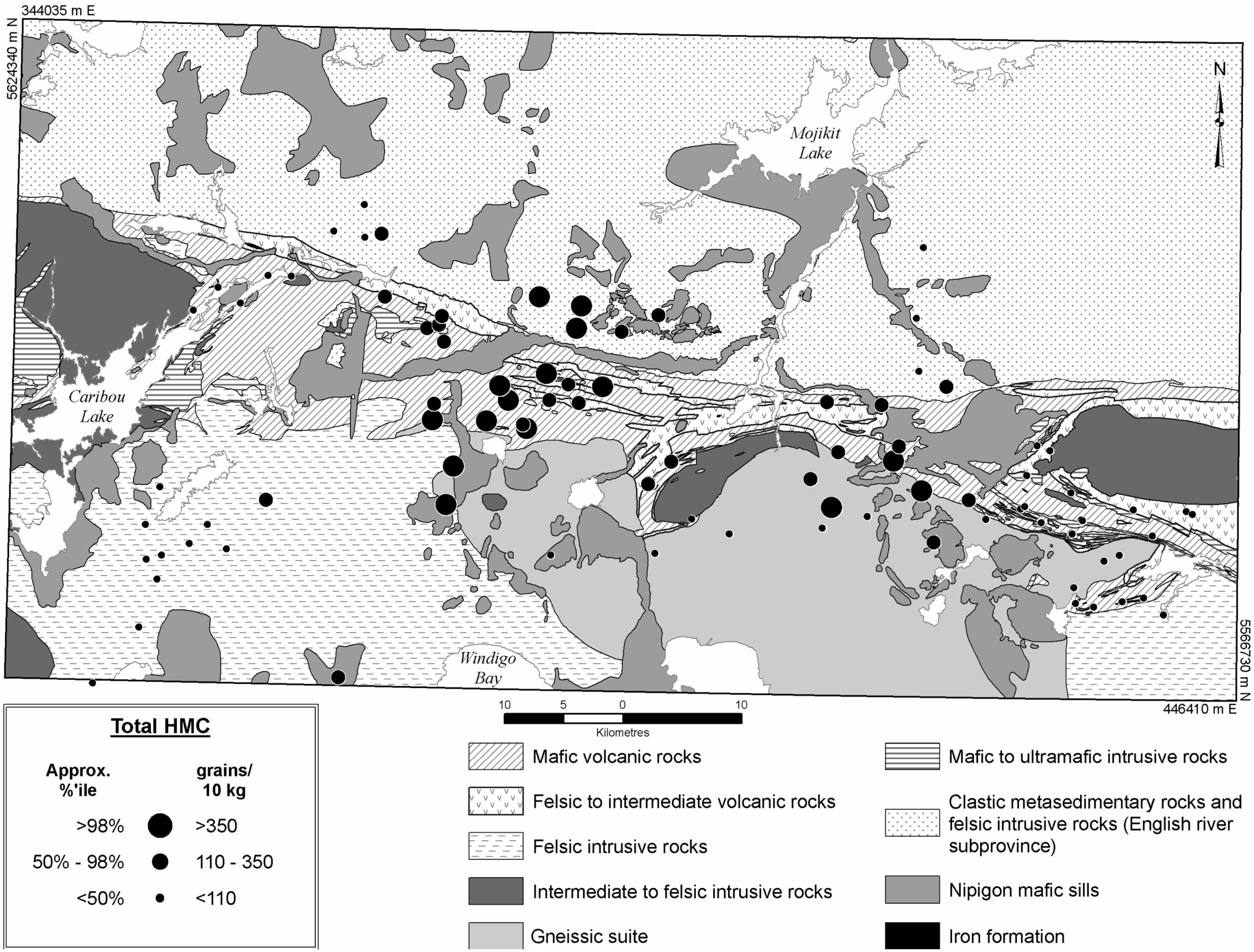

Figure 10. Total weight of heavy mineral concentrates from till samples collected in the study area.

Pristine gold grains occur as wires, rods or leaves. The transport history of these types of grains can be interpreted in 2 ways either as short glacial transport or that they may have been produced *in situ* by the chemical or physical breakdown of clasts, such as "sulphide grains containing fine particulate gold. In this case, little information is gained on the transport history of the gold; however, important information is acquired on the style of mineralization" (Bajc 2000, p.9). With modified grains, the original shape is modified, edges are bent, crumpled, folded and curled and can have striated surfaces as a result of glacial transport. It is thought that the bedrock source for modified grains is generally close to the sample site (Averill 1988; DiLabio 1990; Bajc 2000). Finally, reshaped grains may be flattened, rounded or intensely folded and are thought to be the result of transport distances which are greater than the other 2 previous types of gold grains (Averill 1988; DiLabio 1990; Bajc 2000). According to Bajc (2000, p.13), "… large numbers of gold grains within any given sample should be treated as potentially significant regardless of gold shape characterization".

The results of gold grain analysis are presented in Figures 11 and 12. The total number of gold grains in 10 kg of till is calculated to range from 0 to 31 grains. There are 2 areas that contain anomalous gold grain counts ($x+3\sigma$). The highest count (31 grains/10 kg, 32% of which are pristine or modified) occurs 2.25 km northeast of Pikitigushi Lake in an area underlain by mafic volcanic rocks and distal tuffs (05-pjb-115). Individual recovered gold grains are up to 200 μm in size. The anomaly occurs in an area of several existing showings for gold and copper (Ontario Geological Survey 2004).

Another till sample from the same general area contains 14 grains /10 kg, mostly reshaped grains (05-pjb-114). A sample collected about 2.2 km northwest of Ketchikan Lake near Landore Resources BAM occurrence contained 19 grains (65% pristine or modified, 05-pjb-102) and a nearby sample, 17 gold grains (41% pristine or modified grains, 06-pjb-090) per 10 kg sample of till. Neither sample was taken directly down-ice flow of the BAM occurrence (trench T15).

COPPER GRAIN DATA

The 2 samples that contained elevated grain counts of gold in the area 2.25 km northeast of Pikitigushi Lake also contained 5 grains each of native copper per 10 kg sample (05-pjb-114, 05-pjb-115). The most likely source for native copper is the Nipigon diabase sills; however, the closest mapped area of diabase is approximately 5 km away.

Platinum and Palladium Data

No platinum or palladium mineral grains were observed in the heavy mineral concentrates collected for this study.

Kimberlite Indicator Minerals (KIMs)

Very few kimberlite indicator minerals were identified in the heavy mineral concentrates (Figure 13). Samples with high number of potential kimberlite indicator mineral grains contain large numbers of chromite grains that are thought to have originated from local mafic to ultramafic intrusions within the Toronto Assemblage rocks (Berger 1992) rather than kimberlite (*see* "Chromite Grain Data"). The Cr_2O_3 and MgO contents of the chromite grains are lower than chromites associated with diamond inclusion field chromites.

Other kimberlite indicator mineral grains commonly occur in low numbers in the samples collected. Only 4 pyrope garnets were identified in the heavy mineral concentrates and they all are of G9 (lherzolite) composition (05-pjb-075, 1 grain; 06-pjb-059, 2 grains; 06-pjb-080, 1 grain). These 3 samples contain few (<3 grains) of other kimberlite indicator minerals excluding chromite.

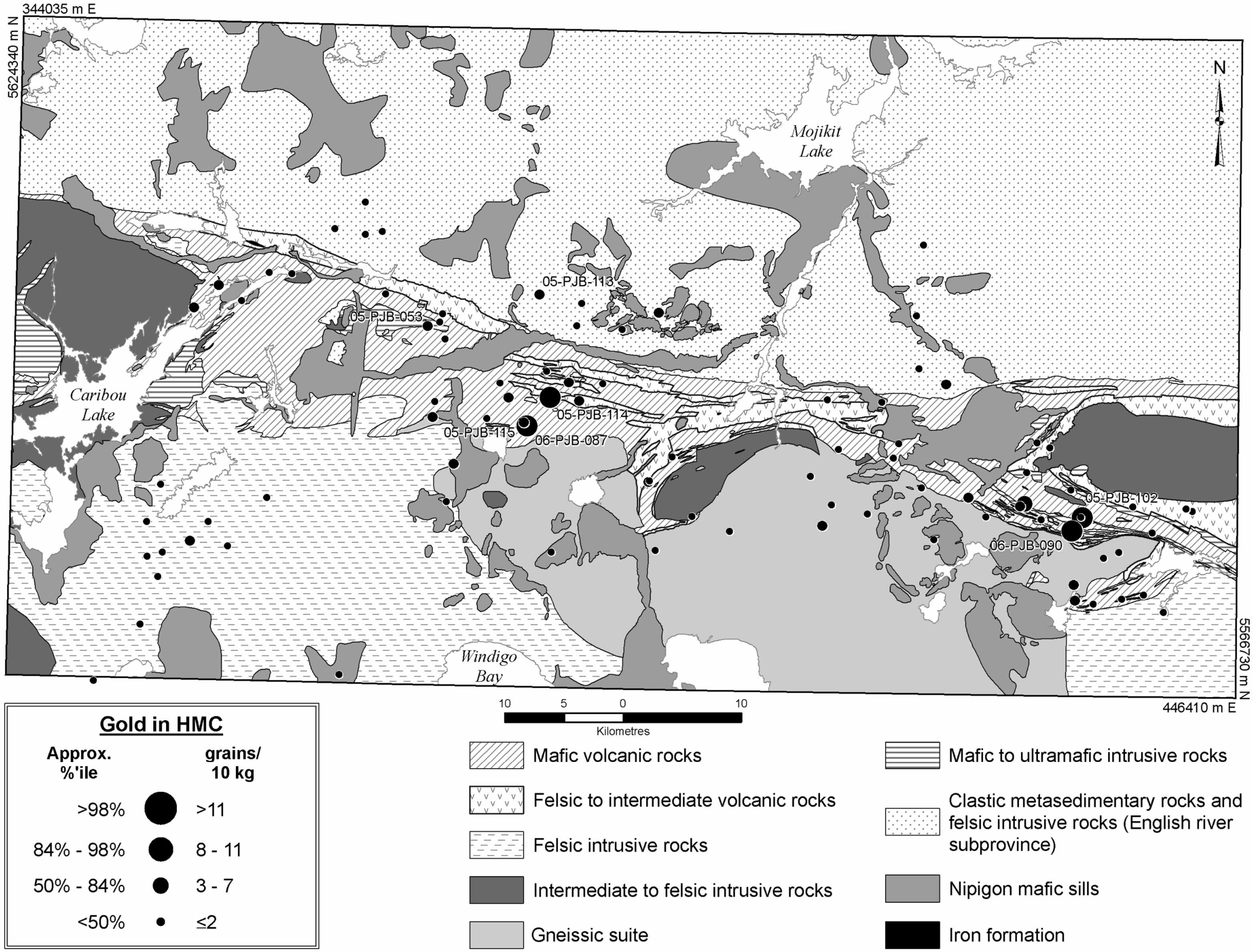

Figure 11. Total number of gold grains in the heavy mineral concentrates of till samples collected in the study area.

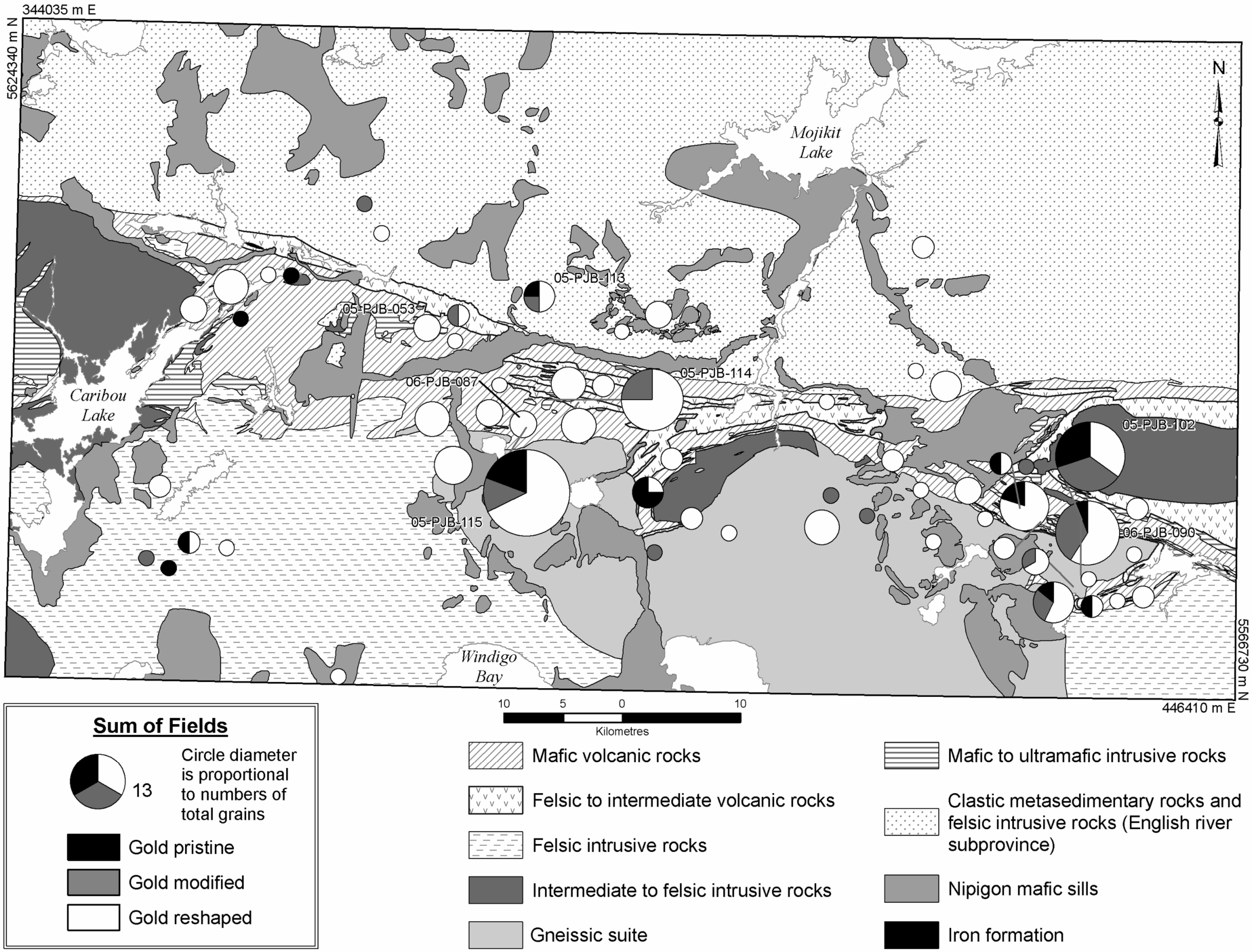

Figure 12. Pie diagrams of the relation of pristine, modified and reshaped gold grains in till samples collected in the study area.

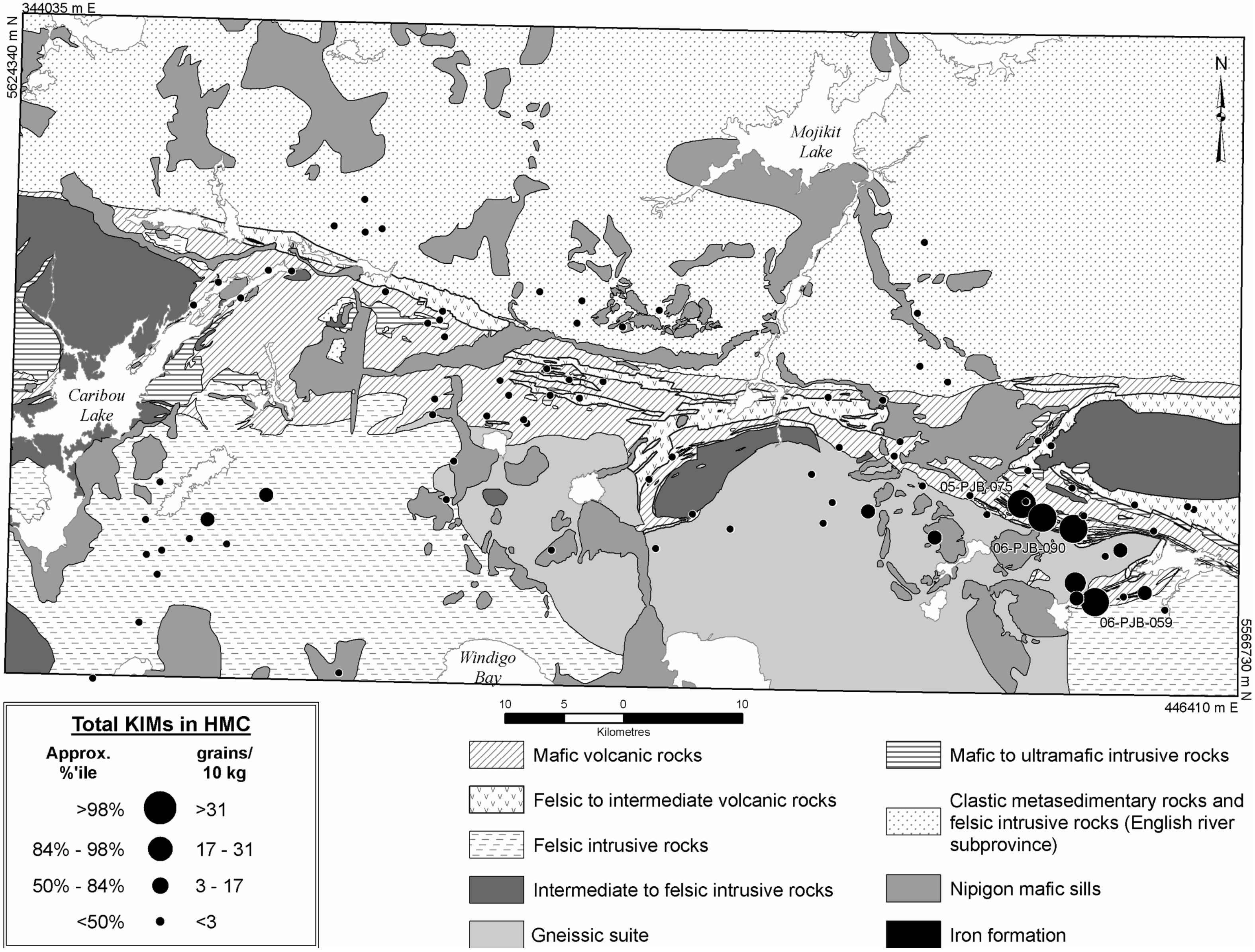

Figure 13. Total number of kimberlite indicator mineral grains normalized to 10 kg of sample for till collected in the study area.

Metamorphic/Magmatic Massive Sulphide Indicator Minerals (MMSIM®)

The heavy mineral concentrates were also picked for MMSIM® including the common metamorphosed massive sulphide minerals: gahnite, spessartine, Mn-epidote, staurolite and anthophyllite; and the magmatic massive sulphide indicator minerals: olivine, chromite, bronzite and chalcopyrite (Averill 2001). Figure 14 shows the distribution of MMSIM® grains in till samples of the study area. Samples 06-pjb-090 and 06-pjb-059 contain large quantities of chromite grains that heavily skew the total indicator data.

Sulphide Grain Data

Glacial sediment obtained from drilling is ideal for heavy mineral sampling and analysis because base metals are found in primary sulphide minerals (Averill 2001). In near-surface samples, like those collected for this project, these primary sulphide minerals can be destroyed due to weathering processes and, therefore, the number of sulphide grains can be treated as minimum values.

Over 40% of all samples contained pyrite (FeS_2) grains. Three samples contained over 200 grains of pyrite/10 kg of till sample. Sample 06-pjb-090 contained over 16 000 grains, sample 05-pjb-121 an estimated 250 grains and 05-pjb 077, 238 grains. The sample containing the highest count of pyrite grains also contained the highest count of chromite grains.

Chalcopyrite ($CuFeS_2$) grains occur in 21 of the samples collected. They are nominally stable in surface sediments worldwide (Averill 2001). Averill (2001, p.74) suggests that "observed chalcopyrite grains are clearly survivors of a once-larger sulphide mineral population". Sample 06-pjb-058 contained an estimated 35 grains of chalcopyrite and is located at the southwest end of Joy Lake.

Arsenopyrite (FeAsS) grains (7 grains) occur in only one sample (06-pjb-029) located about 3 km north of MacKenzie Lake, south of the community of Armstrong. Three grains of cinnabar (HgS) were identified in a till sample (06-pjb-044) taken about 2.5 km north of Linklater Lake.

Chromite Grain Data

Twenty-six out of 91 samples contain chromite grains and 9 sites had more than 5 chromite grains/10 kg of till (Figure 15). The majority of the latter sites occur within the Caribou Lake greenstone belt (Toronto Assemblage) in the area between Joy and Toronto lakes and North Laumane and Ketchikan lakes. Two samples from sites, 05-pjb-121 and 06-pjb-075, overlying granitic and gneissic terrain south of the Caribou Lake greenstone belt had 6 and 8 grains, respectively. Chromite grains exceed 2200 grains in sample 06-pjb-090 taken northeast of Junior Lake and 1200 grains in sample 06-pjb-059 east of Joy Lake. The large numbers of chromite grains in these 2 samples may be the result of post-depositional break-up of boulders containing abundant chromite grains rather than as a result of individual grain dispersal; however, no such weathered rock fragment was noted during sampling.

The chromite grains are likely of crustal origin derived from sill-like intrusions of mafic and ultramafic rocks. The rocks of the Toronto Assemblage, dominantly mafic metavolcanic rocks and thin mafic to ultramafic intrusions, occur in the area with high chromite grain counts and estimates (>21 grains/10 kg sample).

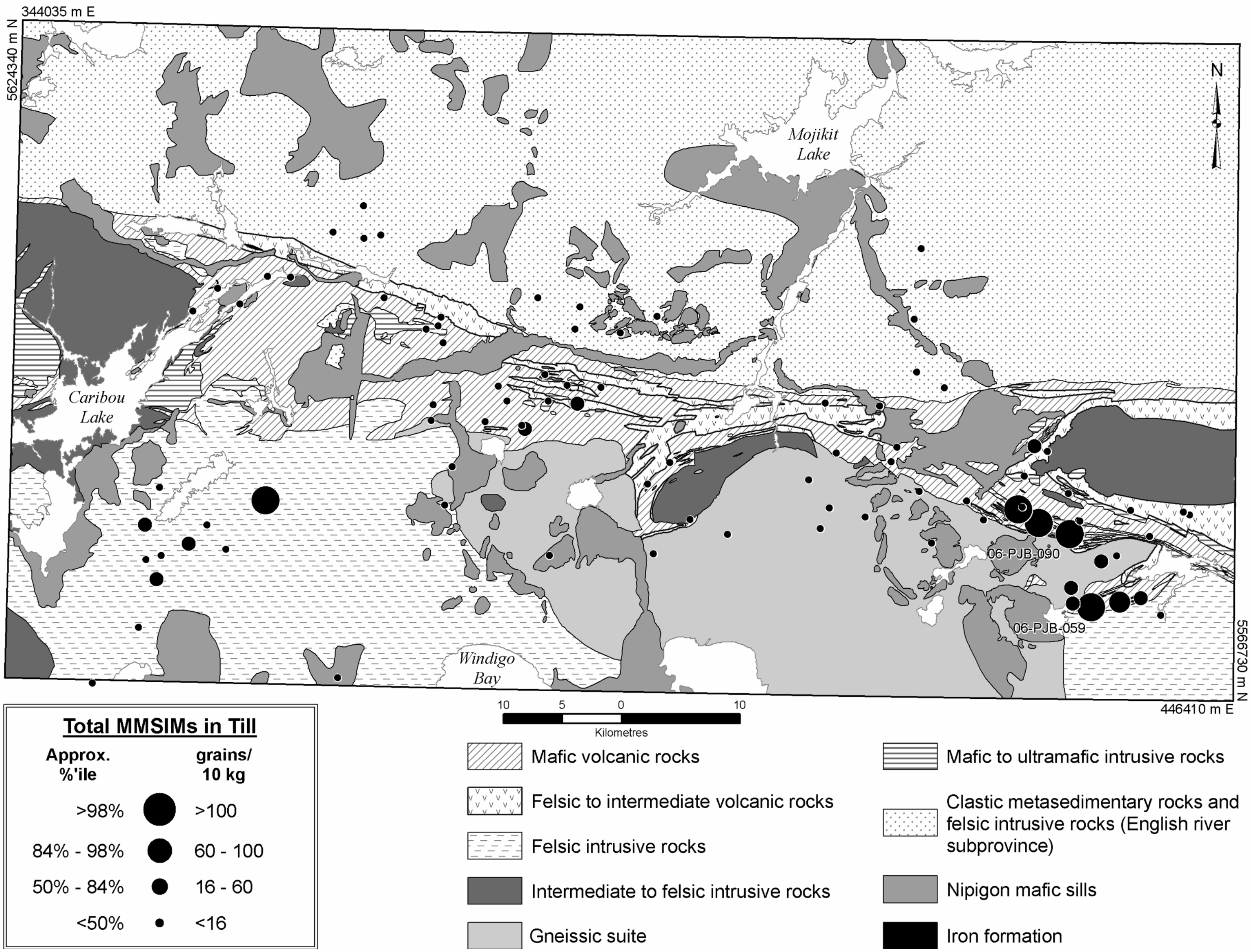

Figure 14. Total number of metamorphic/magmatic massive sulphide indicator mineral (MMSIM$^{®}$) grains normalized to 10 kg of sample for till collected in the study area.

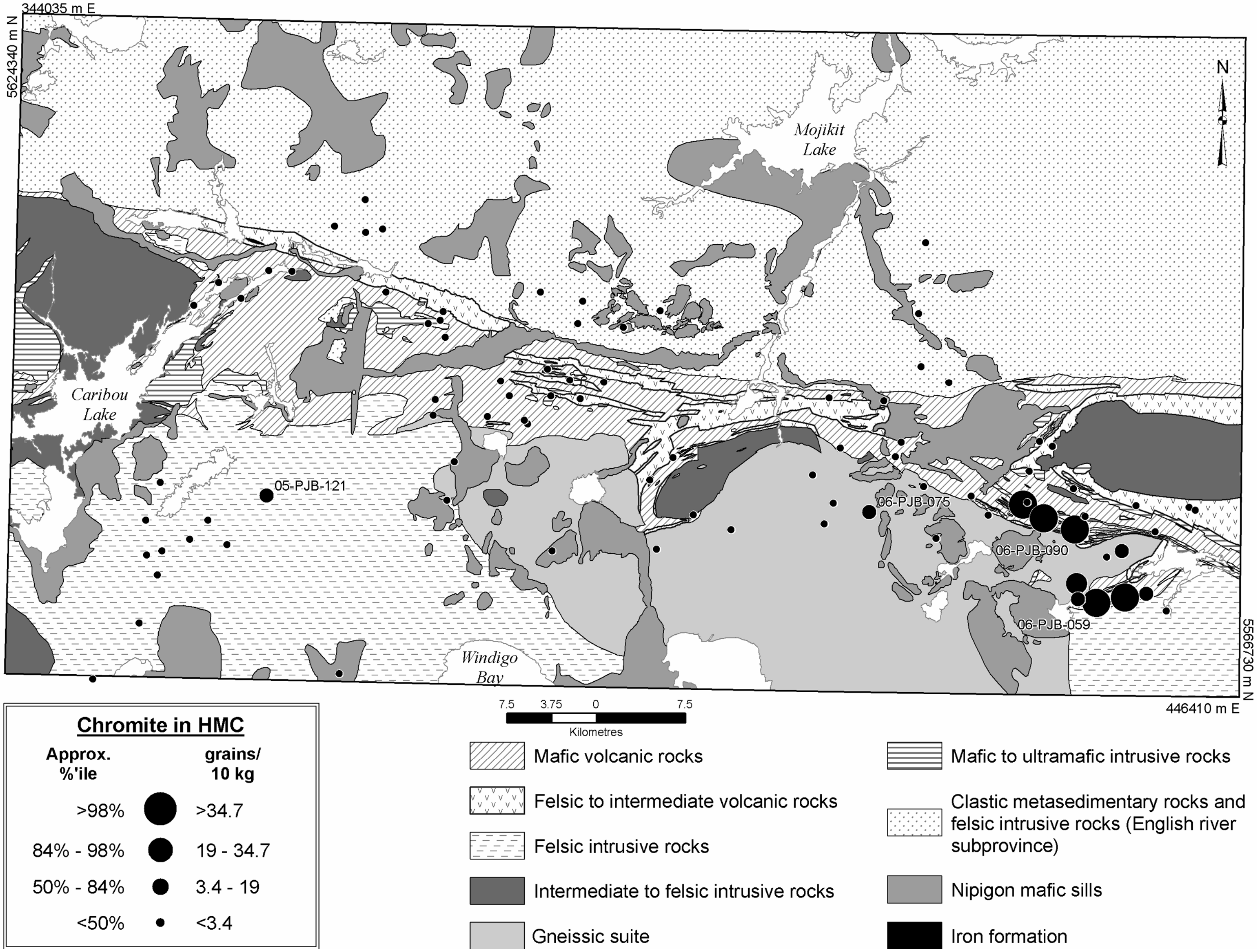

Figure 15. Total number of chromite grains normalized to 10 kg of sample for till collected in the study area.

Gahnite Grain Data

Gahnite ($ZnAl_2O_4$) grains occur in 8 of the heavy mineral concentrates analyzed and their quantity in till samples ranged from 0 to 6 grains/10 kg (Figure 16). Sample 06-pjb-043 contains 6 blue-green grains/ 10 kg of gahnite. This sample is located within the English River Subprovince approximately 5 km north of Linklater Lake. A sample (04-pjb-009b) with 5 green gahnite grains occurs in proximity to the gneiss–granite–diabase contact about 5.5 km southwest of Pikitigushi Lake and another sample (05-pjb-108) 4.5 km northwest of Pikitigushi Lake contains 3 green gahnite grains per 10 kg of till. This sample is located near a gneiss–diabase–mafic metavolcanic–sediment contact. The remaining sites containing gahnite grains are located within mafic metavolcanic rocks or occur on gneissic rocks immediately down-ice of mafic metavolcanic rocks.

The chemical composition of selected gahnite grains was determined by electron microprobe analysis. Gahnite grains from 05-pjb-096, 06-pjb-076, 05-pjb-108 and 06-pjb-055 plot within group 1 of Morris et al. (1997), which they suggest are derived from rare-element pegmatites and peraluminous granites. Samples 04-pjb-009b and 06-pjb-043, the samples with the most gahnite grains, contain gahnites that plot in group 3 of Morris et al. (1997), which they suggest are derived from aluminous sedimentary rocks. Sample 06-pjb-043 also contained group 2 gahnites and 1 iron-rich gahnite. Group 2 gahnite grains are thought to be recovered from volcanogenic massive sulphide (VMS) deposits (Morris et al. 1997). Gahnites from the remaining samples analyzed were of group 2 compositions.

GEOCHEMISTRY

In addition to providing background information on elemental concentrations in the environment and the natural ranges in concentration of element within the Caribou Lake greenstone belt, potential exploration target areas are indicated in the C-horizon till matrix and heavy mineral geochemical data sets (MRD 229–Revised). Element concentration distributions are similar to those reported by Bajc (2000) from the western part of the Shebandowan greenstone belt for most elements.

Heavy Mineral Fraction

The geochemistry of the heavy mineral concentrates was done despite the potential influence of contributions from the Nipigon diabase sills; however, this should be considered when interpreting this data (*see* Figure 10).

One area of interest is located over rocks of the English River Subprovince, adjacent to, and north of, the Caribou Lake greenstone belt. One sample (05-pjb-058) collected here, about 3 km east of Palava Lake, contained anomalous levels of many elements, but, in particular, rare earth elements. A concentration of dysprosium (Dy) was approximately 10 times greater than the mean concentration and concentrations for Pr, Nd, Sm, Gd and Tb between 4 and 6 times the mean (e.g., Dy, Figure 17). Most of the remaining REE concentrations were approximately 2 times their respective mean (Eu, Er, Ho, Tm, Yb and Lu). Enrichment also occurred for Y, La, Ga, Pb, U and Th in this sample. An adjacent sample (05-pjb-066) contained anomalous Cs and Rb values.

Electron microprobe analysis of heavy mineral grains from sample 05-pjb-058 contained about 1% monazite grains (1.7% by area) and about 0.05% xenotime grains (0.1% by area). Monazite is likely the main source of the light REE and Th, and xenotime the source of the heavier REE and the U.

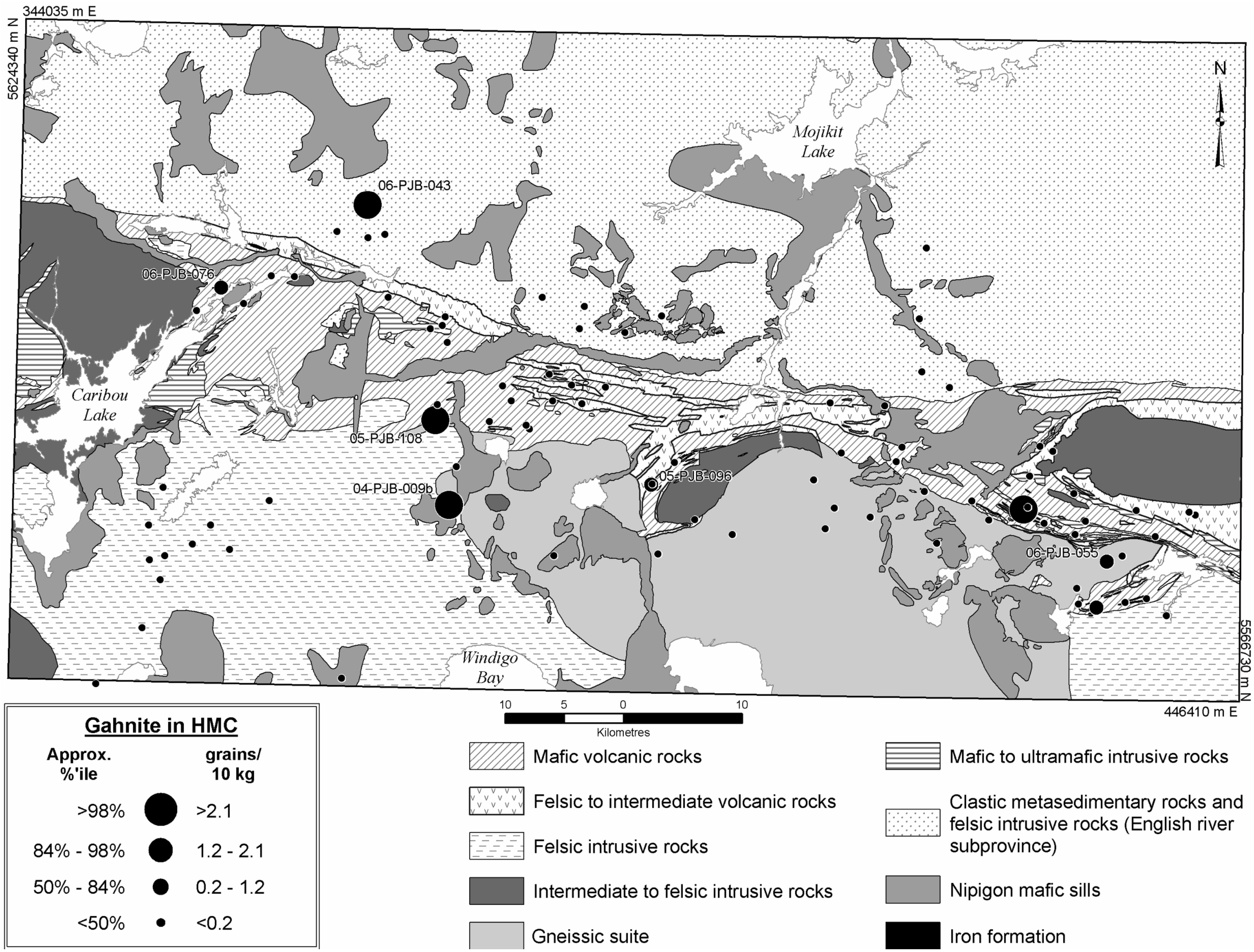

Figure 16. Total number of gahnite grains normalized to 10 kg of sample for till collected in the study area.

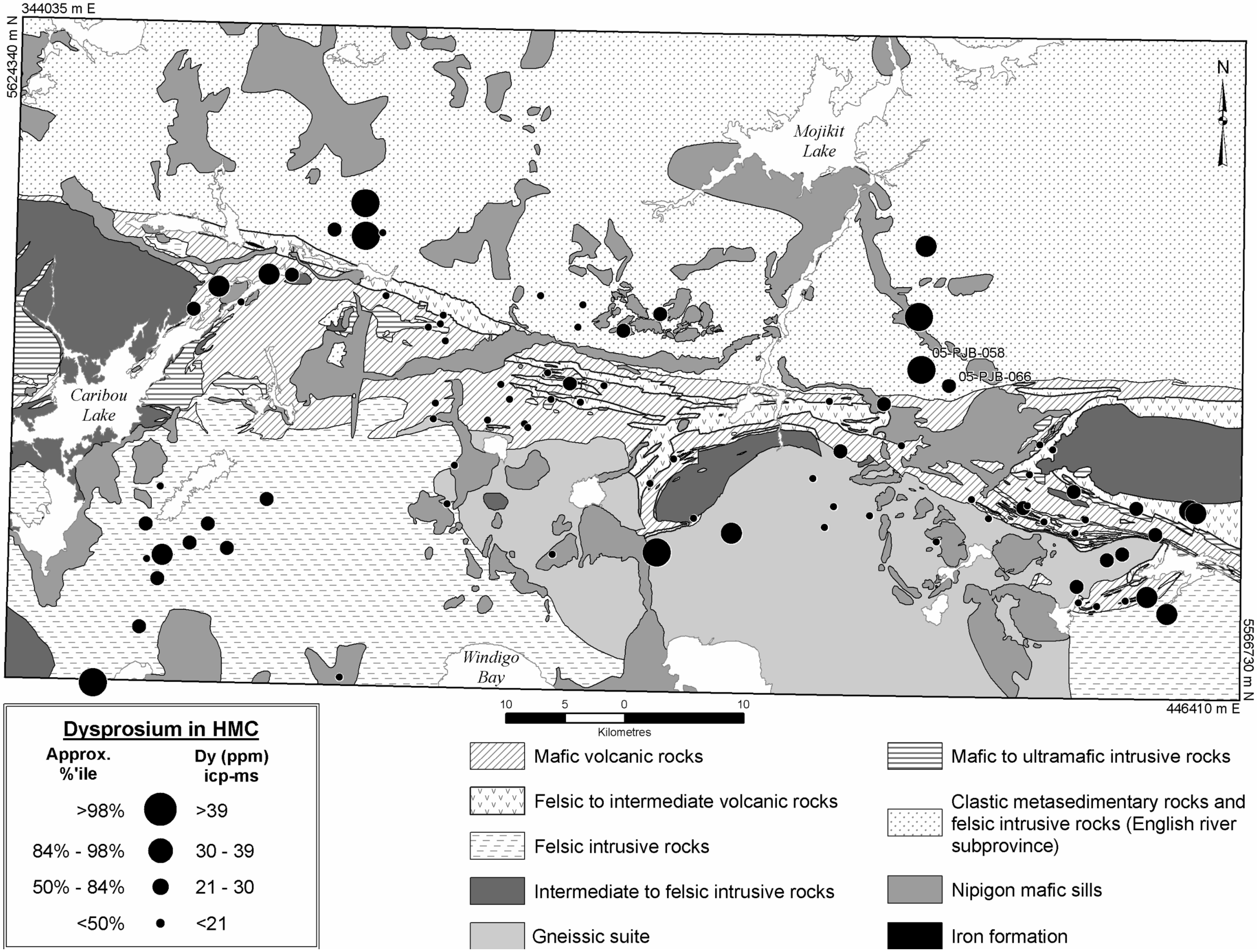

Figure 17. Dysprosium content in till samples (<63 µm fraction) collected in the study area.

The area south of the Summit pluton contains regionally high values of the following elements: Nb, Sb, Sn, Sr, Ti, W and Zr. Also in this area, anomalous or elevated values of Zn and Mo were reported from the geochemical analysis of the heavy mineral concentrates.

Till Matrix Fraction

Gold concentrations (Figure 18), as determined by nickel sulphide–fire assay with ICP–MS finish, in the –63 µm till matrix samples (aqua regia digestion) mirror the results from the gold grain counts. A value of 129 ppb was obtained from a sample (05-pjb-124) collected in the vicinity of Landore Resources BAM occurrence. This sample site is roughly down-ice flow of sample 05-pjb-102 that contained an anomalous amount of gold grains. Sample 05-pjb-102 and samples 05-pjb-123 and 06-pjb-090 collected nearby also contained anomalous levels of Au and may represent part of a larger dispersal train.

Elevated levels of gold were obtained from sample 05-pjb-115 collected northeast of Pikitigushi Lake. This sample also contained the greatest number of gold grains. An elevated gold concentration occurred in sample (06-pjb-071) located on a small island along the east shore of Caribou Lake opposite Keller Island. The most anomalous antimony (Sb) concentration was also obtained from this sample.

Other samples containing anomalous concentrations of antimony were collected throughout the Caribou Lake greenstone belt including the Landore Resources BAM occurrence area and the area northeast of Pikitigushi Lake (Figure 19). One sample (05-pjb-035) located over granitic terrane about 7.5 km west of the community of Armstrong was also anomalous in Sb.

Although no indicator minerals of platinum and/or palladium mineralization were found in the heavy mineral concentrates, several samples contained elevated or anomalous levels of platinum group elements. Palladium was at anomalous levels in 3 samples (06-pjb-048, 06-pjb-049, 06-pjb-053) collected about 4 km northwest of Gort Lake, 4 samples (05-pjb-066, 05-pjb-111, 06-pjb-046 and 06-pjb-083) taken within the English River Subprovince, one sample (06-pjb-090) near Landore Resources BAM occurrence and one sample (06-pjb-088) overlying Nipigon diabase (Figure 20). Platinum is also anomalous in 3 of the 4 till samples (05-pjb-111, 06-pjb-046 and 06-pjb-083) collected over English River Subprovince metasedimentary rocks, 2 samples (06-pjb-048, 06-pjb-049) in the Gort Lake area, one sample (06-pjb-116) north of Pikitigushi Lake and one sample (06-pjb-060) south of Joy Lake (Figure 21).

A small dispersal train (Figure 22) of Mo in till (ICP–MS) highlights the Kilometre 61 molybdenum occurrence (Linear Metals Corp.); however, there are only weak responses in the content of the associated elements at this occurrence (Cu and Ag). There are other samples containing anomalous Mo; however, the sample immediately down-ice flow of Kilometre 61 contains the highest value of Mo obtained in the survey.

Rare-element pegmatites such as the Linear Metal Corp. Seymour Lake Ta-Be-Li property is also reflected in till samples collected on site (e.g., Li, Figure 23). Till in this area contain regionally anomalous values for Ta, Be, Li, Cs, Ce and Cu and elevated values for Ag, Co, Dy, Er, Eu, Ho, Lu, Nb, Rb, Ti, Tl, Tm, W, Y and Yb. Rare-element pegmatites in the Falcon Lake area are also indicated in till samples by anomalous values of Be, Cd, Cs, Li, Rb, Sc, Dy, Er, Ho, Y, Sn, Tl, Tm, Ba, Co, Cu, Zn and K and elevated values of Ce, Ga, Gd, Eu, La, Lu, Nd, Sm, Pr, Al, Co, Fe, Mn, P, Tb, Th, U, Ti and Yb. Some of the elements may be derived from rocks that subcrop up-ice flow of the sample sites.

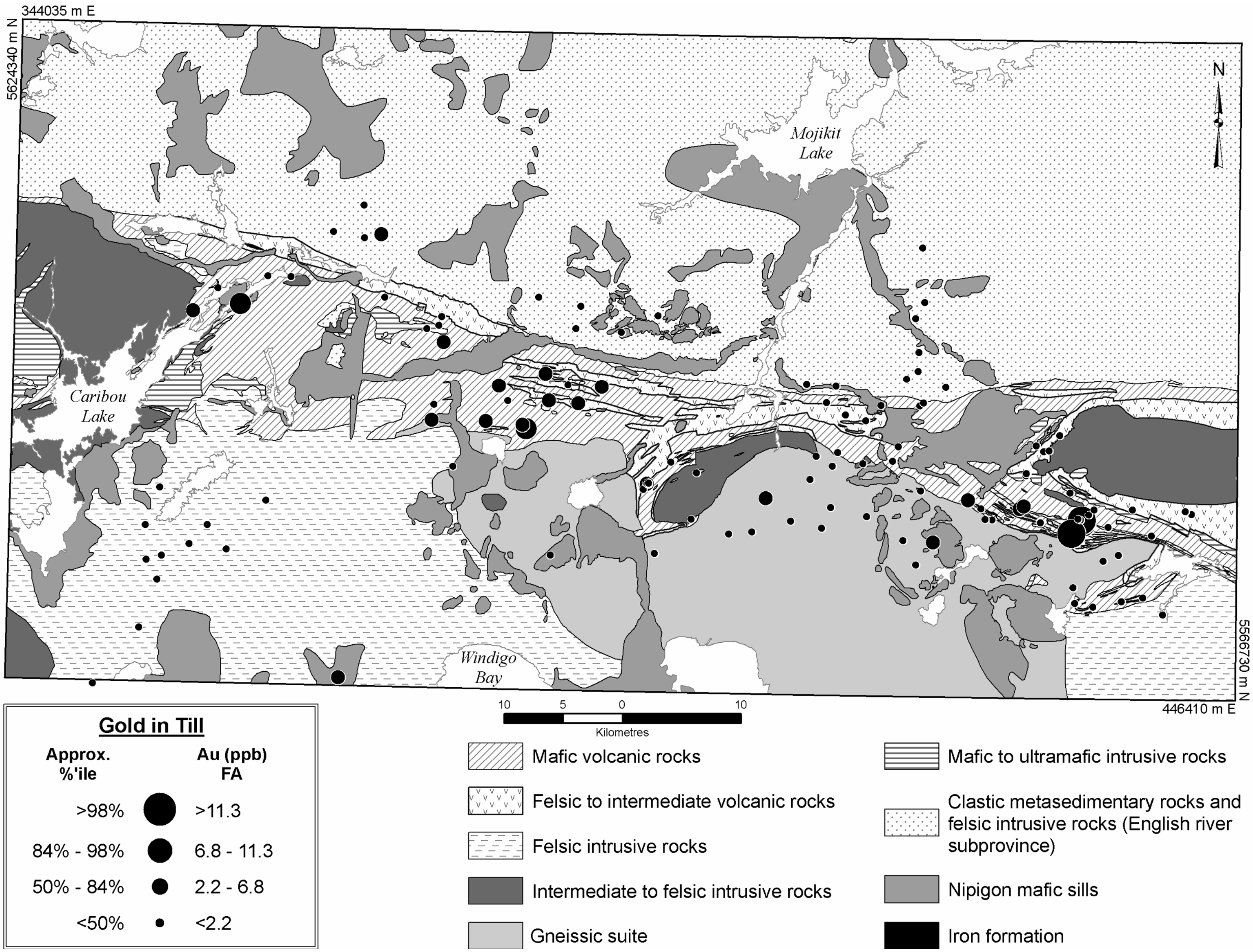

Figure 18. Gold content in till samples (<63 μm fraction) collected in the study area.

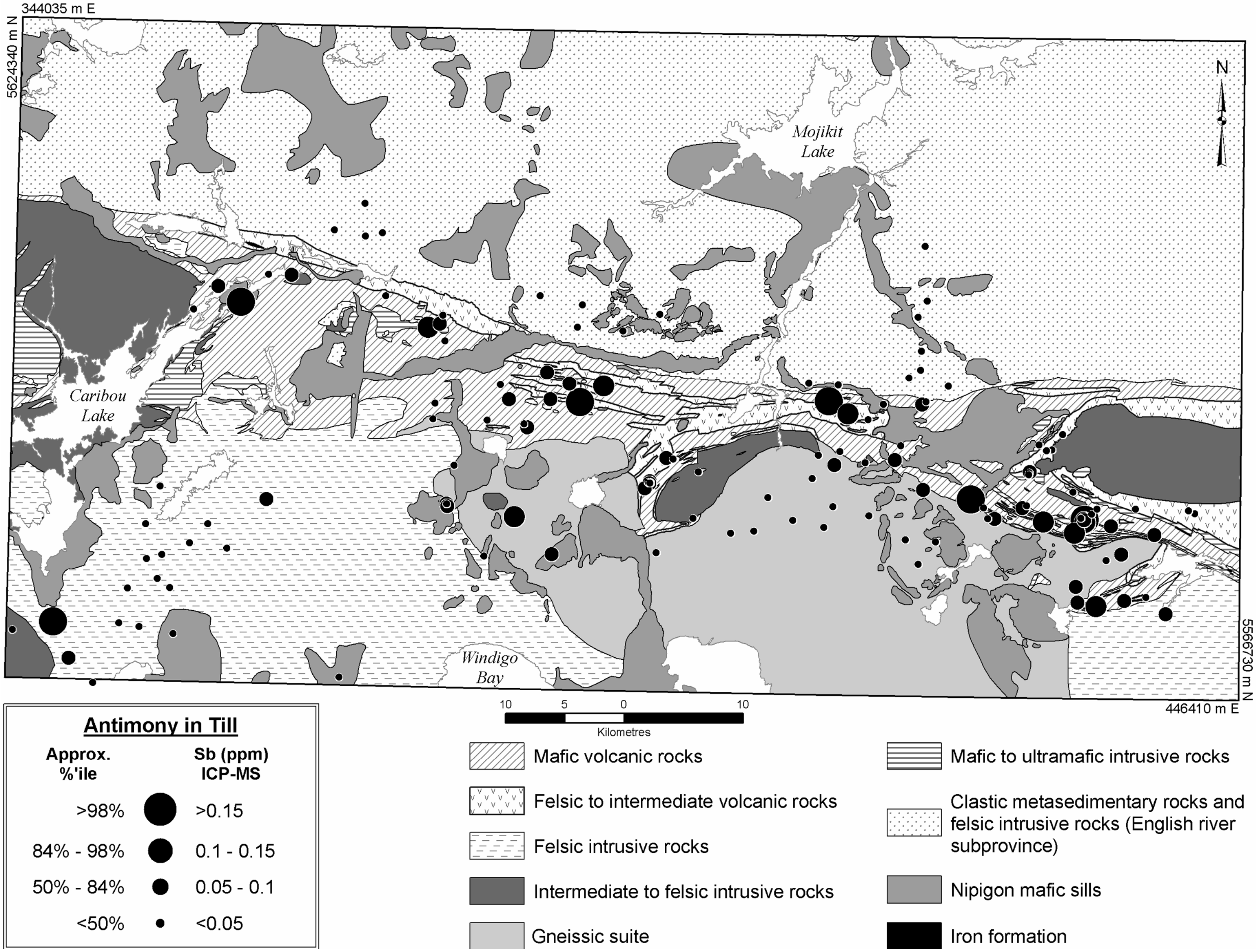

Figure 19. Antimony content in till samples (<63 µm fraction) collected in the study area.

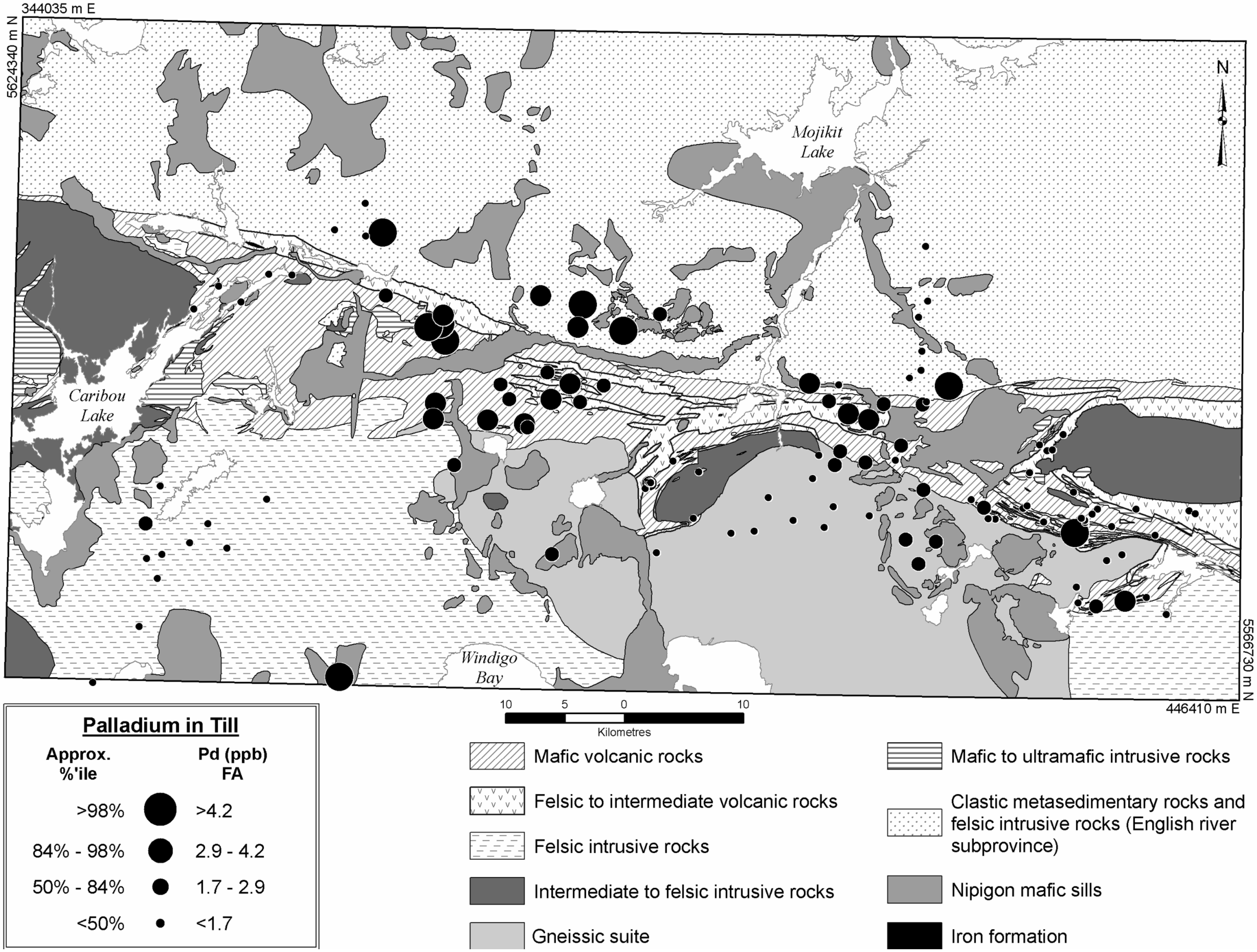

Figure 20. Palladium content in till samples (<63 µm fraction) collected in the study area.

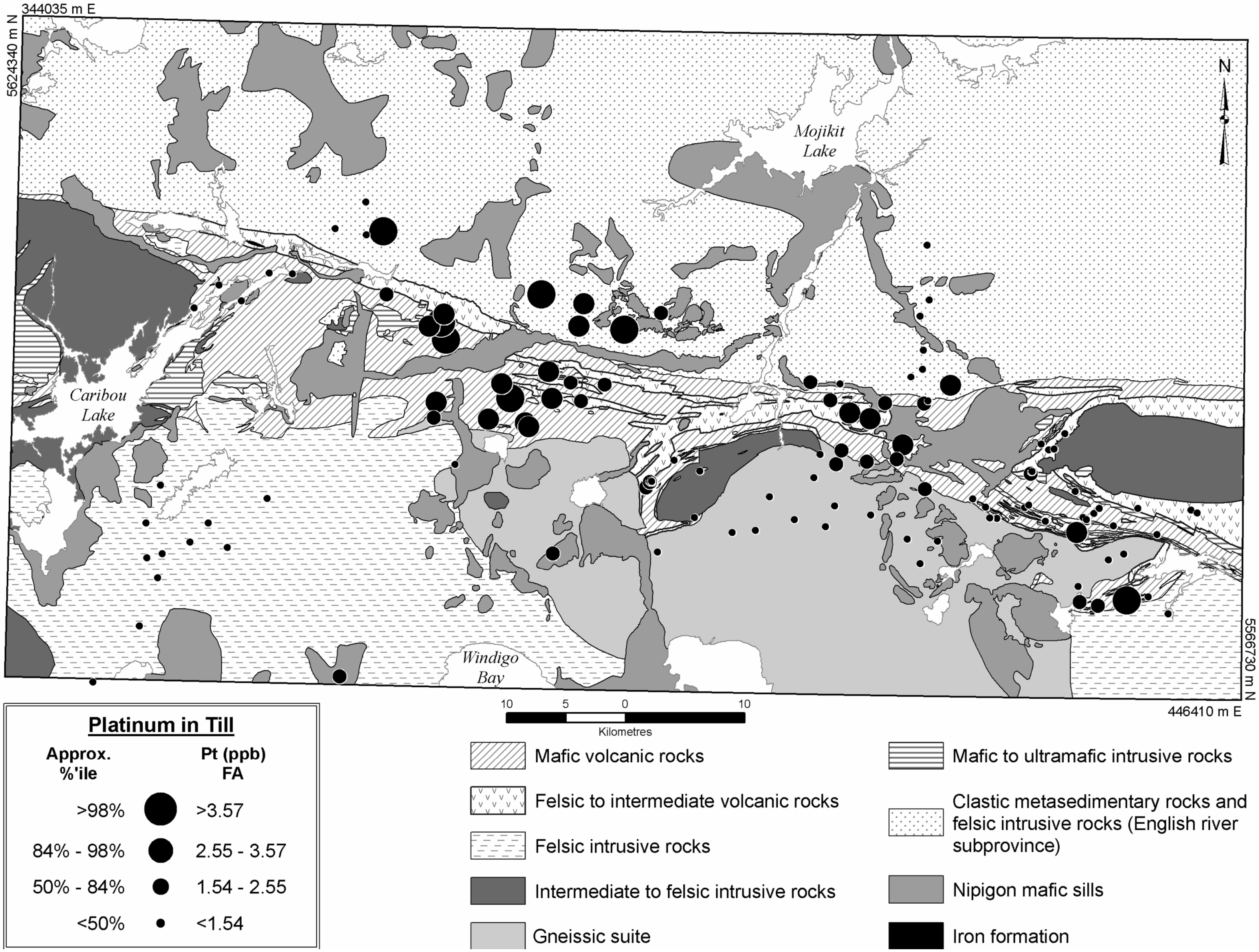

Figure 21. Platinum content in till samples (<63 µm fraction) collected in the study area.

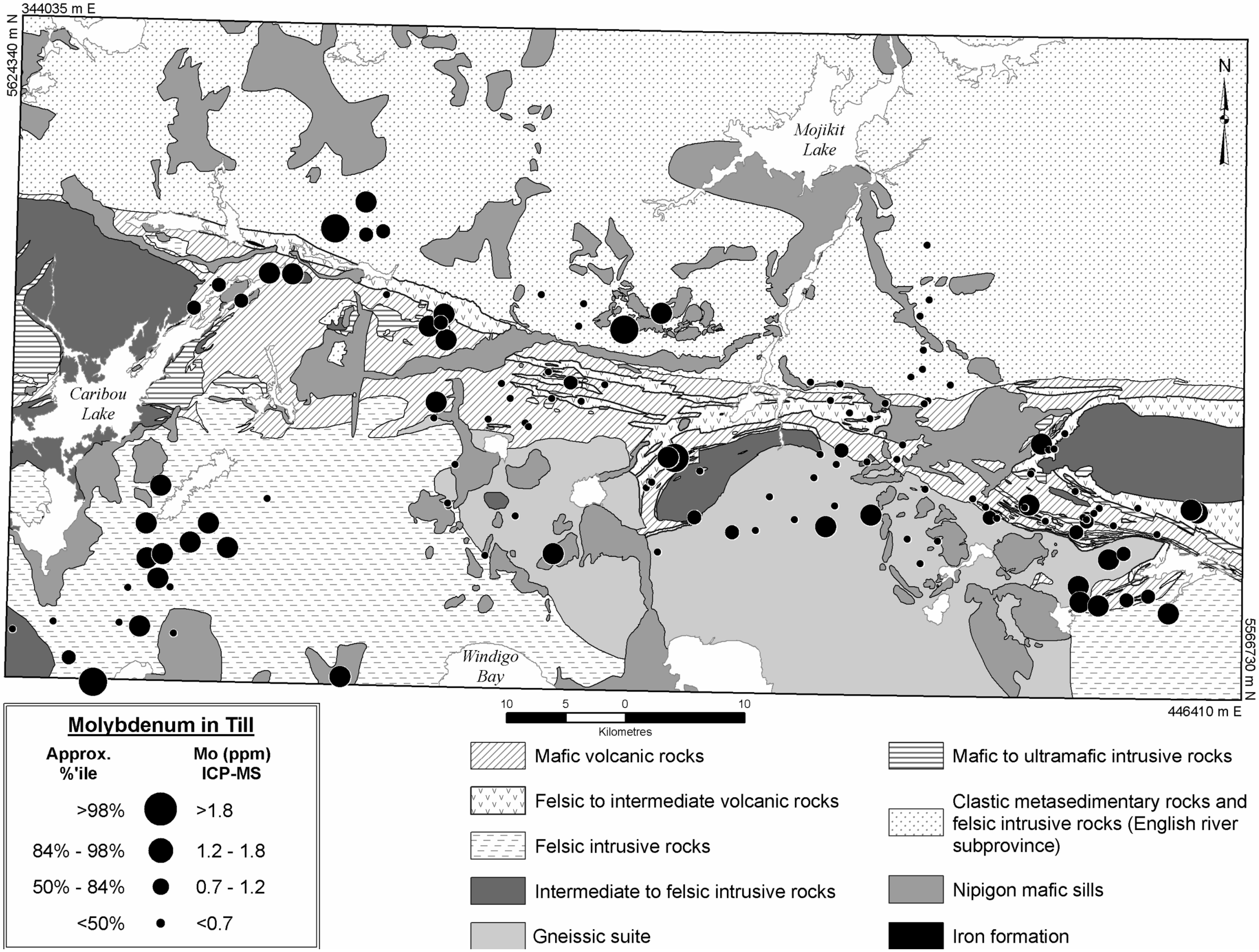

Figure 22. Molybdenum content in till samples (<63 µm fraction) collected in the study area.

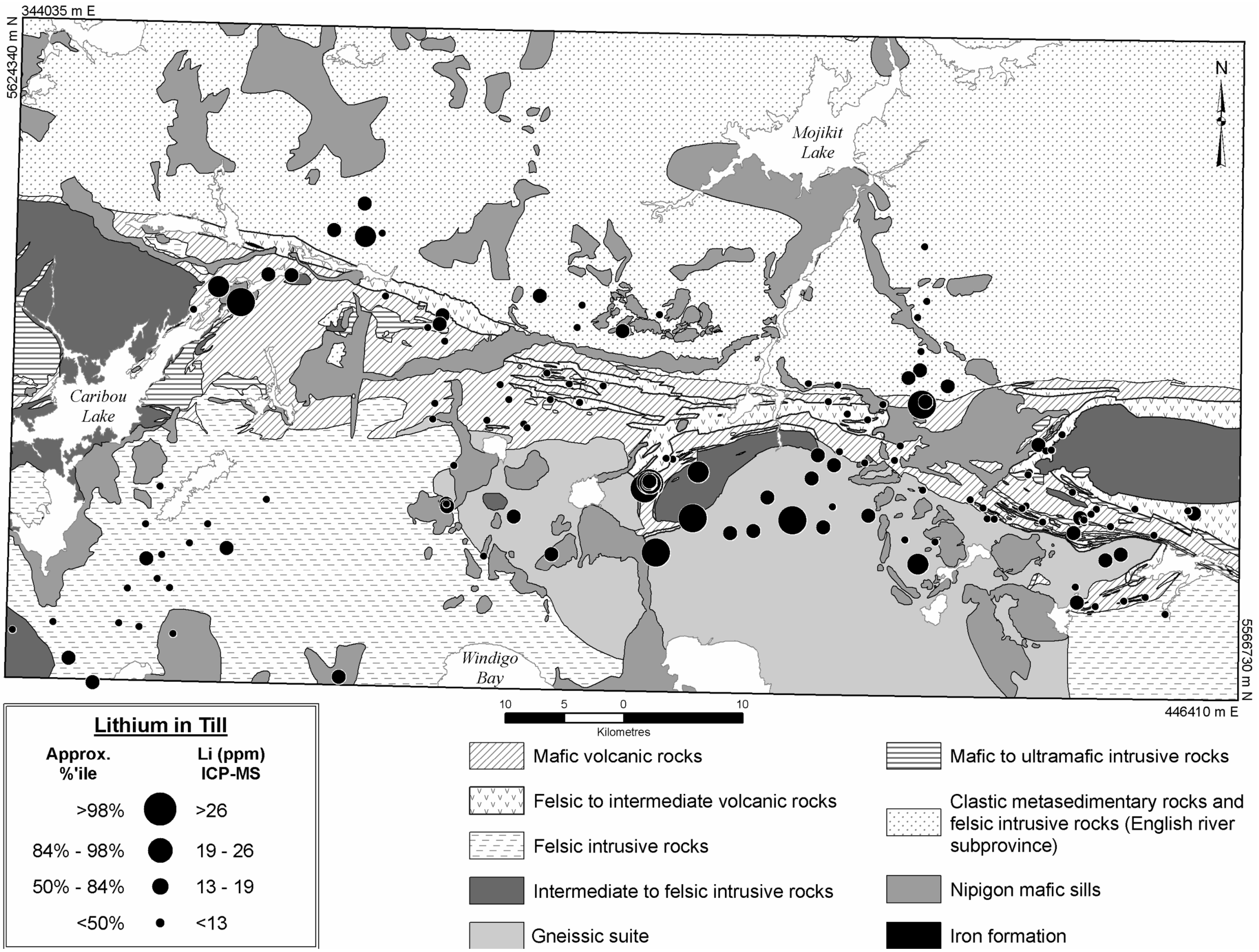

Figure 23. Lithium content in till samples (<63 µm fraction) collected in the study area.

Several till samples in the vicinity of the Seymour Lake pluton contain anomalous and/or elevated concentrations of Li, Nb and Rb, ± Tl. Mapping by MacDonald (2006) indicates the outcropping of pegmatite dikes either within the pluton or the adjacent gneissic rocks. As mentioned, the area immediately north of the greenstone belt within the clastic metasedimentary rocks of the English River Subprovince is also indicated as a potential area for rare-element pegmatites. Results from 2 samples (04-pjb-015 and 04-pjb-009b) collected south of Pikitigushi Lake may also be worth investigating further.

Nickel, in anomalous concentrations in till samples, occurs over Toronto Assemblage mafic metavolcanic rocks along the southwest margin of the Caribou Lake greenstone belt (Figure 24). Anomalous Ni level occurs with anomalous levels of Au, Sb, Cu, Pb and Zn in a sample (06-pjb-071) located on a small island along the east shore of Caribou Lake opposite Keller Island. Two samples (05-pjb-113 and 06-pjb-046) containing anomalous Ni values are located within the clastic metasedimentary rocks of the English River Subprovince.

Till samples containing anomalous levels of Cu (Figure 25) occur on the small island along the east shore of Caribou Lake opposite Keller Island (06-pjb-071), in the central part of the greenstone belt northeast of Pikitigushi Lake (05-pjb-115 and 05-pjb-120), in the area of the Linear Metals Corp. Seymore Lake South Aubrey pegmatite (05-pjb-099), near the Landore Resources BAM occurrence (05-pjb-102) and about 500 m south of Joy Lake (06-pjb-059). Samples with elevated Cu values occur in all these areas except at Caribou Lake and in the area west of Falcon Lake and about 4 km northwest of Gort Lake.

Zinc is at anomalous levels in 4 till samples: the Caribou Lake sample (06-pjb-071), northeast of Pikitiguishi Lake (05-pjb-120), a sample (05-pjb-068) collected in the Falcon Lake area and a sample (05-pjb-113) taken 4.5 km east of Ratte Lake in an area mapped as metasedimentary migmatites (MacDonald 2006). Elevated levels of Zn in till occur north of Falcon Lake, northeast of Pikitigushi Lake, northwest of Gort Lake and in the Caribou Lake area (Figure 26).

Lead (Figure 27) occurs in anomalous and elevated levels in 9 samples collected over English River metasedimentary rocks, particularly near the contact with the Caribou Lake greenstone belt. Samples 05-pjb-057, 05-pjb-058 and 05-pjb-064 contain anomalous values of Pb. In addition, sample 06-pjb-071 collected from the small island along the east shore of Caribou Lake opposite Keller Island and sample 04-pjb-015 collected about 5 km south of Pikitigushi Lake are anomalous with respect to lead.

Chromium is the only element to have 2 separate populations in till matrix samples. In general, there is one population centred on about 25 ppm and a second population exceeding 100 ppm. The set of samples taken from the central part of the greenstone belt roughly correspond to the lower population and the higher one to areas of mafic and ultramafic intrusions, older volcanic sequences or Nipigon diabase sills. One sample (06-pjb-059), containing anomalous levels of Cr, is located south of Joy Lake. Many samples contain elevated values of Cr (Figure 28).

Conclusions

A better understanding of the former directions of ice flow that deposited till in the area is one result of this regional mapping and till sampling project. Although complex, the till left by the glacier was commonly deposited during the youngest or last flow event. The till reflects local bedrock conditions at most sites sampled and, therefore, is a valuable sampling media in mineral exploration in this region. Several know mineral occurrences were detected in the results of either the heavy mineral concentrates or the till matrix geochemistry. Many of the samples that contain multi-element anomalies should be considered for potential follow-up work. Some areas of interest might include the north end of Caribou Lake, the area northwest of Gort Lake, and rare-element pegmatites in the gneissic terrane south and migmatite terrane north of the Caribou Lake greenstone belt in addition to the areas currently under investigation.

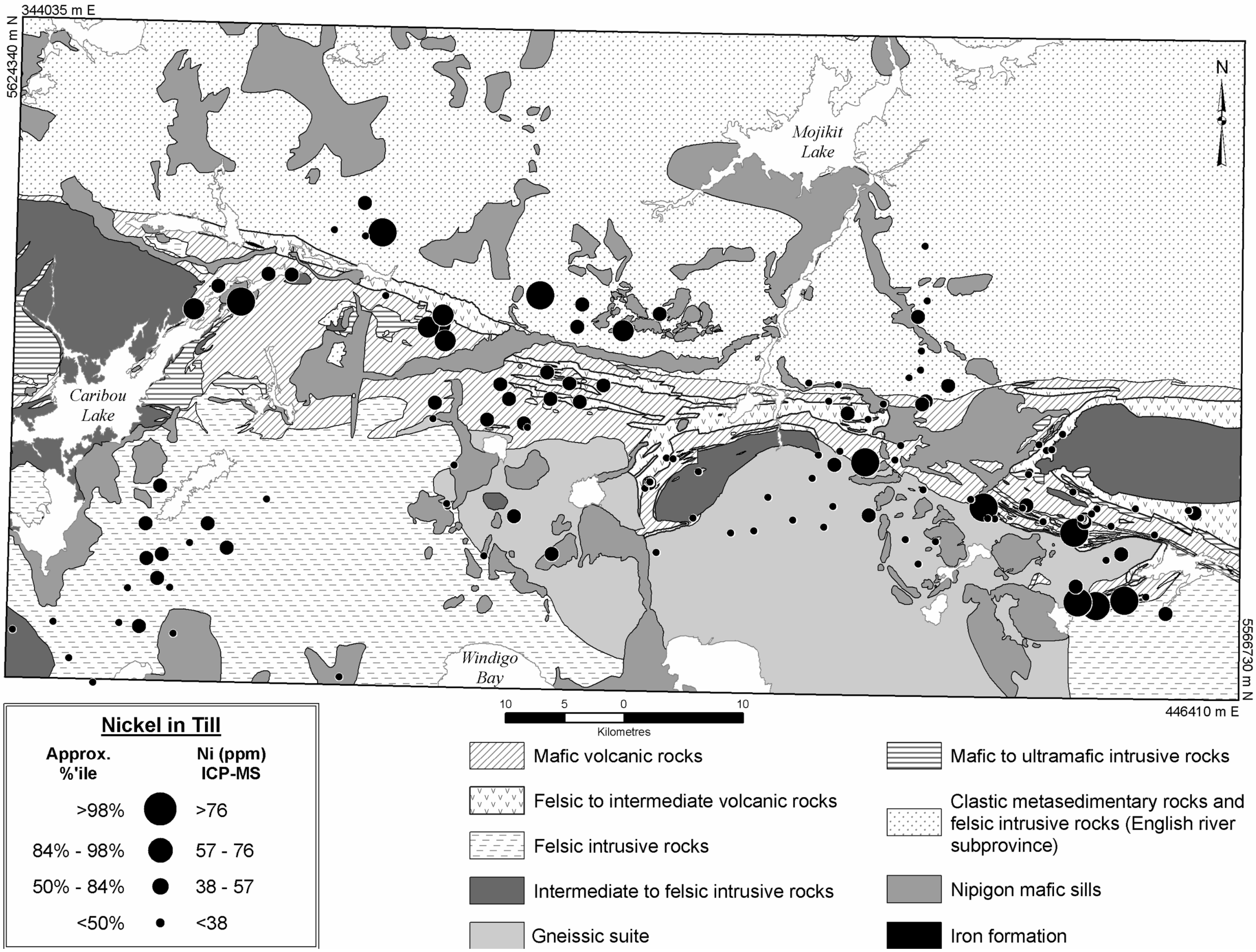

Figure 24. Nickel content in till samples (<63 µm fraction) collected in the study area.

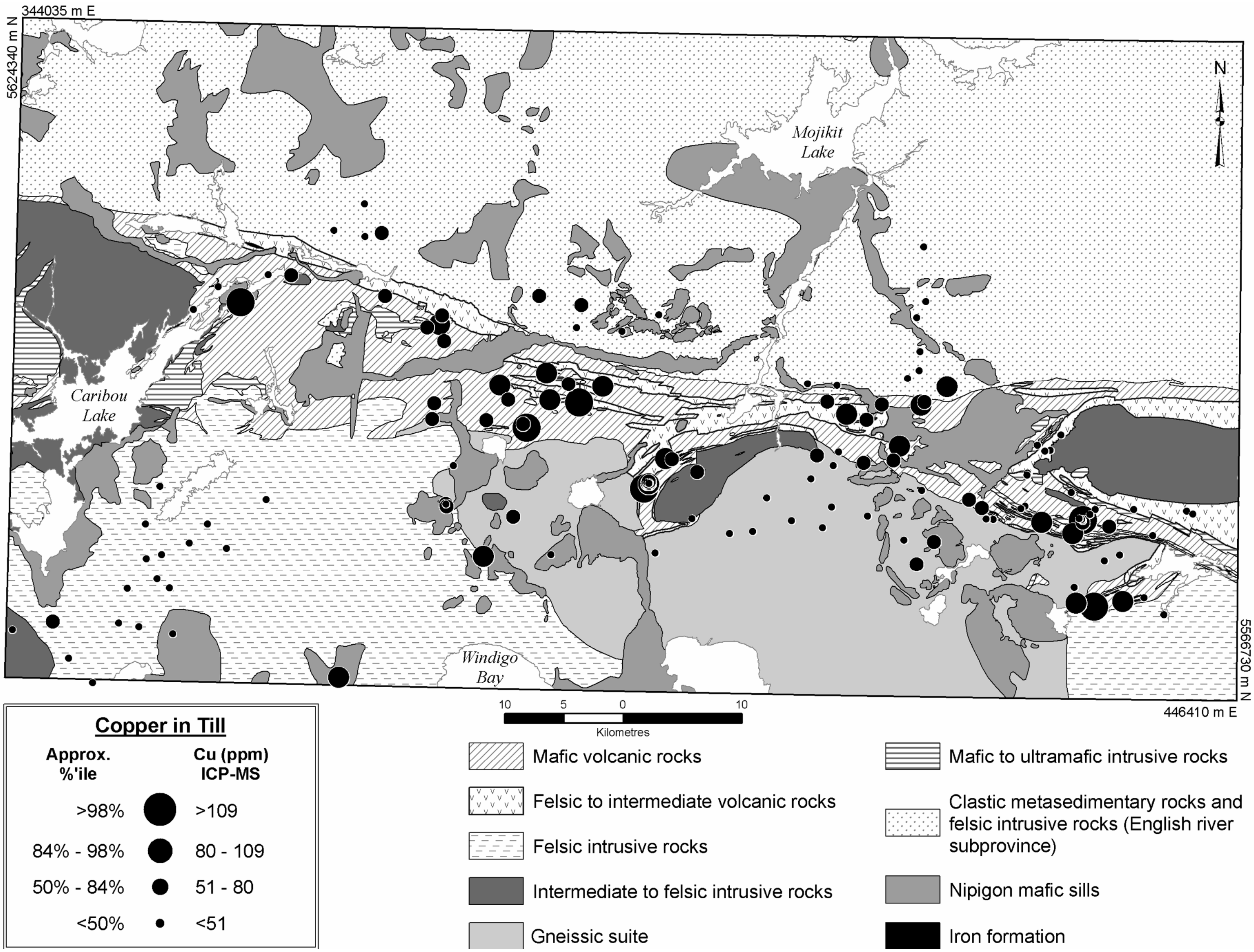

Figure 25. Copper content in till samples (<63 µm fraction) collected in the study area.

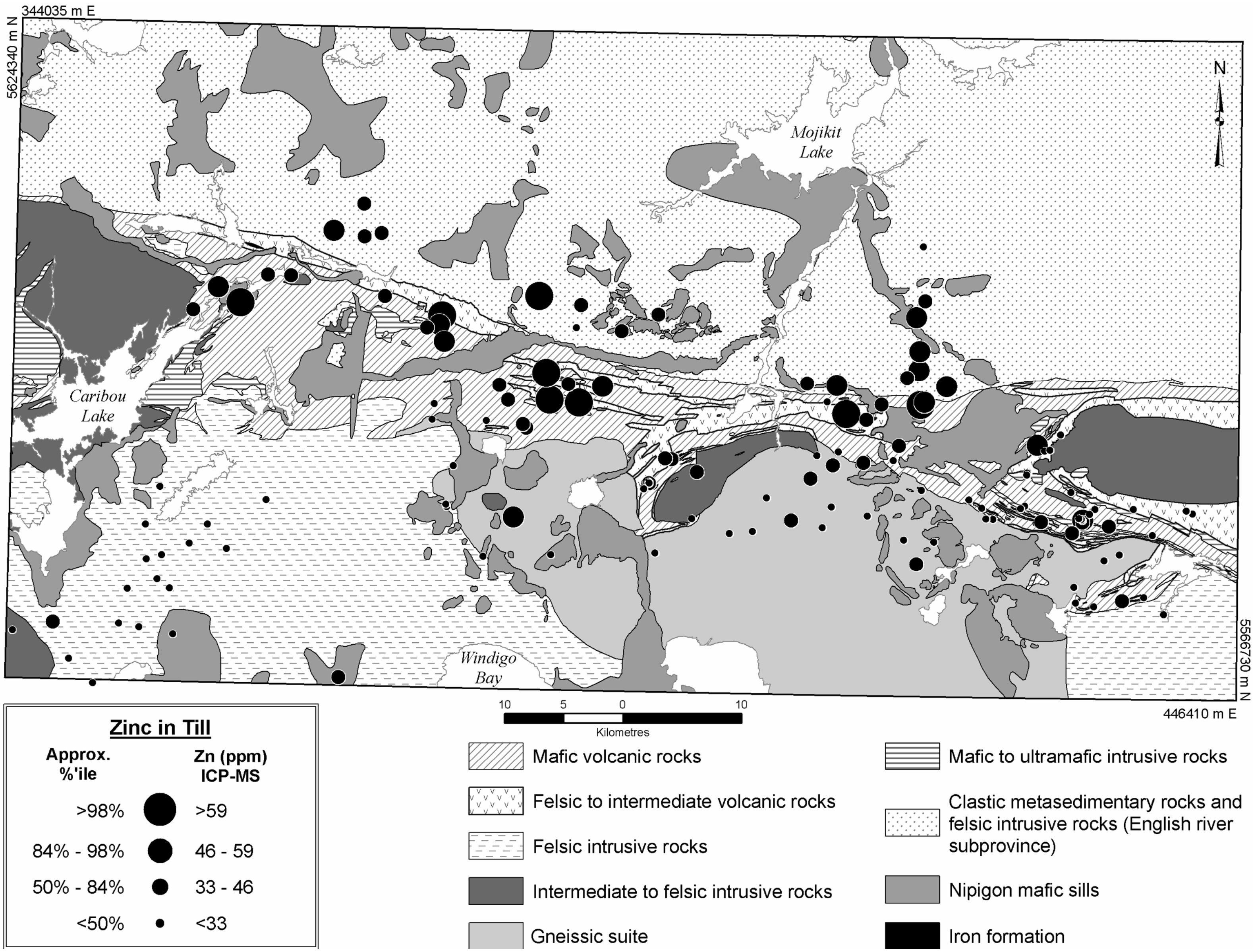

Figure 26. Zinc content in till samples (<63 µm fraction) collected in the study area.

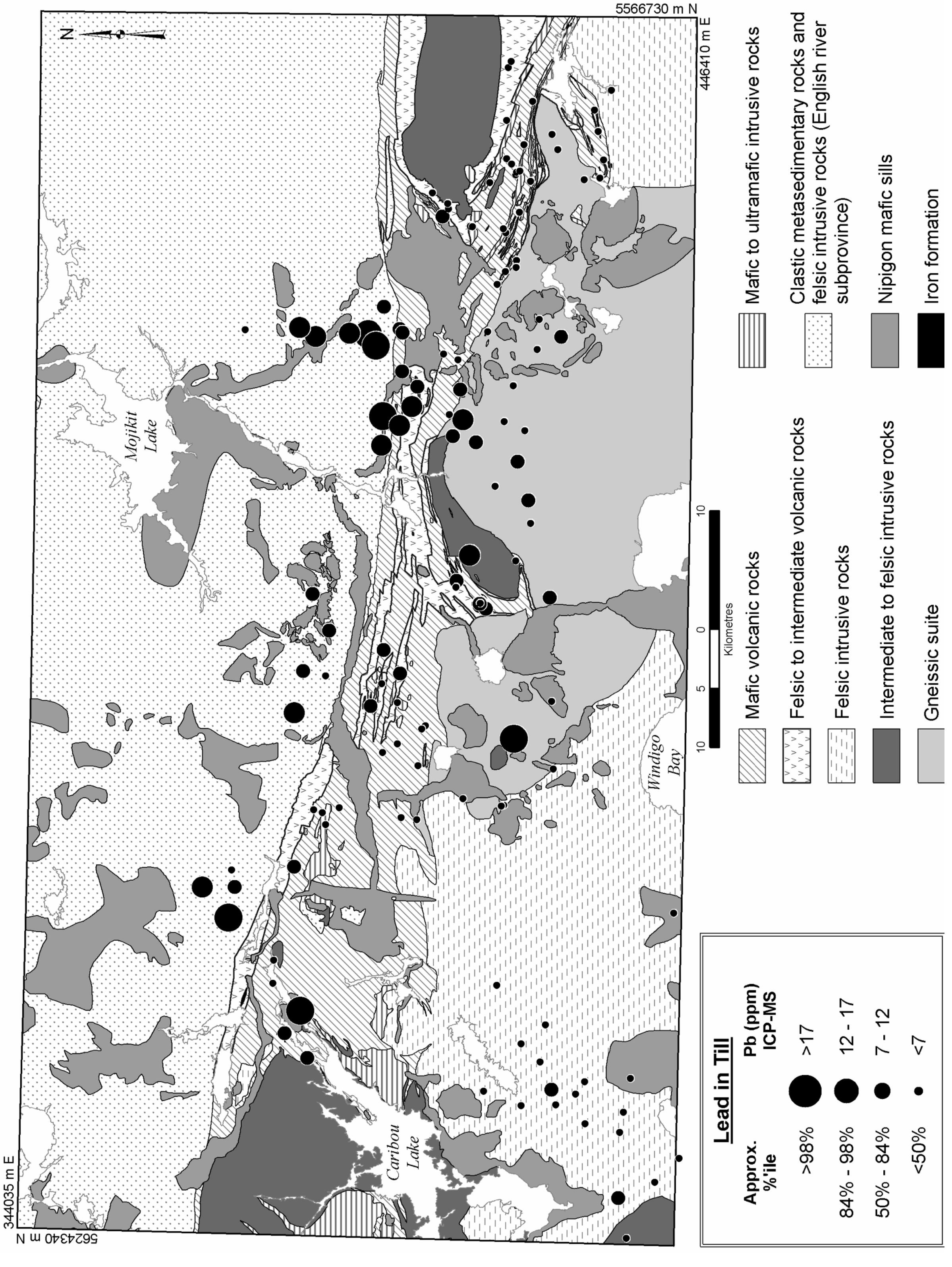

Figure 27. Lead content in till samples (<63 μm fraction) collected in the study area.

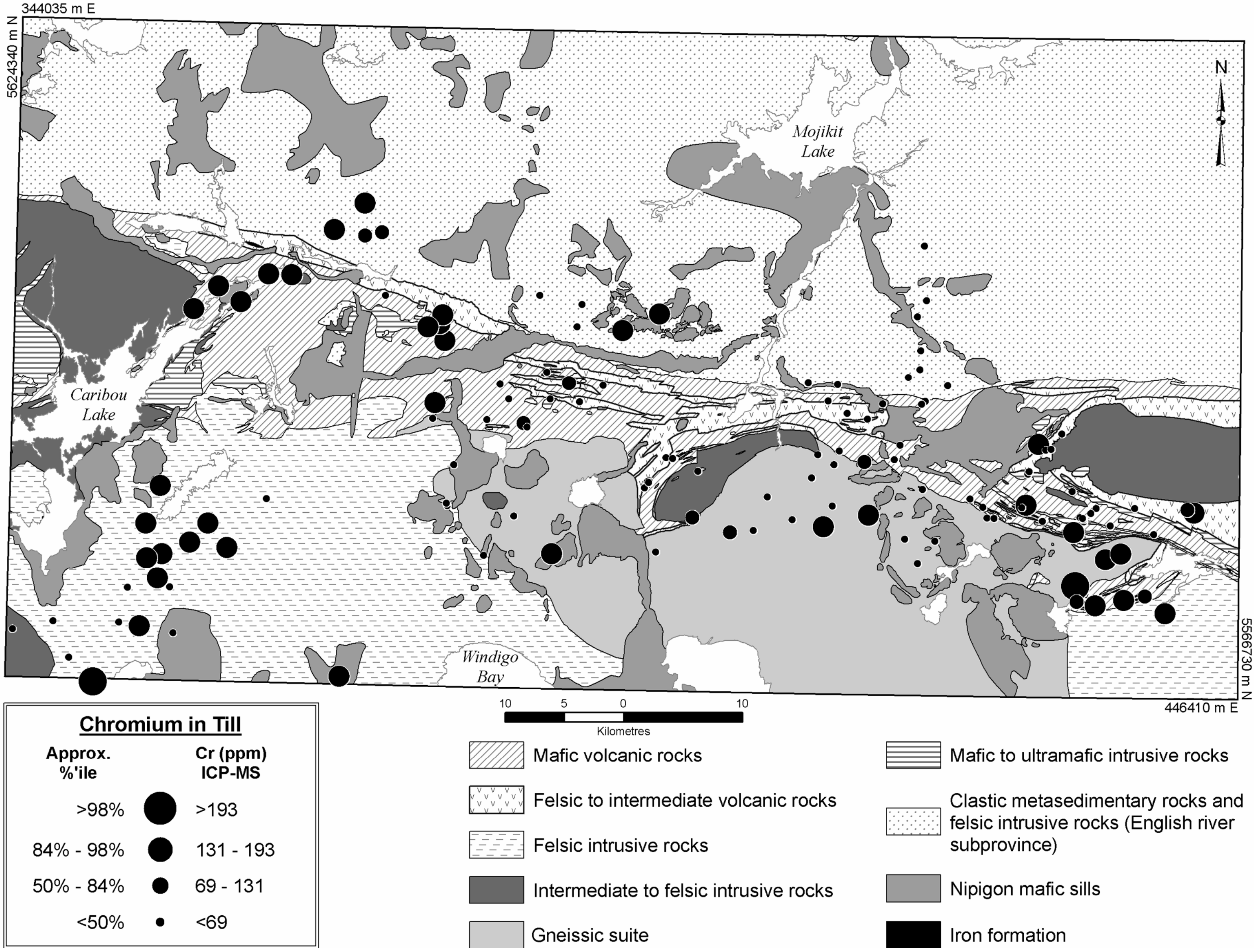

Figure 28. Chromium content in till samples (<63 µm fraction) collected in the study area.

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Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
LENGTH					
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
AREA					
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
VOLUME					
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
CAPACITY					
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
MASS					
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
CONCENTRATION					
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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