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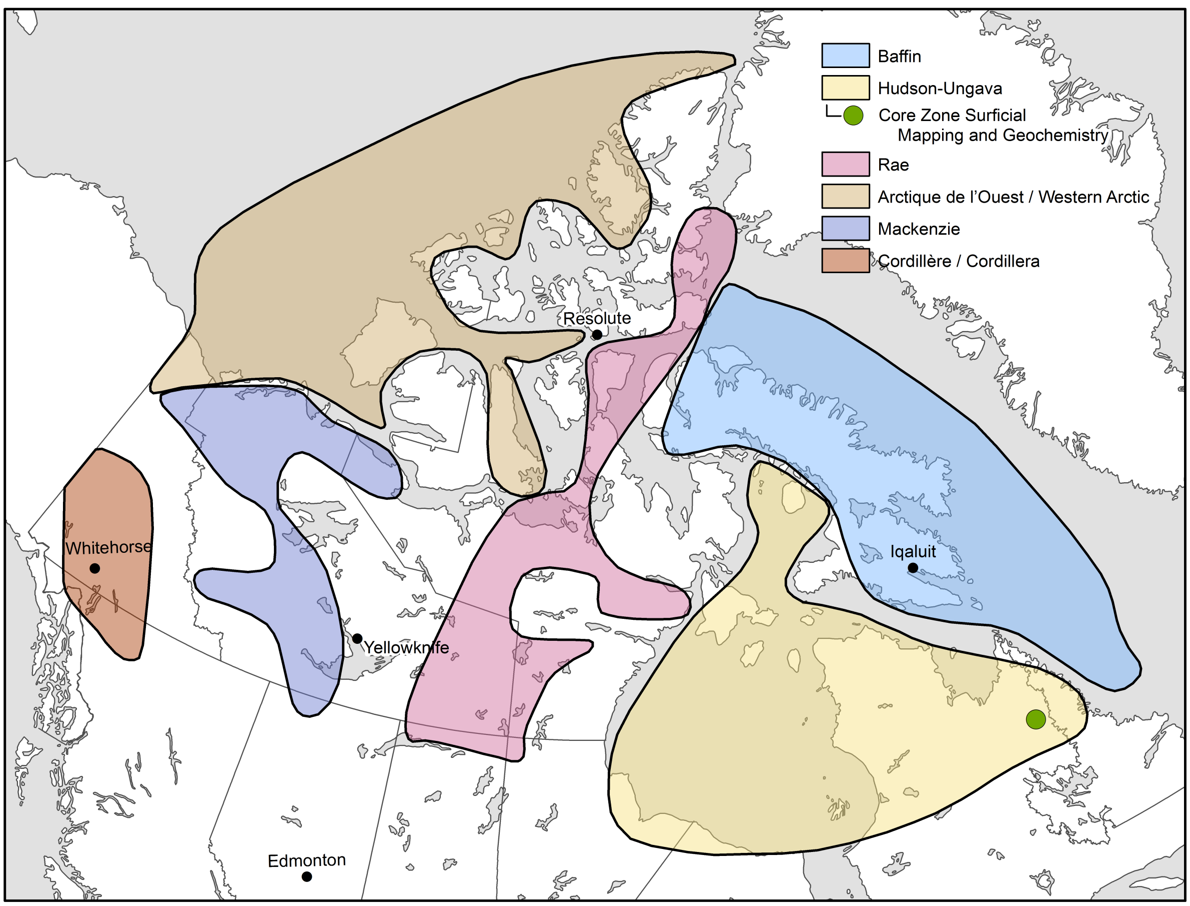
Foreword

The Geo-mapping for Energy and Minerals (GEM) program is laying the foundation for sustainable economic development in the North. The Program provides modern public geoscience that will set the stage for long-term decision making related to responsible land-use and resource development. Geoscience knowledge produced by GEM supports evidence-based exploration for new energy and mineral resources and enables northern communities to make informed decisions about their land, economy and society. Building upon the success of its first five-years, GEM has been renewed until 2020 to continue producing new, publically available, regional-scale geoscience knowledge in Canada's North.

During 2017, research scientists from the GEM program successfully carried out 27 research activities, 26 of which will produce an activity report and 12 of which included fieldwork. Each activity included geological, geochemical and geophysical surveying. These activities have been undertaken in collaboration with provincial and territorial governments, Northerners and their institutions, academia and the private sector. GEM will continue to work with these key partners as the program advances.



Location of the GEM project areas across Canada. Green dot indicates location of study the area.

Summary

This activity report summarizes accomplishments of the GEM 2 Hudson-Ungava Surficial Mapping and GeochemistryActivity focused on northeast Quebec and west central Labrador. This research is being carried out in collaboration with the Ministère de l'Énergie et des Ressources naturelles du Québec (MERNQ) and the Geological Survey of Newfoundland and Labrador (GSNL). This report complements the first three years' activity reports that were published by McClenaghan et al. (2014, 2015, 2016). The overall objective of this activity is to produce new regional geoscience data including surficial geology, geochemistry, and radiometrics to support natural resource exploration and development in the Hudson-Ungava region. Activities include surficial and bedrock mapping, till geochemistry and indicator mineralogy, lake sediment geochemistry, geochemical database management and web-deivery of data, and gamma-ray spectrometry studies.

Surficial mapping has led to an improved understanding of the glacial history of the study area. Regional till geochemistry and mineralogy sampling have identified precious and base metal anomalies in the west part of the study area that warrant further investigation. Reconnaissance lake sediment geochemical data have been compiled for the Core Zone. Geochemical maps are to be released later this Fall and highlight metal-rich areas that warrant further investigation. Different gamma-ray spectrometry methods were tested and compared and can be used to support surficial mapping. Data management activities have facilitated web access to publications and data for this project as well as other GEM-1 and GEM-2 activities.

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Chapter 1 Project Overview

M. Beth McClenaghan, Wendy A. Spirito, and Stephen W. Adcock

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Introduction

Bedrock mapping and mineral resource exploration in northern Quebec and Labrador is challenging because information about the bedrock geology is poorly documented and, in parts, bedrock is covered by surficial (glacial) sediments deposited by a complex sequence of glacial flows related to a migrating ice divide. For significant parts of northern Quebec and Labrador, there are no surficial geology maps, till geochemical data or indicator mineral knowledge. This lack of information results in poorly understood drift thickness, glacial history, and dispersal mechanisms and ultimately hinders mineral exploration.

To address these knowledge gaps and support resource exploration, the GSC as part of the GEM 2 Program and in collaboration with the Ministère de l'Énergie et des Ressources naturelles du Québec (MERNQ) and the Geological Survey of Newfoundland & Labrador (GSNL) are conducting new surficial mapping and surficial geochemical studies as part of an integrated regional mapping program centred on Archean "Core Zone" rocks between the Torngat Orogen to the east and the New Quebec Orogen to the west (Wardle et al., 2002) (Figs 1.1, 1.2). These surficial activities will produce new regional geoscience data that will be used to greatly increase geological knowledge and support natural resource exploration and responsible resource development.

Activity reports summarizing field and laboratory activities in the first three years of the project were published in 2014, 2015 and 2016 (McClenaghan et al., 2014, 2015, 2016). This open file is the fourth and final activity report for the project and focuses on activities for 2017. Bedrock mapping and geochronology activities for the entire Core Zone are summarized in Corrigan et al. (2015, 2016).

Scientific question to be addressed

The overall scientific question being addressed by these research activities is: how can improved bedrock knowledge, surficial mapping, surficial geochemistry, and indicator mineral sampling facilitate exploration and support resource discovery in the Hudson-Ungava region?

Goals and objectives

The specific goals and objectives include:

- Develop new glacial dispersal models to support increased exploration effectiveness and successes in Quebec and Labrador;
- Develop and improve exploration geochemistry methods to encourage exploration in prospective regions using till geochemistry, indicator minerals, and lake sediment geochemistry;
- Transfer new geoscience knowledge to the mineral exploration industry and academia through workshops, public presentations, conference posters, and talks;
- Increase the content, promotion, and awareness of the GSC's Canadian Database of Geochemical Surveys as an efficient exploration tool;

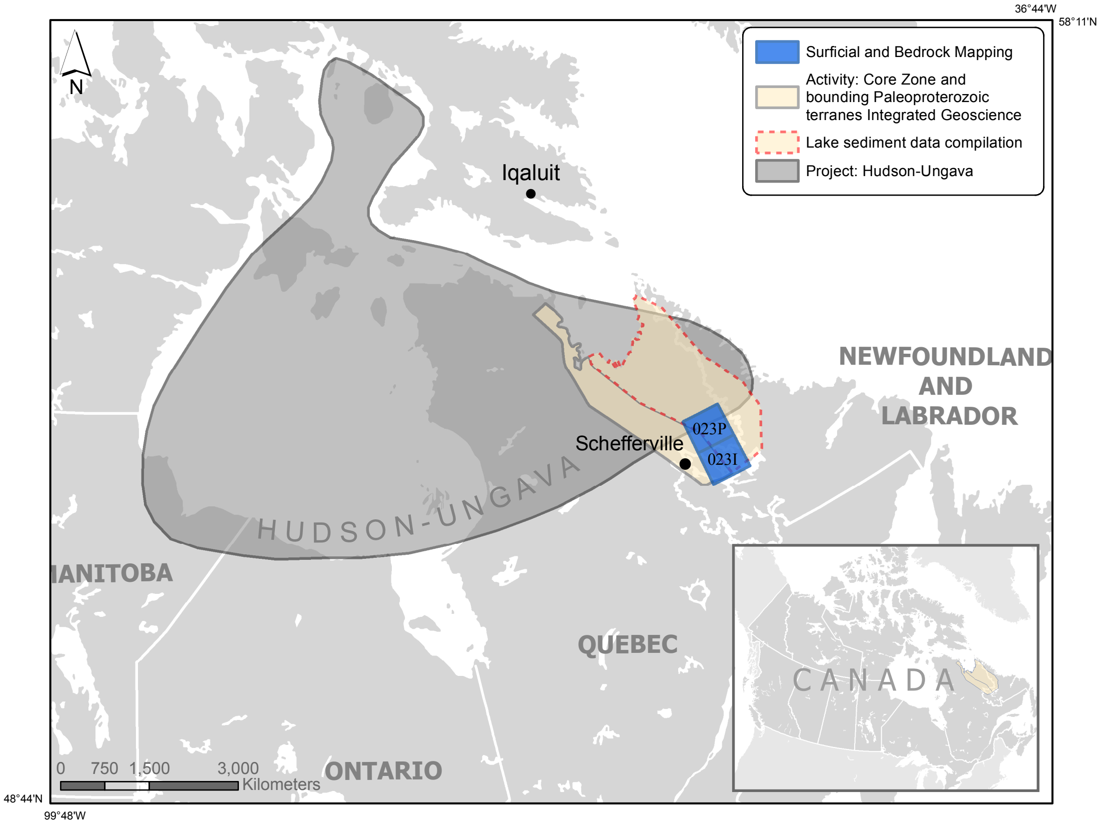

Figure 1.1. Location of the Core Zone and bounding terranes study area (beige polygon), south Core Zone surficial and bedrock mapping area (blue box), and the Core Zone lake sediment geochemical data compilation area (red dashed line) within the overall Hudson-Ungava GEM 2 project area (grey polygon).

• Increase bedrock knowledge with a view to determining the nature and heritage of crust exposed between the Archean North Atlantic and Superior cratons, given that mineral exploration strategies are predicated by whether the medial "core zone" shows affinity to the Archean Rae craton, to cryptic Meta-Incognita terrane, or constitutes a distinct crustal domain/block;
• Determine the timing of major penetrative deformation across the southern core zone, and assess its character and timing in light of current tectonic models involving 1.87 Ga collision with North Atlantic craton to the west and ca. 1.82 Ga collision with Superior craton to the east;
• Mentor and train highly qualified personnel (HQP).

Canadian Database of Geochemical Surveys

The Canadian Database of Geochemical Surveys (CDoGS) stores geochemical data and metadata from GEM and other surveys (Adcock et al., 2013). The public interface to the database can be found at http://geochem.nrcan.gc.ca . The database is continuing to grow and currently holds over 10 million geochemical analyses for sample media of various types collected across Canada. Metadata for till geochemical surveys carried out by the GSC in the Core Zone in 2014 to 2016 (see Chapter 3) and lake sediment survey (NGR) reanalysis completed in 2014-2015 (see chapter 4) have been added to the database and are available on the CDoGS web site and are available for download and viewing in Google Earth™. Geochemical data for till samples collected in 2015 and 2016 are currently being added.

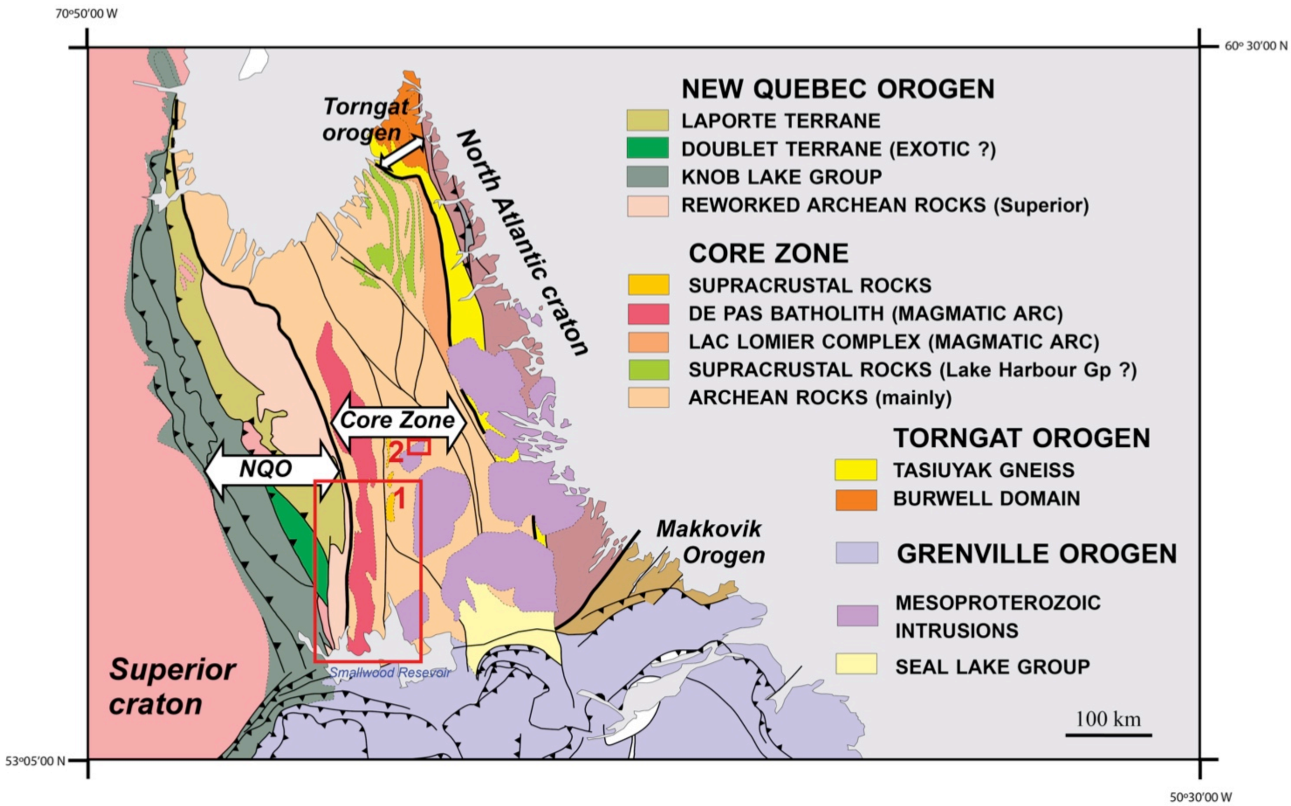

Figure 1.2. Simplified bedrock geological map of the Core Zone and bounding orogens. Boxes show areas under investigation: 1) south Core Zone surficial mapping; 2) Strange Lake area. Modified after James et al. (2003).

Procedures have been developed to automate the compilation of compatible data into single datasets. For example, end users can now download a single Microsoft® Excel file to quickly obtain all of the analyses for U for all of Canada, instead of downloading individual files for each survey. In the Excel file, filters can be used to refine the data to include only those samples analysed by a particular technique, using a specific digestion and by a specific lab, for example. Regional geochemical maps can now be produced with significantly less effort because the data are already in one file.

Figure 1.3 shows U values (aqua regia/ICP-MS) for a subset of a large number (n=6131) of reanalysed GSC-NGR lake sediment samples in the southern Core Zone area. The data for these samples has been published in McCurdy (2016) and McCurdy et al. (2016).Values are higher overlying the southeast trending Labrador Trough that includes the Schefferville area.

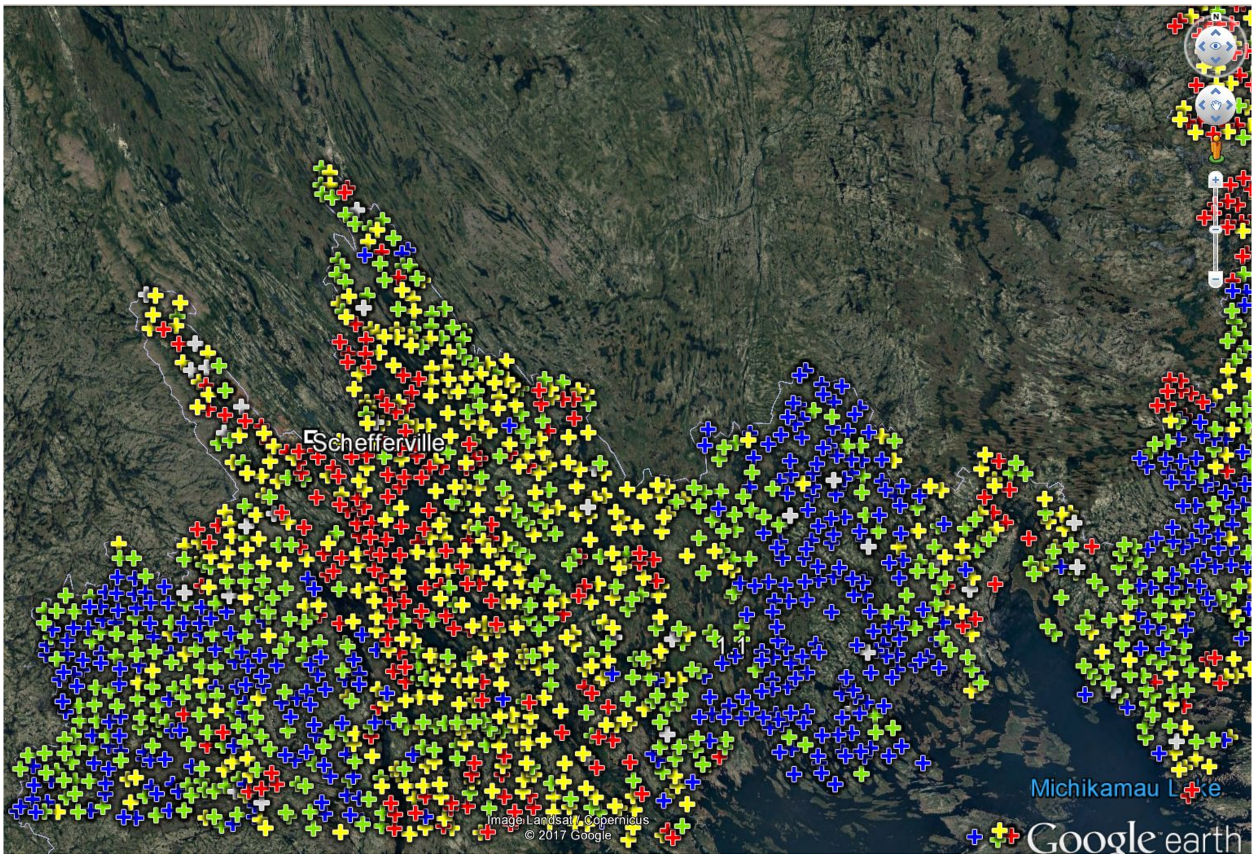

Figure 1.3 Uranium concentration (ppm) in a subset of 6131 reanalysed GSC-NGR lake sediment samples (aqua regia; ICP-MS) (McCurdy, 2016; McCurdy et al., 2016). Uranium values are classified by quartile: red crosses indicate the highest values; blue crosses represent the lowest values; white crosses represent no values.

Acknowledgments
These surficial research activities are part of the GEM 2 Hudson-Ungava Project, which is under the scientific leadership of David Corrigan with GSC management support from Réjean Couture, Danny Wright, Lila Chebab, and Jennifer Bates. Dan Kerr (GSC) is thanked for their review of this report.

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Chapter 2 Glacial History and Surficial Mapping

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Introduction

Surficial geological mapping was conducted in the summers of 2014, 2015, and 2016 as a major part of the GEM2 Hudson-Ungava Core Zone surficial activity. This mapping focused on the erosional history of the Ancestral Labrador ice divide (Vincent, 1989), as well as the distribution, composition, and sedimentological properties of surficial sediments located within NTS map sheets 23I (Woods Lake) and 23P (Lac Résolution), within the provinces of Quebec and Newfoundland and Labrador. This region was previously identified as an area affected by complex ice flow (Veillette et al., 1999; Clark et al., 2000; Jansson et al., 2002). The complex ice-flow, coupled with the lack of regional scale surficial mapping has made mineral exploration in the region difficult. This chapter outlines the basic methodology and results of surficial mapping activities, geochronology, and GIS landform analysis. Detailed field sampling and analytical methodology are described in McClenaghan et al. (2016a, b) and Rice et al. (2017a, b). This work will result in important reference material for future mineral exploration projects in the region, and will provide significant insights for mineral exploration in regions affected by complex ice-flow regimes. This report is an update on the surficial mapping activities reported in Rice et al. (2016)

Methods

Till sampling

Glacial sediments (till) were targeted for sampling at a spacing of approximately 8-12 km. Sample density was determined by a combination of factors including mineral potential of the regional bedrock geology, accessibility via helicopter, and site potential for mapping ice-flow indicators (e.g., striae, rat-tails and rôche moutonnées). In regions of prospective bedrock with mineral showings or occurrences, a tighter sample density was employed. Sample density was decreased in less prospective bedrock, till-poor regions as well as areas not conducive to helicopter landings. In the northern part of the study area, and at higher elevations where permafrost was discontinuous, mud boils were targeted for sample collection, following GSC till sampling protocols defined by Spirito et al. (2011) and Plouffe et al. (2013). Regions not affected by discontinuous permafrost were collected by hand digging below oxidized soil profiles, targeting the C-horizon till. Two samples were collected at each site: 1) a 3-5 kg sample for geochemical analysis of the <0.063 mm silt and clay fraction and 2) a 10-15 kg sample for recovery of indicator minerals (*see chapter 3*, *this volume*).

Pebble counts

The 10-15 kg samples collected for indicator mineral recovery contained clasts, and those larger than 5.6 mm were separated, washed with an acid solution to remove any oxidation stains or cemented matrix coatings, and returned to the GSC for clast lithology analysis. The washed clasts were coned and quartered to randomly select ~ 350 clasts from each sample. These randomly selected clasts were classified as one of 16 lithologies: 1) mafic intrusive, 2) intermediate intrusive, 3) felsic intrusive, 4) leucogranite, 5) ultramafic, 6) Doublet Zone metavolcanics, 7) metasediment, 8) Laporte Domain rocks (granite with muscovite), 9) Lac Zeni amphibolite, 10) vein quartz, 11) quartzite, 12) Mistinibi paragneiss (migmatite), 13) Michikmau intrusives (granite and anorthosites), 14) Juillet syenite, 15) iron formation (oolitic Jasper, banded to massive magnetite/hematite, and specularite), and 16) others, that reflected the bedrock lithologies known to occur in and around the study area (Wardle et al., 1997; Sanborn-Barrie et al., 2015; Sanborn-Barrie, 2016). Classification has been completed and the data will be interpreted using ArcGIS (ESRI©) to investigate spatial relationships between lithologies, underlying bedrock geology and ice flow patterns.

Landform analysis
Landsat & ETM+ (scan-line corrector on) obtained from the Canadian Geobase portal (www.geobase.ca) at 30 m resolution was utilized for landform analysis. These satellite data were amalgamated with digital elevation model data from Shuttle Radar Topography Mission (SRTM) obtained from the United States Geological Survey's Earth Explorer online portal (www.earthexporer.usgs.gov) (30 m resolution). The use of satellite data allows for the measurement of large and/or complex landforms not easily recognized through traditional aerial photography or field surveying. To ensure landforms smaller than the resolution of the satellite data were not overlooked, preliminary surficial maps produced as part of this research project were also amalgamated in ArcGIS®. Following procedures outlined by Clark et al. (2009), these amalgamated data layers were used to identify elongate glacial landforms and to measure their azimuth, length, and width. The orientations of these landforms were used in conjunction with measured striations to improve understanding of the ice-flow history within the area. Additionally, the length and width data were used to determine the elongation ratio of the landforms (elongation=length/width) which can be used as a proxy for relative basal ice flow velocity (Clark, 1999; Stokes and Clark, 2003). Publications detailing these results will be released as part of a Ph.D. thesis being completed by the senior author at the University of Waterloo.

Subglacial erosional index
Further to the physical dimensions of the landforms, the abundance of landforms, and lake density were also used to create a "subglacial dynamics" index. This index incorporates lake density, average landform elongation, and landform density within 5 km^2 cells to quantify the amount of subglacial erosion that has affected the landscape. Due to construction of the hydroelectric dam at Churchill Falls and creation of the Smallwood Reservoir, regions surrounding the large man-made lake will be masked from analysis. Data analysis is ongoing and will be released as part of the aforementioned Ph.D. thesis.

Geochronological sampling
Samples of bedrock and large erratic boulders were collected for cosmogenic ^{10}Be age determination to constrain the timing of ice-margin retreat. These samples were collected following procedures outlined by Gosse (2001), Gosse and Stone (2001), and Briner et al. (2005). Till samples were also collected for ^{10}Be inventory, whereby the abundance of ^{10}Be from till and bedrock samples will be used as a proxy for measuring the subglacial erosional vigor, following procedures outlined by Staiger et al. (2006) and Ross et al. (2015).

Additionally, proglacial littoral beach sediments from former shorelines of glacial lakes McLean, Naskaupi, and Low were collected for Optically Stimulated Luminescence (OSL) age determination to further constrain deglacial ages determined by cosmogenic nuclide ages. The OSL samples were collected following procedures outlined by Aiken (1998), Duller (2004), and Lian and Roberts (2006).

Surficial Mapping
Surficial maps characterize the surficial geology of a region while providing a visual representation of the distribution of sediments. These maps are created to document not only the surficial material across the region, but also include field data measurements (e.g., striation data) and are therefore an important tool in understanding the glacial history of the region. Eight 1:100 000 scale surficial geology maps are being published through this project, covering NTS map sheets 23I and 23P. Aerial photographs, ranging in scale from 1:50 000 to 1:60 000 from the National Air Photo Library, Ottawa are being used for classification of the surficial geology. Ariel photograph interpretation of stereographic photo-pairs through a stereoscope allows for 3-dimensional visualization of the landscape, enhancing the accuracy of surficial map unit separation based on vegetation, topography, reflectivity, and texture of the surface (Mollard and James, 1984). Aerial photographs are annotated by hand directly on the photographs, and then digitized using GIS software at the GSC, Ottawa. During fieldwork, the surficial geology was verified at each sample location and surficial units were investigated and classified according to the GSC Surficial Data Model (v.2.3; Deblonde et al., 2017).

Results
Raw analytical data from all samples collected over the three field seasons (2014-2016) have been received. Over the course of this project a total of 483 field locations were visited, of which, 280 samples were collected for geochemical analysis, 258 samples were collected for heavy mineral identification, 251 paleo-ice flow measurements were taken, 12 sites were sampled for cosmogenic nuclide analysis, and 6 sites were sampled for OSL dating.

Till compositional data
Geochemical and indicator data are described in Chapter 3 of this report. Clast lithology analysis has been completed (Fig. 2.1) and will be released as a Geological Survey of Canada Open File report in late 2017. Results from the pebble analysis have identified several distinct lithologies that can be used to better understand glacial dispersal. Different lithologies display different patterns of dispersion, with some yielding no clear dispersal patterns. The mafic intrusive, intermediate intrusive, leucogranites, ultramafic, and "other" clast lithologies displayed no discernable pattern across the study area.

Abundances of quartzite and vein quartz clasts are higher near a large quartzite ridge within the Laporte Domain (*cf.* Sanborn-Barrie et al., 2015) and are dispersed to the northwest, east, and southeast. However, several quartzite and vein quartz clasts plot with no clear pattern scattered to the south and southeast, possibly indicating complex dispersal, or dilution from more easily eroded lithologies to the south (*i.e.* metasediments and Doublet volcanics). Similarly, plots of the Laporte Domain clasts show high abundances over their bedrock source, but have short dispersal patterns to the northwest and southeast, and are limited to ~ 30 km radius from the bedrock source.

Plots of Michikmau intrusives, Juillet syenite, Lac Zeni amphibolite, and Mistinibi paragneiss lithologies all display high abundances overlying their respective bedrock units, with no significant dispersal patterns. The small geographical extent of the Juillet syenite and Lac Zeni bedrock unit may be the reason for their limited dispersal. The Michikmau and Mistinibi bedrock units are located at the far eastern edge of the map sheet where ice flowed consistently to the east or northeast, meaning any dispersal pattern from these units would be to the east of this study area, plotting off the map area. The felsic intrusive clasts, largely associated with the De Pas Batholith, were the most commonly identified clast during classification of the till samples. As a result, they have a very broad distribution across the study area. Despite this broad distribution, dispersal fans to the east and south of the De Pas are evident, with a small dispersal fan to the northwest at the most northern edge of the map area. Additionally, there is a lack of felsic intrusive clasts on the west/southwest of the De Pas and lower felsic intrusive abundances on the western edge of the De Pas, likely indicating a dilution from lithologies being dispersed from the southeast (iron formation, Doublet Zone volcanics, and LaPorte Domain metasediments).

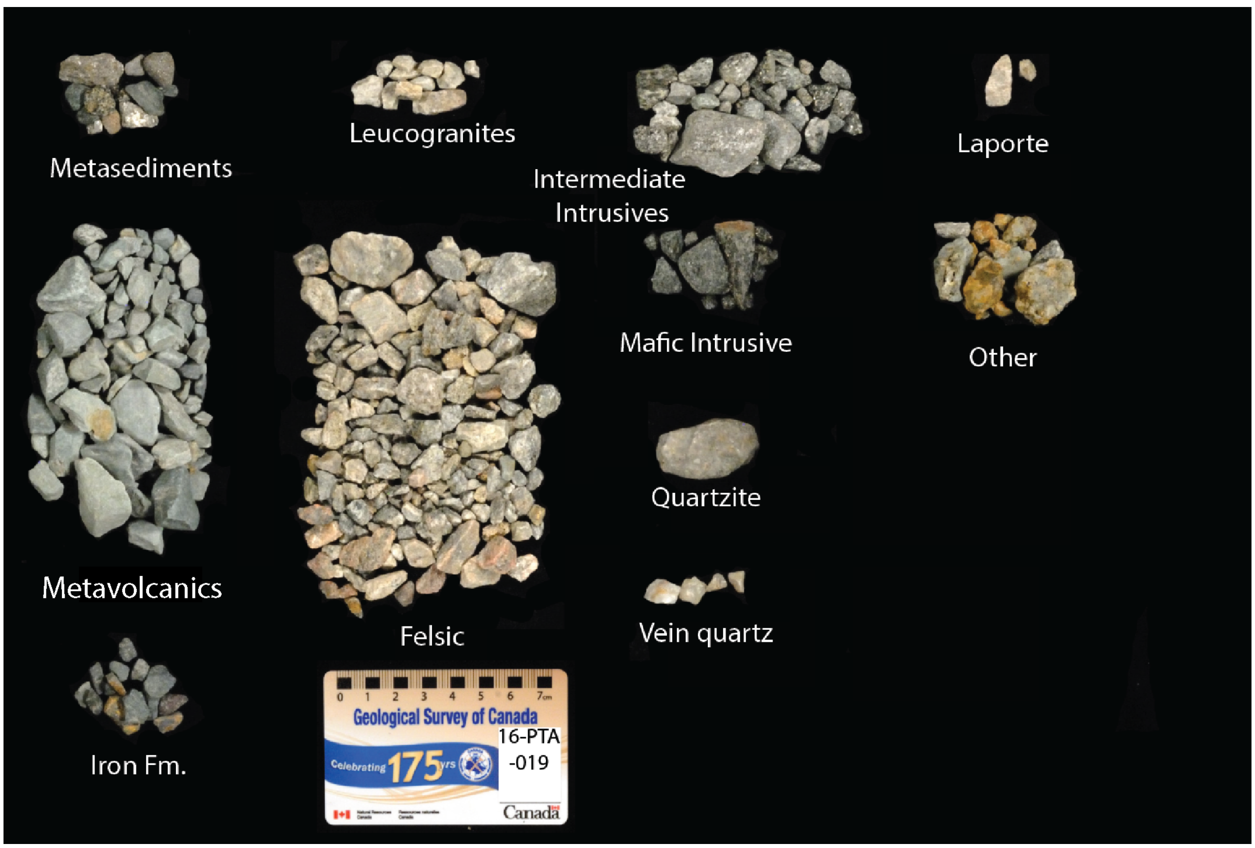

Figure 2.1. Example of pebble lithology analysis of till sample 16-PTA-019 that overlies the eastern orthogneiss, showing the abundances of different lithologies.

The iron formation rocks, metasediments, and Doublet Zone volcanics all have high abundances near their respective sources, but also display interesting dispersal patterns. The iron formation clasts indicate a predominantly eastern dispersal pattern, having been transported ~ 60 km from their source, the Labrador Trough rocks to the east. There are small abundances of iron formation clasts to the north of the Doublet Zone volcanics, however it is unclear if those clasts were transported to the north from the iron formation bedrock unit within the study area, or transported eastward from the Labrador Trough rocks that trend northwest (just west of the mapping area). The Doublet Zone volcanics, located directly north of the iron formation bedrock unit, shows a broader dispersal pattern fanning to the east and southeast. A plot of metasedimentary clasts located directly north of the Doublet Zone volcanics bedrock unit display two distinct dispersal patterns (Fig. 2.2) a long southward dispersal train (~ 60 km) and a slightly shorter eastward dispersal across the De Pas Batholith (~50 km).

These clast dispersal data provide key insights into the erosional and depositional history of the Laurentide Ice Sheet near the Ancestral Labrador ice divide. The dispersal patterns also correlate well with the ice flow history outlined by Rice et al. (2017c). A short northeastward dispersal is observed in all of the bedrock lithologies in the southwest part of the map area, confirming the northeastern flow (flow 1- *cf.* Rice et al. 2017c). Additionally, the dispersal of felsic intrusive clasts, associated with the De Pas batholith, to the west, confirm the establishment of a dispersal center on or to the east of the De Pas batholith (flow 2). Finally, the eastward/southeast dispersal of all bedrock lithologies in west and center regions of the map area confirms an eastward flow following the migration of the ice divide to the west (flow 3). Additionally, the iron formation dispersal pattern identified through this investigation confirms the dispersal pattern described by Klassen and Thompson (1993), and extends the dispersal distance by ~ 15 km to the east and northeast.

Landform analysis
Streamlined glacial landforms (e.g., flutings, crag-and-tail forms, etc.) are most abundant on the eastern edge of the mapping area and are oriented to the northeast in the north, to the east in the center, and to the east-southeast in the southern edges of the mapping area. From this investigation and through air photo interpretation and helicopter observation, the Cabot Lake ice stream was identified (*c.f.* Rice et al. 2017c). The Cabot Lake ice stream was not previously mapped by recent compilations of large ice streams associated with the LIS (Margold et al., 2015). Landform analysis has been completed and will be published as part of the senior author's Ph.D.

Subglacial erosional index
Landform abundance data were also used in conjunction with landform elongation ratios and lake density to create an index of subglacial erosion. These results will also be published as part of the authors Ph.D. publications. Preliminary results (Fig. 2.3) suggest there was more erosive ice in the eastern portion of the mapping area, as opposed to the northwestern portion, where the ice margin migration occurred.

Geochronological sampling
All of the submitted geochronological results have been received. Only four of the submitted OSL samples resulted in usable ages. These ages provide useful data for constraining ice margin

retreat across the region. Only a single previously reported age for deglaciation and possible drainage of Lake Naskaupi was reported by Short (1981), at 6815±125 cal. years BP (SI-1959). However, Short's (1981) sample was collected from freshwater lake sediments lacking abundant organic material and the age calculations could be misleading (Vincent, 1989).

Ten till samples were collected for ^{10}Be abundance analysis. Nine bedrock samples and two erratic samples were collected for cosmogenic age determination. Eight of the cosmogenic samples, all collected in 2015, yielded poor results; however, data from the twelve samples collected in 2016 yielded much lower uncertainty errors and will be the primary data source for cosmogenic age determination. Geochronology work will also be published as part of the senior author's Ph.D.

Surficial Mapping

A variety of surficial deposits and landforms were identified within the mapping area. The northern portion of the mapping area (NTS 23P) consists of abundant highland clearings, covered by till veneers, perched erratics and small bedrock outcrops. These highlands are flanked by thick till blankets that infill the valleys. The upland regions along the De Pas Batholith have been washed by meltwater outwash processes, and are often in proximity to various glaciofluvial outwash deposits.

Paleo-ice flow indicators measured within the mapping area suggest a complex ice-flow chronology including a westward migration of the Ancestral Labrador ice divide, creating a complete reversal of ice flow in the northwestern part of the map area. In the east-central part of the mapping area, eskers have been deposited in a radial pattern originating from De Pas batholith and oriented to the east and southeast. Evidence of meltwater erosion and reworking was also identified throughout the northern map sheet, including Nye channels, eskers, kames, lateral meltwater channels, washed bedrock surfaces, and other glaciofluvial features associated with ice sheet ablation and meltwater erosion, transportation, and deposition.

Chronological striation data supports established ice flow reconstructions, with an early northeast flow (Fig.2.4- flow 1) likely flowing from the Quebec highlands (Veillette et al., 1999). This was followed by a buildup of an ice dome somewhere near the eastern edge of the De Pas Batholith with ice flow radiating from this general area (flow phase 2). Following this radial flow, the ice dome shifted westward as indicated by cross cutting flows observed on the northwest side of the mapping area (Fig. 2.4- top right). Detailed ice flow reconstructions will be released as academic journals as part of the senior author's Ph.D. requirements.

Two glacial lakes inundated the northern part of the mapping area: glacial Lake Naskaupi (Ives, 1960a; Barnett and Peterson, 1964) occupying the general basin of the George River in the northeast, and smaller glacial Lake McLean (Ives, 1960b; Barnett, 1967) in the northwest. Regions affected by the inundation of the proglacial lakes are characterized by washed bedrock surfaces, winnowed till, and littoral beach deposits. The maximum elevation of glacial Lake Naskaupi within the mapping area was 486 ±5 m. Glacial Lake McLean reached a maximum elevation in the mapping area of 426 ± 5 m.

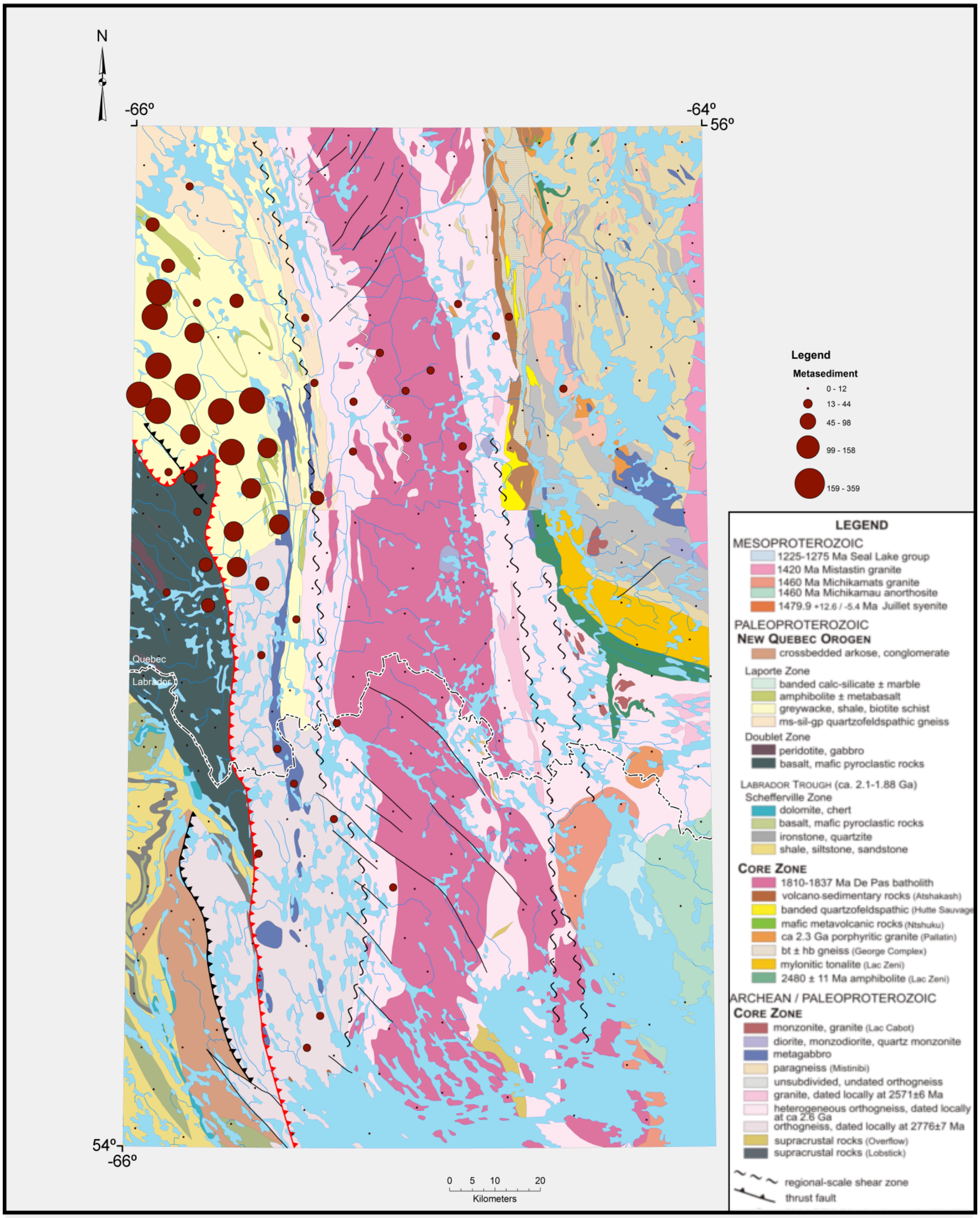

Figure 2.2: Distribution of metavolcanic clasts from till samples shows higher concentrations over the Laporte Zone, but also showing dispersal to the east and south-southeast. Bedrock geology from Wardle et al. (1997) and Ministère de l'Énergie et des Ressources naturelles (2010).

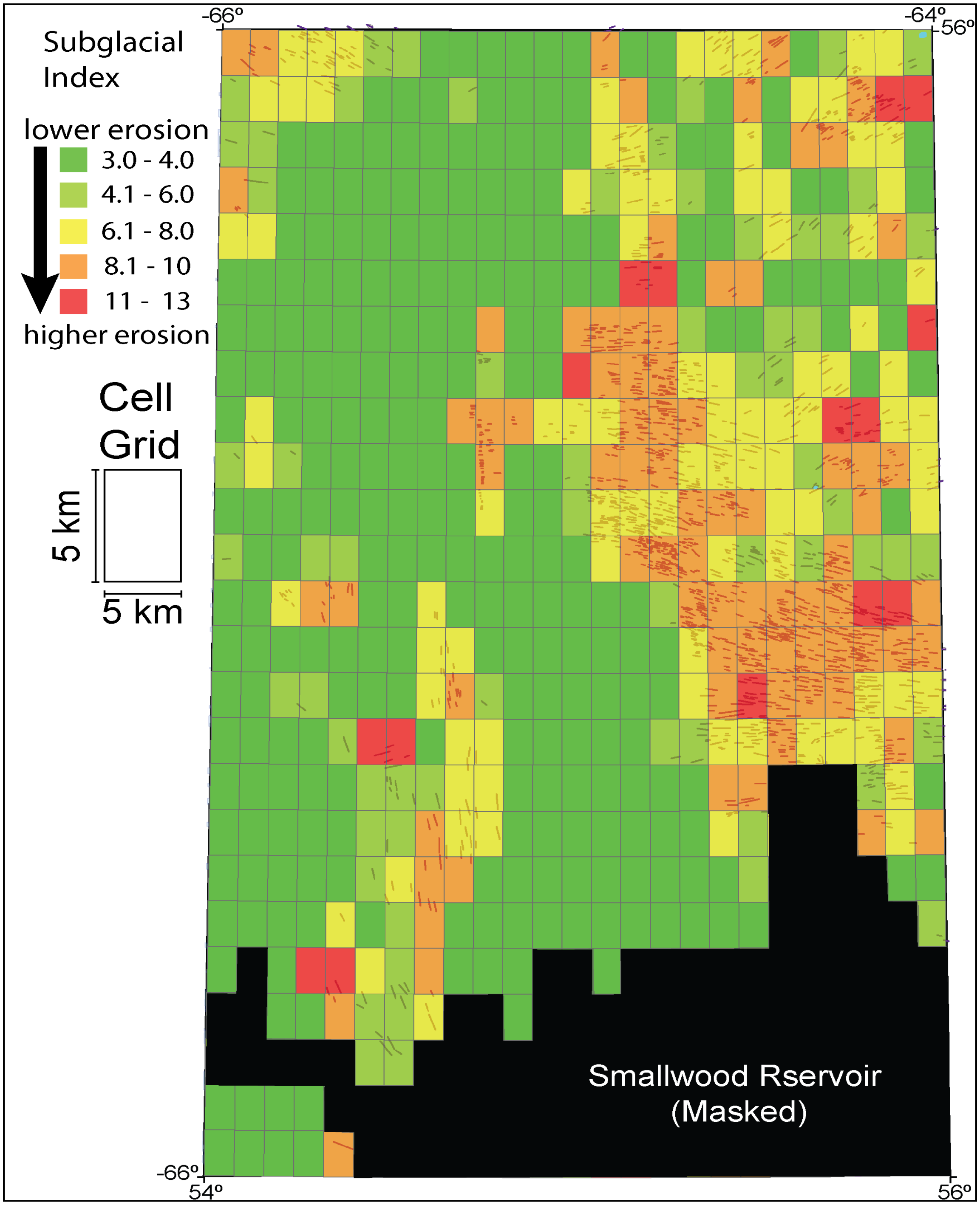

Figure 2.3: Preliminary subglacial erosional index map of the study area. This map indicates the value of the average elongation ratio of landforms, the number of glacial lineations, and the abundance of lakes within a given cell (5 km x 5 km) as an index of subglacial erosion. The glacial erosion index is higher in the east and southwest parts of the study area. The Smallwood Reservoir, a man made hydroelectric reservoir was masked from this interpretation.

The southern part of the mapping area (NTS map sheet 23I) contains fewer highland clearings, which are more commonly covered by small trees and other small vegetation. The valleys between uplands are draped by thick till blankets. These poorly drained lowlands are dominated by fens and wetlands that make access by helicopter difficult. Paleoflow indicators measured within this map sheet indicate a less complex ice flow history with no evidence of ice flow reversal. Ice flow generally shifted from an early northeastern flow to an east then southeastern direction. Mega-scale glacial lineations (MSGLs) oriented towards the east have been identified associated with the Cabot Lake ice steam, just east of Lac Cabot, as well as other large crag-and-tail landforms that are oriented to the east and southeast. Large eskers radially punctuate the crosscutting aforementioned oriented landforms. These esker complexes are often associated with kettle lakes, kettle depressions, kames, and other outwash deposits. A single, previously undefined proglacial lake, glacial Lake Low (Paulen et al., 2017) inundated the region to an elevation approximately 8 m above the current Smallwood Reservoir (474 m). Evidence of this glacial lake includes winnowed till deposits and littoral beach sediments.

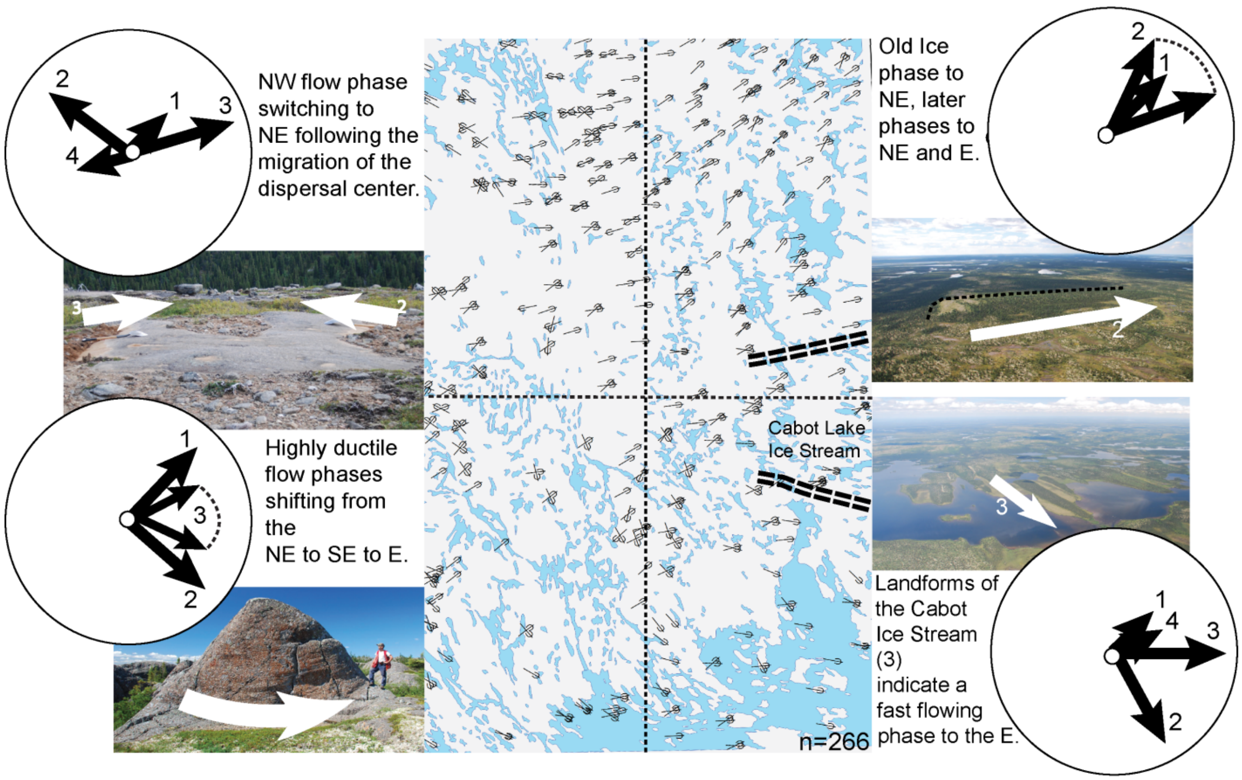

Figure 2.4. A summary map of the 226 striation measurements taken across the mapping area. The four quadrants show how the changing ice-flow conditions affected different geographical regions. The arrows represent the approximate ice flow vector for each stage of ice flow (1-4) with flow 1 representing early northeast flow across the entire map area. Flow 2 representing the first radial flow, flow 3 representing radial ice flow following the westward shift of the dispersal center, and flow representing late deglacial flows which were highly variable. Evidence of ice flow reversal can be observed in the top right after a shift from flow 2 to flow 3. Finally, flow 4 represents the deglacial flow of the ice sheet.

To date, surficial geology maps have been published for NTS 23I/SE (Paulen et al. 2017), and NTS 23P/NE (Rice et al. 2017d). The remaining six maps will be released in the spring of 2018. A report focusing on the contributions by the Geological Survey of Newfoundland and Labrador to the surficial mapping and regional till sampling has been released and focuses on western Labrador (Campbell et al., 2017).

Discussion and future work
The diverse landscape of the study area (NTS 23I and 23P) reflects an extensive and complex glacial history, characterized by multiple ice-flow trajectories including complete ice-flow reversal. As a result of this ice-flow reversal, the subglacial erosional vigor fluctuated drastically across the region. Regions affected by highly erosive ice are characterized by thick sediment deposition, large sculpted landforms, long distance till transport, and streamlined landforms. In contrast, regions with minimal glacial erosion are characterized by thin till, large perched erratics, and more complex glacial transport histories.

Currently, a general ice flow hypothesis has been established, and the legitimacy of this model will be tested against measured field and lab data: cosmogenic ^{10}Be abundances and exposure dates, OSL, geochemical, indicator mineral, and pebble lithology data, all of which will be completed and released in forthcoming GSC Open Files and other academic journal publications. Through this work, a better understanding of the surficial geology and changing glacial dynamics will be obtained. These data will be a useful resource to aid natural resource exploration and responsible resource development in the region.

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Chapter 3 Till Geochemistry and Mineralogy

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Introduction

As part of the surficial mapping and geochemical studies are being carried out under the Hudson-Ungava GEM 2 project, reconnaissance-scale surface till sampling was completed across the southern Core Zone in NTS sheets 23I and 23P (*see Chapter 2*). Till samples were analyzed geochemically to aid in surficial mapping and provenance studies and to assist in the evaluation of the mineral potential of the region. In additional to these new till samples, archived splits of till samples collected in 1986 and 1987 (Klassen and Thompson, 1993) by the GSC in the current study area were geochemically re-analyzed. The mineralogical and geochemical results for till samples summarized here should be interpreted using the ice flow patterns outlined in Chapter 2 and Figure 3.1.

Methods

Field Methods

New till samples were collected following established GSC protocols (Spirito et al., 2011; McClenaghan et al., 2013) that are described in detail in McClenaghan et al. (2016a,b, 2017) and Rice et al. (2017a,b). At each sample site, two types of samples were collected: a large till sample (7 to 13 kg) for recovery of indicator minerals, and a ~ 3 kg sample for till matrix geochemical analysis and archiving. A total of 260 till samples were collected over the three field seasons (2014-216). Location and metadata for all till samples collected are reported in McClenaghan et al. (2016,a,b, 2017) and Rice et al. (2017a,b).

Sample processing and indicator mineral picking

Till samples were processed in a commercial lab to recover a heavy mineral fraction for examination of indicator minerals using protocols described by Plouffe et al (2013). A detailed description of the processing methods used and the unmodified laboratory reports are published in McClenaghan et al. (2017). First, the <2.0 mm material was passed over a shaking table and the heavy table concentrate was recovered and micropanned to recover fine-grained gold, sulphides, and other indicator minerals typically <0.25 mm in size. The minerals in the panned concentrates were counted, their size and shape characteristics recorded and returned to the sample. The pre-concentrates were then further refined using heavy liquid separation in methylene iodide diluted to a specific gravity (SG) of 3.2. The ferromagnetic fraction of each sample was removed and the non-ferromagnetic heavy mineral fraction was sieved into three size fractions: 0.25-0.5, 0.5-1.0, and 1.0-2.0 mm which were then visually examined for indicator minerals.

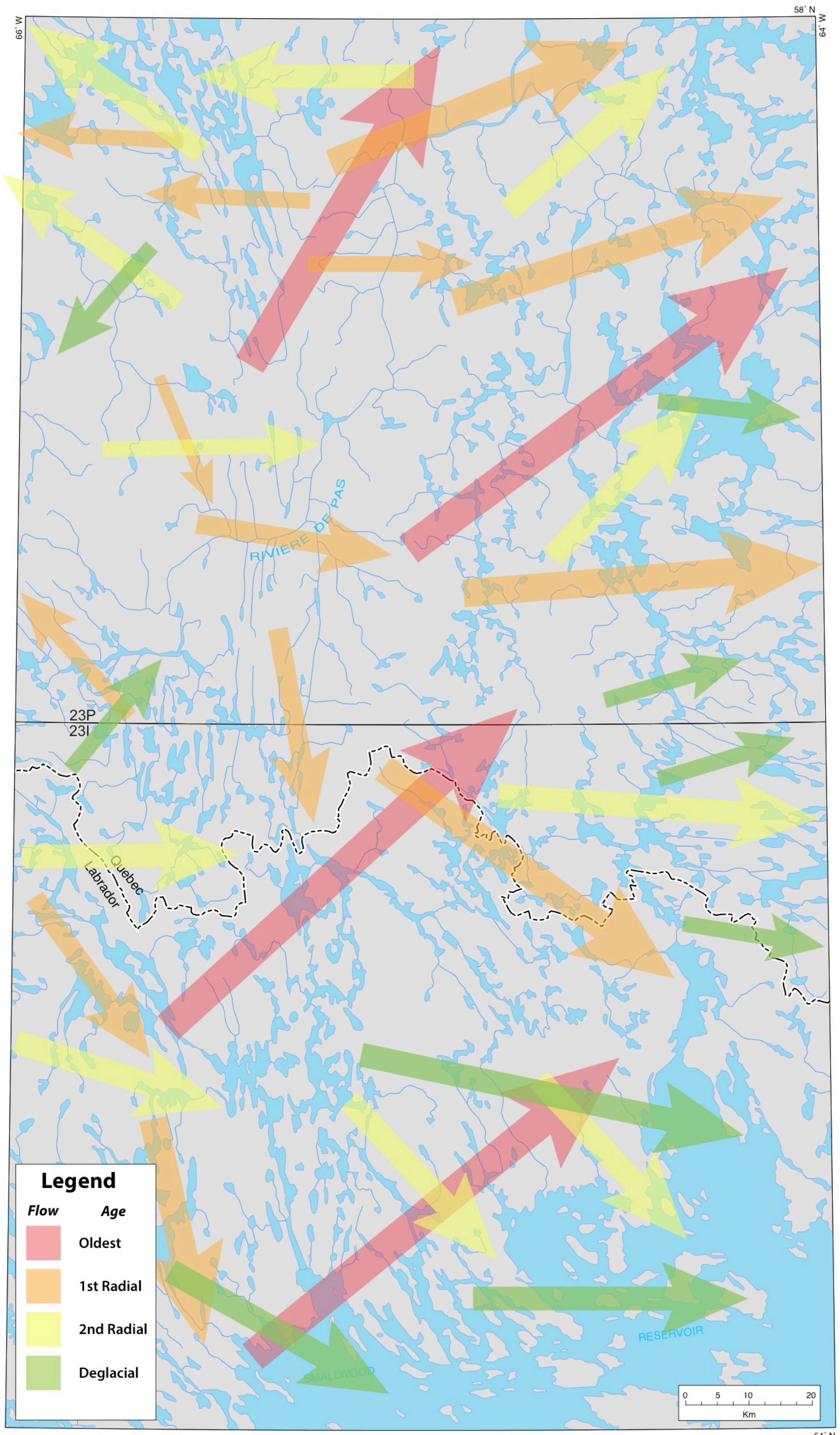

Figure 3.1 Generalized summary of mapped ice-flow indicators from the study area, 2014-2016. Red arrows indicate the oldest flow direction observed in the region, and was likely from the Quebec Laurentian highlands (cf., Veillette et al., 1999). Orange arrows indicate the earlier phase of radial flow from the Labrador ice centre during the main Wisconsin phase of the Laurentide Ice Sheet. Yellow arrows indicate a later phase of radial flow from the ice centre. Green arrows indicate deglacial flow trajectories, including the ice streams that were directed to the Labrador coastline to the east.

Geochemical analysis
The 3 kg till samples were submitted to the GSC Sedimentology Laboratory, Ottawa. Each sample was dried, an ~800 g split was removed for archiving, and the remainder sieved to recover the <0.063 mm fraction for geochemical analysis at a commercial laboratory. Samples were analyzed using: 1) a modified aqua regia digestion ($HCl:HNO_3$ in a 1:1 ratio) followed by an ICP-MS determination on 0.5 g; 2) lithium metaborate/tetraborate fusion followed by nitric acid digestion/ICP-ES and -MS on 0.2 g); and, 3) fire assay/ ICP-ES/MS analysis on 30 g aliquots of till samples for Au, Pt, and Pd. Geochemical data are reported in McClenaghan et al. (2016b) and Rice (2017b).

Results

Indicator Minerals
The abundances and distribution of selected indicator minerals in the 2014-2016 till samples are presented as a series of maps in McClenaghan et al. (2017). The distribution of gold grains in the pan concentrate of till samples normalized to 10 kg of < 2.0 mm is shown in Figure 3.2. Of potential interest is the general elevated gold grain content in till (>6 grains /10kg) in the west central part of the study area, principally overlying the Doublet Zone mafic volcanic rocks. There, sample 16-PTA-057 (Fig. 3.2) contains the greatest abundance of gold grains (63 grains/10 kg) as compared to the rest of the study area. One large sand-sized gold grain (Fig. 3.3) was recovered from sample 16-PTA-112 (Fig. 3.2) located over the Core Zone orthogneiss. This gold grain is noticeably larger than the silt-sized gold grains observed in the rest of the till samples. The reshaped nature of this large grain suggests that it could be far travelled (DiLabio, 1990). The bedrock source(s) of gold in till in this region is suspected to be local mafic volcanic bedrock.

Figure 3.4 shows the distribution of platinum group mineral (PGM) grains in the pan concentrate of till samples across the study area. Ten till samples contain 1 to 2 grains/10 kg of either sperrylite ($PtAs_2$) or moncheite ($(Pt,Pd)(Te,Bi)_2$) and occur in clusters across the area: i) samples that overlie or are just east (down ice) of metagabbro in the southwest part of the study area; ii) samples that overlie Mistinibi paragneiss in the northeast part of the area and were affected by northeast and southwest ice flows, and thus may be down ice of ultramafic rocks in that region; and iii) samples that overlie the Laporte Zone metasedimentary rocks and were affected by a complex pattern of radial flow from a migrating ice divide (Fig. 3.1) that could have dispersed PGM minerals from ultramafic pods within the Doublet Zone.

Figure 3.5 shows the distribution of chalcopyrite grains in the 0.25-0.5 mm heavy mineral fraction of till samples across the study area. Similar to gold grain distribution, chalcopyrite content in till samples (1-6 grains /10kg) is highest in the west central part of the study area, principally overlying the Doublet Zone mafic volcanic rocks. Elevated abundances in till also occur overlying ultramafic rocks to the east of the Doublet Zone and down ice (east) of the ultramafic rocks.

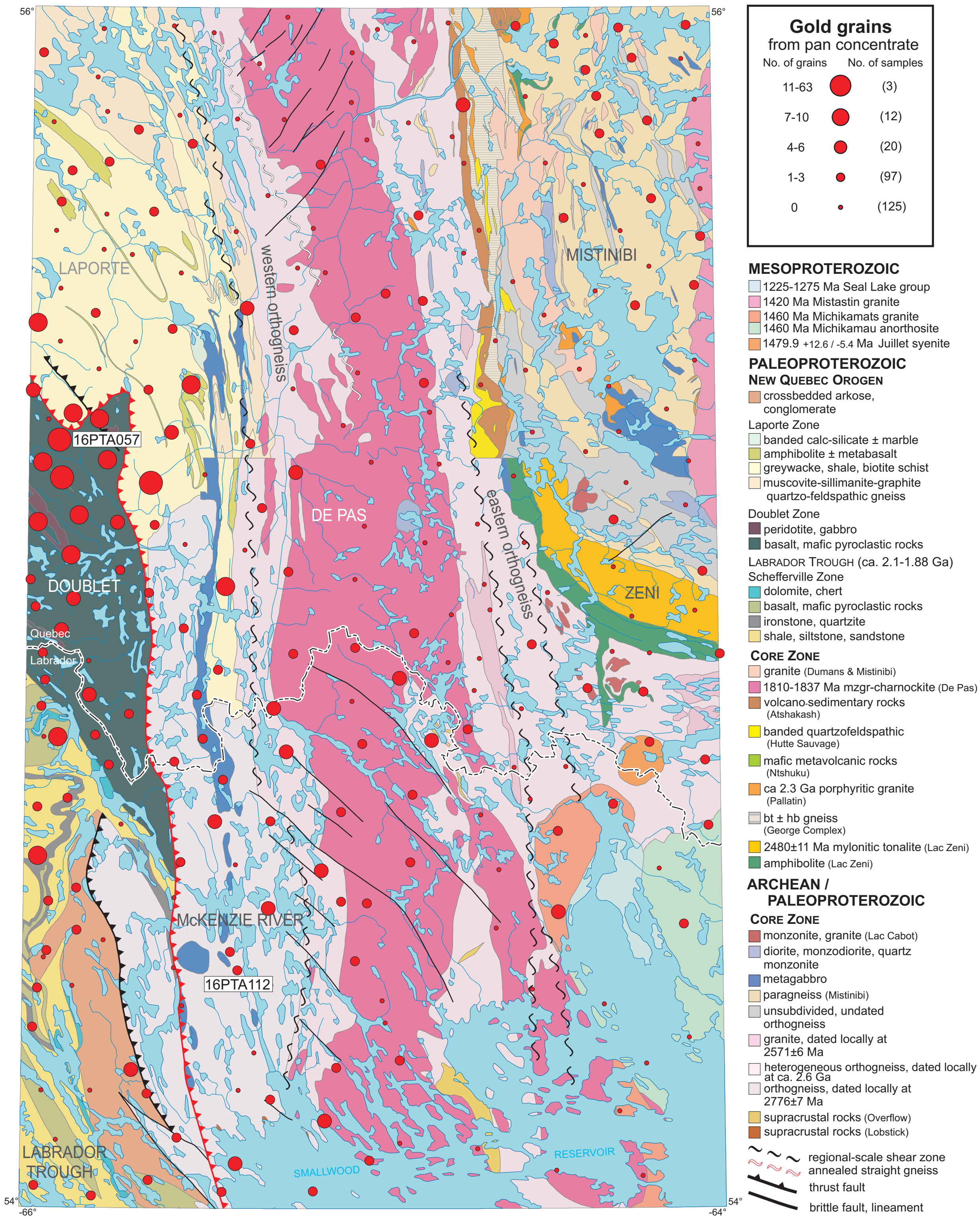

Figure 3.2. Distribution of gold grains recovered from the pan concentrate of till samples, normalized to 10 kg sample mass across the southern Core Zone (from McClenaghan et al., 2017).

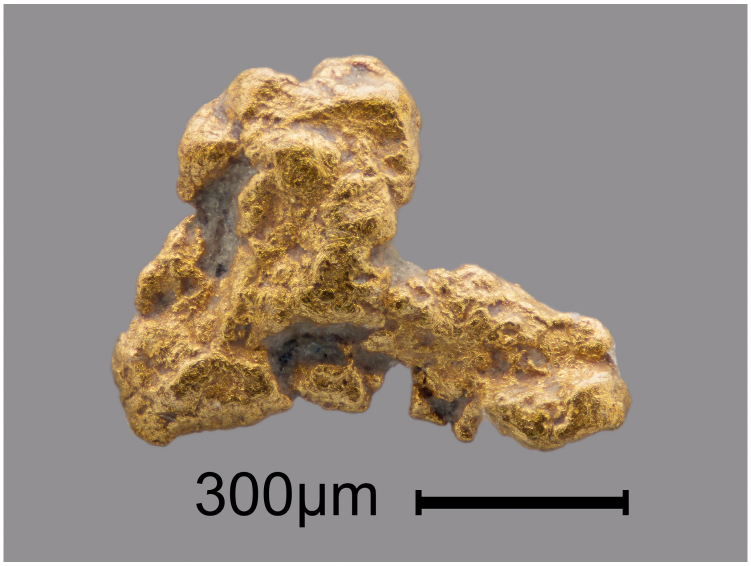

Figure 3.3. Photograph of a large reshaped gold grain recovered from till sample 16-PTA-112. Photo by Michael J. Bainbridge photography.

Till geochemistry

The abundances and distribution of selected elements in the 2014-2016 till samples are presented as a series of maps in Rice et al. (2017b). Till samples collected over the Laporte Zone, Labrador Trough (Knob Lake Group), and Doublet Zone mafic volcanic rocks have distinct geochemical signatures characterized by elevated Cu, Zn, Au, Pt, Pd, and Sb contents. The elevated gold (Fig. 3.6) and silver values in till over the Doublet Zone coincides with the elevated gold grain content discussed above (Fig. 3.2). The elevated Sb values in till is likely related to the large geochemical province defined by elevated Sb abundance in organic lake sediments that overlies the entire 600 km length of the Labrador Trough recently reported by Amor et al. (2016).

Conclusions

Precious and base metal anomalies have been identified in till in the west part of the study area, overlying mafic and ultramafic rocks. Ice flow patterns across the study area are complex, reflecting shifting ice divides through time. Follow up of these anomalies should take into account this complex ice flow sequence summarized in Figure 3.1.

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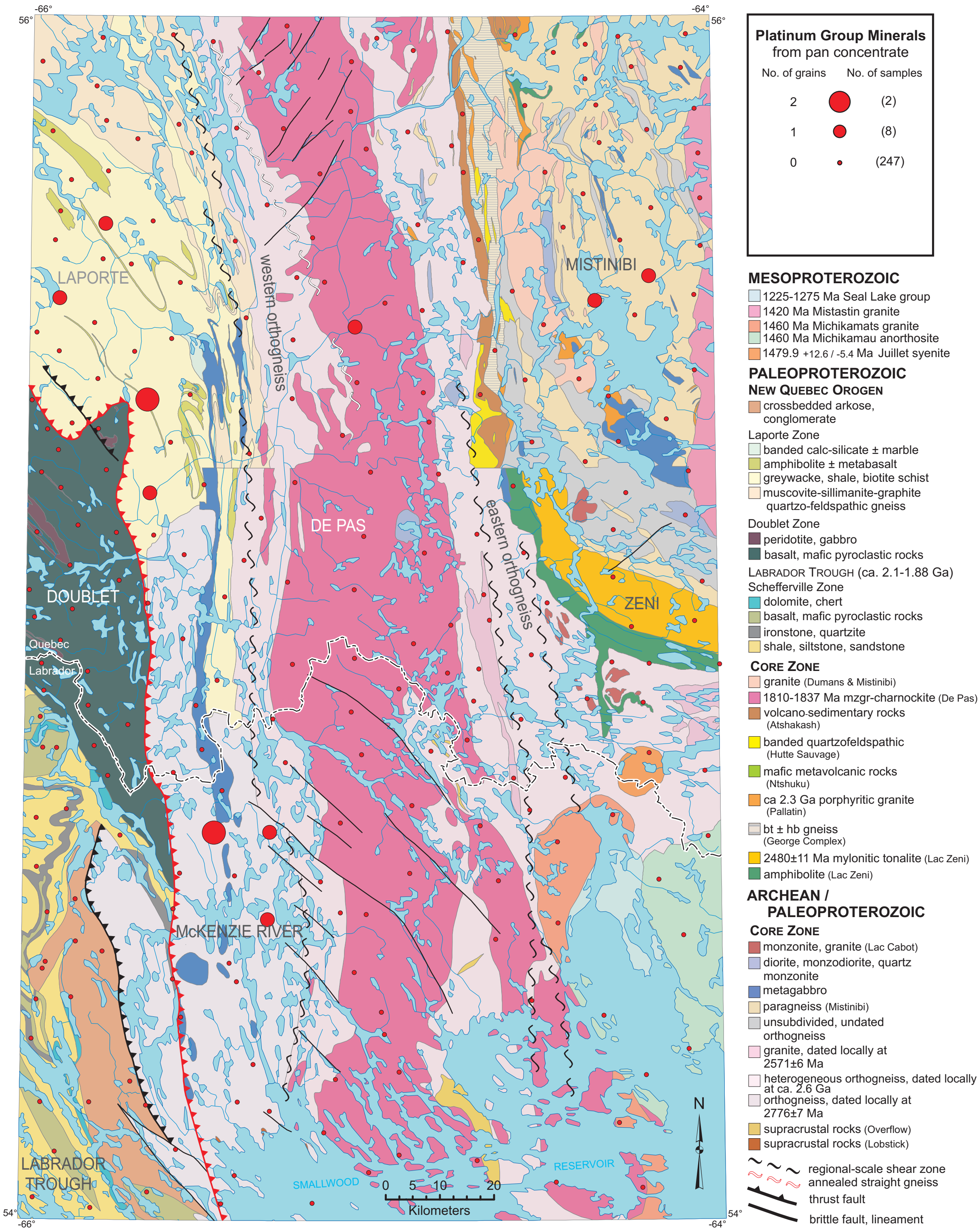

Figure 3.4. Distribution of platinum group mineral (PGM) grains recovered from the 0.25-0.5 mm non ferromagnetic heavy mineral concentrate of till samples, normalized to 10 kg sample mass across the southern Core Zone. Modified and updated from McClenaghan et al. (2017).

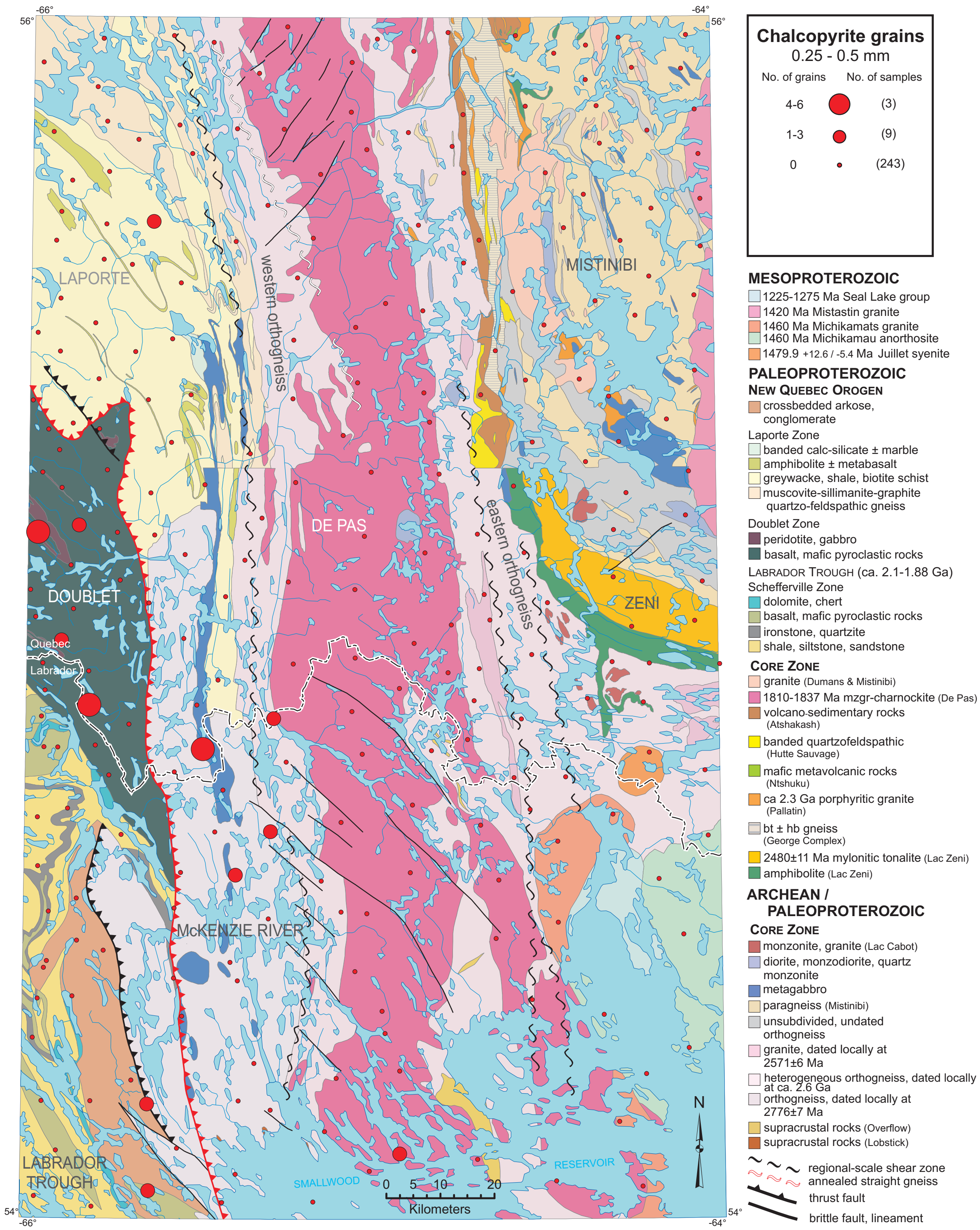

Figure 3.5. Distribution of chalcopyrite grains recovered from the 0.25-0.5 mm non ferromagnetic heavy mineral concentrate of till samples, normalized to 10 kg sample mass across the southern Core Zone (from McClenaghan et al., 2017).

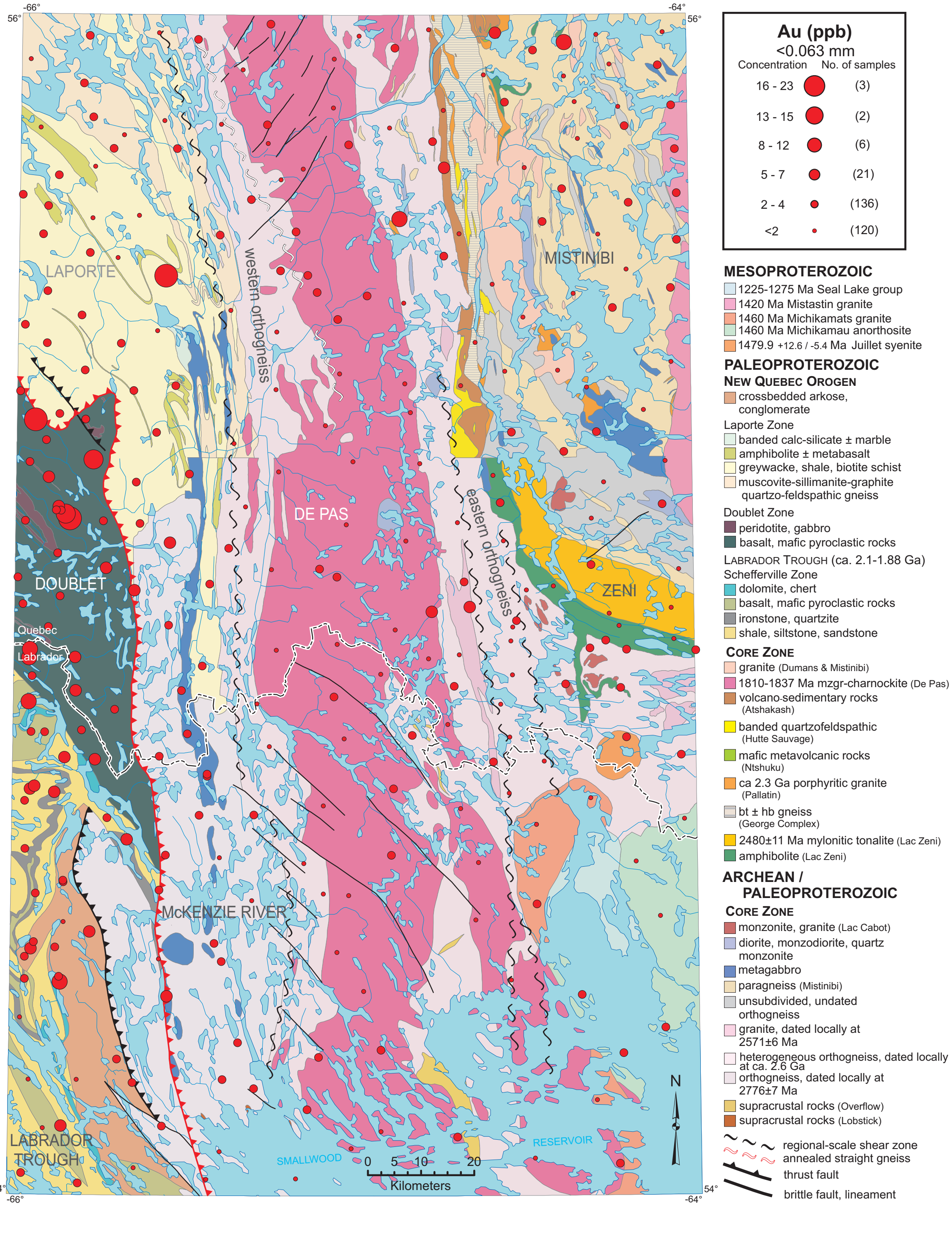

Figure 3.6. Distribution of gold determined by fire assay-ICP-MS in the <0.063 mm fraction of till across the southern Core Zone (from Rice et al., 2017b).

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Chapter 4 Lake Sediment Geochemistry

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Introduction

The goal of this activity is the publication of geochemical maps for northeastern Quebec and adjacent areas of Labrador (Fig. 4.1) for the purposes of mineral exploration and gaining a better understanding of the bedrock geology and surficial processes that influence the distribution of elements in centre-lake sediments.

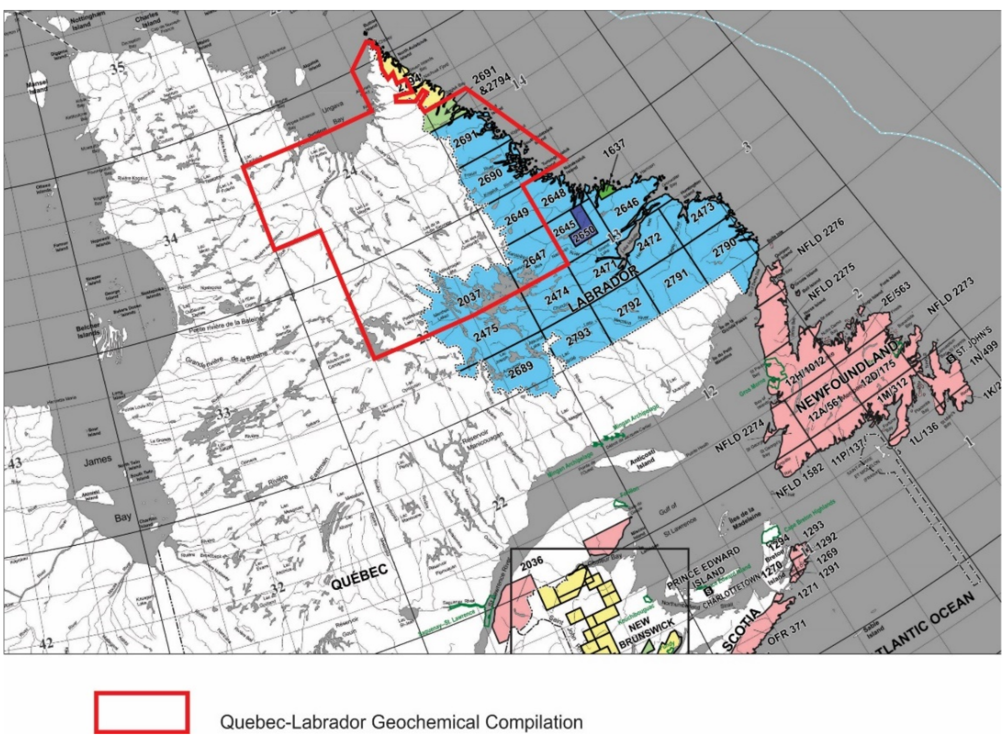

Figure 4.1 Areas of Labrador (blue) within the study area (red line) from which archived lake sediment samples were reanalyzed in order to produce an internally consistent dataset for the entire study area.

Geochemical Data
Data used to compile geochemical maps consist of multi-element analyses of lake sediments from northeastern Quebec and reanalyses of lake sediments from the adjacent portion of Labrador: NTS map areas 23-K, 23-N, 23-P, 24-B, 24-C, 24-E, 24-G, 24-J, 24-K, 24-L and 24-P (Québec only); 13-L, 13-M, 14-D, 14-E, 14-L, 23-I, 23-J, 23-O, 24-A, 24-H, 24-I (Labrador and Quebec); and 14-C and 14-F (Labrador only).

Geochemical data for 26,727 lake sediment sample sites in northeastern Quebec were acquired through the Bureau de la connaissance géoscientifique du Québec, Ministère de l'Énergie et des Ressources naturelles. From these data, records for 16,167 sites containing geochemical data compatible with Labrador reanalysis data were selected for the geochemical compilation. The Labrador dataset comprises records for 5,510 samples. Geochemical data are available for all samples for 53 elements. Labrador samples were reanalyzed for an additional 12 rare-earth elements, which are not considered in the current work; the elements are listed in Table 4.1.

The analytical data for the Quebec lake sediment samples were released after sampling programs conducted in 1982-1984, 1997 and 2009. The new Labrador re-analysis data were released by the GSC in 2016 (McCurdy, 2016; McCurdy et al., 2016). Determinations of loss-on-ignition (L.O.I.) are also available for all Labrador and Quebec samples. Geochemical data for Labrador were reported in a series of GSC Open File reports between 1978 and 1994. Values for Quebec can be obtained through the SIGEOM (2017) website: http://sigeom.mines.gouv.qc.ca/

Geochemical Compilation Atlas
The geochemical compilation atlas is being released as a combined Geological Survey of Canada – Geological Survey of Newfoundland and Labrador open file, in digital (PDF) format. Different coloured symbols represent each of the five quintile class intervals used to illustrate the areal distribution of concentrations for each of 53 elements. Summary statistics in table format are included for each element. Release notes describe sample collection, preparation and analytical methods. A bedrock geology compilation for the survey area and a newly revised Canada Atlas 1:1,000,000-scale base map for hydrological reference (see below) serves as base map for the overlying geochemical data.

Canada Atlas 1:1,000,000-Scale Base Map
The Atlas of Canada 1:1,000,000-scale digital map of Canada forms the hydrological base for the geochemical atlas. Significant positional errors existed in this base map that prevented the publication of the atlas. The base map errors in turn resulted in significant errors in the plotting of sample data such that sample points plotted in the Atlantic Ocean. The base map errors exist to varying degrees across the entire map of Canada. The attached figure (Fig. 4.2) for the Hopedale area on the Labrador coast, illustrates the problem. The base map (white polygons) is from *OpenStreetMap* (OpenStreetMap Foundation, 2017), but other bases are all in agreement. The red lines are from 1:1 million-scale Atlas of Canada, and are systematically offset from the *OpenStreetMap* layer. The coloured dots are lake sediment sample sites, and plot correctly with respect to the OpenStreetMap layer. However, many of the sample sites (blue dots) plot in the Atlantic Ocean when using the Atlas of Canada base map.

Table 4.1. Elements analyzed in current investigation[1].

Element	Units	L.D.L.	< L.D.L	Element	Units	L.D.L.	< L.D.L.
Ag	PPB	2	10	Na	%	0.001	32
Al	%	0.01	0	Nb	PPM	0.02	0
As	PPM	0.1	5009	Ni	PPM	0.1	0
Au	PPB	0.2	4337	P	%	0.001	0
B	PPM	20	21622	Pb	PPM	0.01	0
Ba	PPM	0.5	0	Pd	PPB	10	21465
Be	PPM	0.1	1547	Pt	PPB	2	18100
Bi	PPM	0.02	3534	Rb	PPM	0.1	4
Ca	%	0.01	1	Re	PPB	1	12577
Cd	PPM	0.01	5	S	%	0.02	513
Ce	PPM	0.1	0	Sb	PPM	0.02	6281
Co	PPM	0.1	0	Sc	PPM	0.1	6
Cr	PPM	0.5	2	Se	PPM	0.1	384
Cs	PPM	0.02	14	Sn	PPM	0.1	1867
Cu	PPM	0.01	0	Sr	PPM	0.5	1
Fe	%	0.01	0	Ta	PPM	0.05	21718
Ga	PPM	0.1	28	Te	PPM	0.02	15496
Ge	PPM	0.1	12979	Th	PPM	0.1	350
Hf	PPM	0.02	8186	Ti	%	0.001	12
Hg	PPB	5	86	Tl	PPM	0.02	298
In	PPM	0.02	15737	U	PPM	0.1	26
K	%	0.01	227	V	PPM	2	105
La	PPM	0.5	10	W	PPM	0.1	8587
Li	PPM	0.1	57	Y	PPM	0.01	0
Mg	%	0.01	3	Zn	PPM	0.1	0
Mn	PPM	1	0[2]	Zr	PPM	0.1	213
Mo	PPM	0.01	0				

[1] Labrador samples also analyzed for Dy, Er, Eu, Gd, Ho, Lu, Nd, Pr, Sm, Tb, Tm and Yb.
[2]Mn data include 213 analyses exceeding upper detection limit of 10,000 ppm.
LDL = lower detection limit

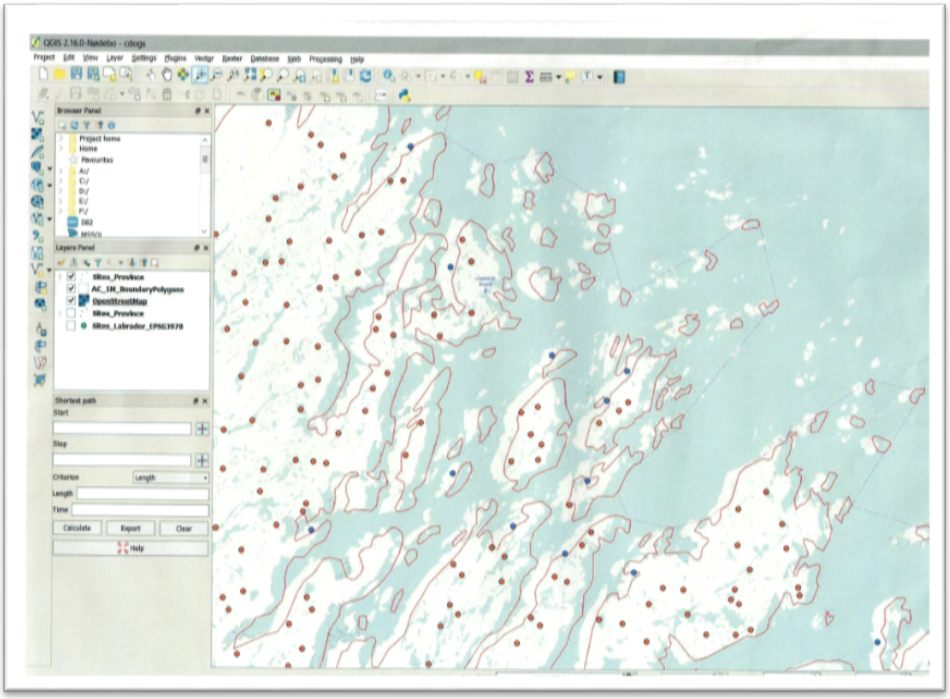

Figure 4.2. Lake sediment sample sites (coloured dots) near Hopedale, Labrador demonstrating the map base errors (red outline versus solid white polygons) that are being corrected prior to publication of the lake sediment geochemical map for the Core Zone.

At a meeting between GSC staff and representatives from CCMEO (Canada Centre for Mapping and Earth Observation), the Atlas of Canada 1,000,000 National Frameworks Data was discussed and it was acknowledged that there were positional displacements of features within the source data, connectivity errors and missing features. CCMEO and the GSC are working together to correct the data in the GEM-2 Hudson-Ungava project area. The corrected version of the base map is expected to be ready by late Fall 2017.

An article published in the December 2016 issue of EXPLORE, the newsletter for the Association of Applied Geochemists, describes the methods used to merge two data sets from neighbouring regions, compiled during differently administered programs, to create seamless geochemical maps (Amor et al., 2016). The article includes a discussion of the problems encountered and solutions devised to produce the digital atlas of geochemistry for northern Labrador and Quebec. Statistical procedures used to compare and validate the amalgamation of the two data sets are outlined. A description of the bedrock geology map compiled for the geochemical atlas is included with the article.

Conclusions

Results from statistical and graphical comparisons of geochemical data from Quebec and Labrador lake sediment samples indicate that analytical data for 53 elements can be used to create geochemical element concentration maps for the entire study area. Several elements are suitable for mapping with some form of levelling.

Future Work/Next Steps
A demonstration of the digital geochemical atlas will be presented at the Newfoundland and Labrador Mineral Resources Review, November 1nd – 4th, 2017, in St John's. A simplified version of bedrock geology for the entire Core Zone study area is nearly complete, as is the corrected 1:1,000,000-scale National Atlas hydrology map. Publication of the geochemical atlas will proceed once the hydrology and bedrock geology digital files are received.

Acknowledgements
We wish to thank Patrice Roy, Bureau de la connaissance géoscientifique du Québec, and Réjean Couture, Geological Survey of Canada, for their timely assistance with establishing the contacts essential for the production of multi-provincial geochemical compilation maps. For assistance with the layout of the geochemical atlas, we thank Paul Champagne and Matt Pyne. We gratefully acknowledge the assistance of Steve Adcock (GSC), Scott Tweedy (CCMEO), Anna Regan (CCMEO), and Aeron Vaillancourt (GSC) for initiating and carrying out the corrections to the Atlas of Canada map.

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Chapter 5 Radiometric Domains and the Integration of Multiple Gamma-Ray Data Sources for a Remote Area of Northern Quebec

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Introduction

Over the past year, studies were completed on the integration of different gamma-ray data sets over the northwestern corner of NTS 23P. This integration included data for potassium, uranium, and thorium radioelement concentrations recorded through airborne, handheld, and laboratory gamma-ray spectrometry (GRS) methods. Radiometric domains, defined as an area on the land surface with an airborne response that is distinct from surrounding areas (Campbell et al., 2007; Fortin et al., 2015), were identified. Observations of four different data sets compared to one another were also completed. The goal was to test these forms of GRS data manipulation to assist mineral exploration in the area.

Methodology

The four data sets were integrated into a GIS to undergo analysis, they include:
1) Airborne GRS collected as part of the Ministère de l'Énergie et des Ressources naturelles du Québec (MERNQ) Romanet Lake airborne geophysical survey (D'Amours and Intissar, 2013). Using these survey data, a ternary diagram was created that shows the ratio of potassium, uranium and thorium concentrations represented respectively by magenta, cyan and yellow. Additionally, the colour saturation scales to the total response magnitude of the area (Broome et al., 1987).

2) Handheld GRS readings of till at surface were recorded with a RS-230 BGO Super-Spec (Radiations Solutions Inc.) portable gamma-ray spectrometer at field sites within the study area. The handheld GRS unit was placed with the sensor facing toward the ground, typically on a mudboil or a vegetated till surface for five minutes, and recorded the radioelement contents of the top 2 cm depth. A total of 21 surface till readings were taken within the study area.

3) Handheld GRS readings of the bedrock surface were also recorded at field sites where the exposed bedrock was within the study area. The same handheld GRS methods and measurement parameters were applied to the outcrop surfaces as the till surfaces. A total of 26 bedrock localities were recorded.

4) Samples collected from regional surficial mapping that occurred within the study area (see Rice et al., this report) were split and 34 till samples collected from ~0.5 m depth were air dried and tightly packed into metal tins. They were then analyzed at the Geological Survey of Canada Gamma-ray Spectrometry Laboratory recording potassium, uranium and thorium contents of the till contained in the tin. These are referred to as lab till samples throughout this section.

Additional data sets, such as pebble counts and wet geochemical analysis of the till matrix were not included in our preliminary studies, but will be included in future GRS analysis of the entire southern Core Zone study area.

Results

Twelve radiometric domains were defined for the study area and are shown in Figure 5.1. Each domain was identified by its unique combination of ternary hue and saturation, airborne radioelement values, underlying bedrock lithologies, topography, and the surficial geology. These data are summarized in Table 5.1. The topography of a domain was classified as low, intermediate, or high based on observations from a DEM, with elevation above sea level (asl). Low lying areas had typical elevations ranging from 307 – 426 m, intermediate domains had elevations of 426 – 546 m, and finally high elevations were classified between 546 – 666 m.

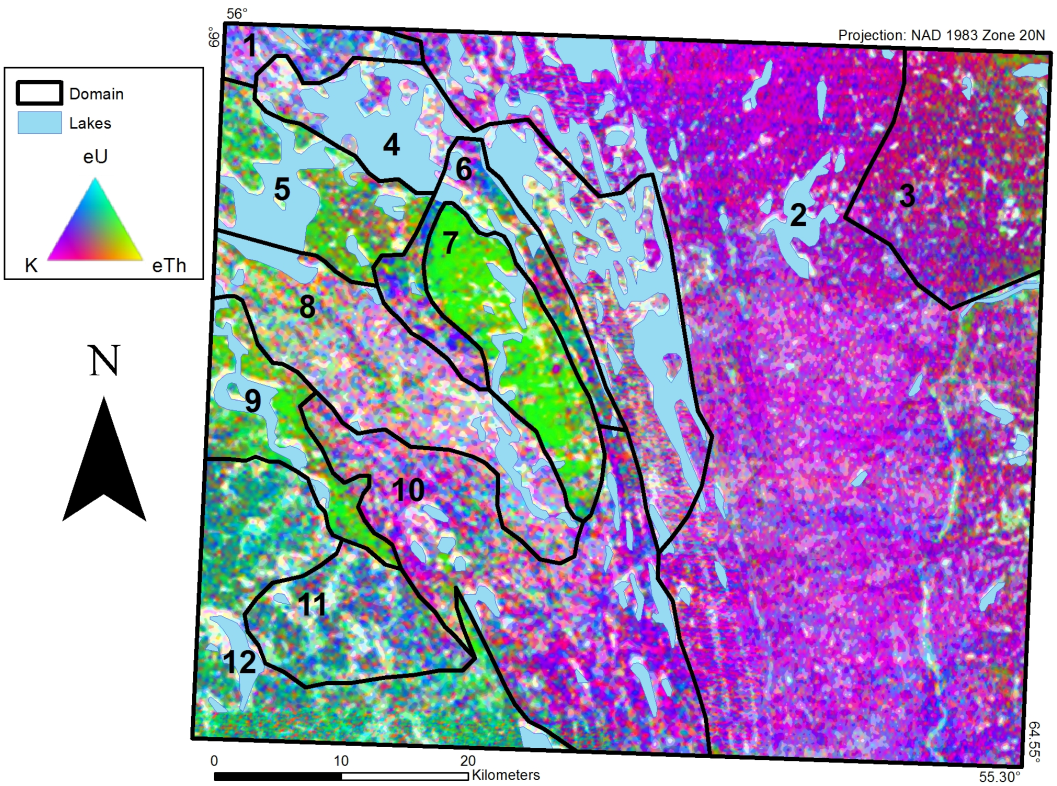

Figure 5.1: Map showing twelve interpreted radiometric domains within the study area based on airborne gamma-ray spectrometry data.

Comparisons between the four different data sets were also completed. Surface till values were plotted against the airborne response showing the best linear regression ($R^2 = 0.78$) (Figure 5.2). Bedrock outcrop measurements plotted against the airborne reading provided a R^2 of 0.36 (Figure 5.2). Finally, lab till samples had a R^2 value of 0.29 (Figure 5.2). Comparison of the remaining GRS methods showed that no major relationships were present. Surface bedrock and till recordings had an R^2 of 0.38, while bedrock measurements compared to lab till samples recorded R^2 values of 0.037. Lastly, surface till measurements to lab till samples showed an R^2 of 0.37.

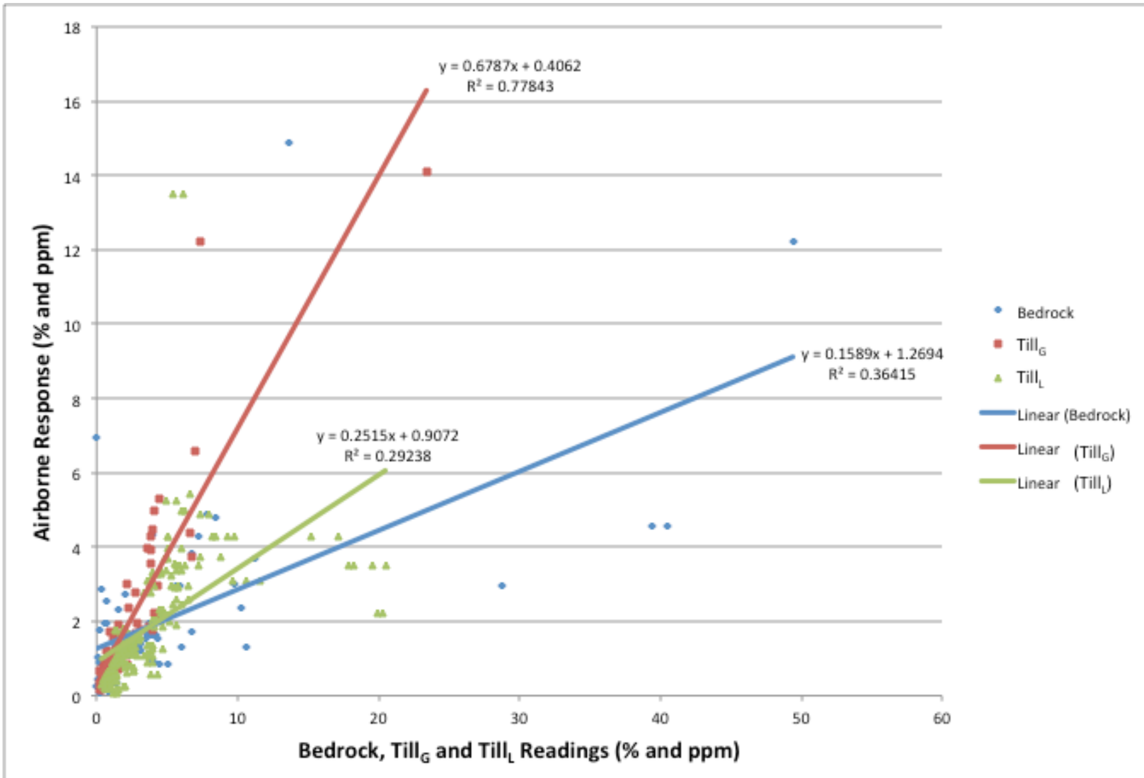

Figure 5.2: X-y scatter plot of hand held gamma-ray surface readings for bedrock (blue diamond), surface till (till$_g$) (red square), and lab till (till$_l$) (green triangle) versus airborne values at the same specific location. Line of best fit has also been included with the equation and R^2 values. The best fit line is the one between surface till and airborne response (red line).

Conclusions

Radiometric domains identified on the eastern side of the study area are most influenced by the underlying bedrock, while domains on the west are most influenced by thick till cover. These patterns were observed because of the higher elevation on the eastern side, where glacial deposits are thinner and there is more extensive bedrock outcrop. Thicker glacial sediment cover characterizes the western side of the study area masking the underlying bedrock sources of gamma-rays. These patterns are further confirmed by the streamlined northwest – southeast orientation of the western domains and the strong correlation in these areas between airborne and surface till gamma-ray signatures.

The correlations of the data sources can also be explained in a somewhat similar manner. The drift-covered bedrock and lab till samples are materials that are not readable from the airborne and handheld sensors. Thus, only the data for the surface till readings are correlative to the airborne response for the study area. These conclusions allow for increased accuracy in mineral exploration for the region. If anomalous airborne GRS surface signals were found in the eastern part of the study area, the source rock would be linked to underlying bedrock. The alternative is true for the western portion of the study area, with the signal originating from till transported from its bedrock source. Further research into the amalgamation of these different data sets would be beneficial, as this report only starts to fill the gap in understanding the interaction of all data sources.

Acknowledgements
Research was completed under the supervision of Professor Emmanuelle Arnaud (University of Guelph, School of Environmental Science), Roger Paulen and Richard Fortin (GSC). The research benefited from the field assistance of Beth McClenaghan (GSC) and Alain Lion (GSC summer student) during the 2015 field season, Jessey Rice (University of Waterloo) and Matt Pyne (GSC) during both the 2015 and 2016 field seasons, and Heather Campbell (Newfoundland and Labrador Geological Survey) for the 2016 field season. Additionally, Alain Rioux and Maxime Gauthier of Innukopters Inc. provided helicopter service, Clara Schattler and Gestion Porlier provided accommodation and meals, and Norpaq Aviation provided expediting services. This logistical support was greatly appreciated.

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Table 5.1: General characteristics of the radiometric domains identified in this study. Topography was classified based on elevation observations from the DEM: low lying 307-426 m, intermediate 426-546 m, and high 546- 666 m. Surficial geology is summarized from Rice et al. (see Chapter 2- this report).

Domain	Ternary Map Hue	Radioelement Average Values	Predominant Bedrock Unit	Elevation	Surficial Geology	Comments/Correlations
1	Blue	Potassium + uranium K (%) – 0.7 eU (ppm) – 0.5 eTh (ppm) – 1.9	Quartzofeldspathic Gneiss	Intermediate	Till veneer	• Small portion in NW corner of study area • Discriminated based on higher U content than surroundings • only airborne readings available
2	Purple/Blue	Potassium + uranium K (%) – 1 eU (ppm) – 0.3 eTh (ppm) – 2.3	Heterogeneous Orthogneiss + Charnockite	High	Till veneer, bedrock outcrop, meltwater channels and glaciofluvial deposits	• Largest domain covering the east side of study area • Based on higher K content throughout • Likely correlated to the bedrock sources exposed at high elevations
3	Red	Potassium + thorium K (%) – 1.3 eU (ppm) – 0.5 eTh (ppm) – 3.7	Heterogeneous Orthogneiss	High	Till veneer and bedrock outcrop	• Small domain located in the NE part of study area • Separated due to higher Th content compared to surrounding Domain 2 • Associated loosely with bedrock contact on east side of De Pas Batholith with orthogneiss contact
4	White/Purple	Low Response/potassium K (%) – 1.9 eU (ppm) – 0.2 eTh (ppm) – 1.2	Greywacke, Shale, Biotite Schist	Low	Till veneer, till blanket and organics	• Low response is likely related to the low-lying topography and surface water absorbing gamma rays • Thicker vegetation cover • Winnowed sediments
5	Green	Uranium + thorium K (%) – 0.6 eU (ppm) – 0.4 eTh (ppm) – 2.7	Quartzofeldspathic Gneiss	Low	Till veneer, bedrock outcrop and organics	• Located in NW part of study area • May have same bedrock source as Domain 7 and 9 because of • SE trending drumlinoid features present
6	Blue	Potassium + uranium K (%) – 0.8 eU (ppm) – 0.5 eTh (ppm) – 2.8	Quartzofeldspathic Gneiss	High	Till veneer and bedrock outcrop	• Thin domain that surrounds Domain 7 • Related to a topographic high that encompasses Domain 7 • Discriminated based on higher U response with some K • Boulder lag beach ridges present • Surficial sediments winnowed
7	Green	Uranium + thorium K (%) – 0.9 eU (ppm) – 1 eTh (ppm) - 6	Quartzofeldspathic Gneiss + Greywacke, Shale, Biotite Schist	Intermediate	Till veneer and till blanket	• Large strong homogeneous U and Th response • Possible correlation to Domain 5 and 9
8	White/Green /Purple	Low Response/potassium K (%) – 0.6 eU (ppm) – 0.3 eTh (ppm) - 2	Greywacke, Shale, Biotite Schist + Amphibolite with Metabasalt	High	Till veneer and till blanket	• Similar to Domain 4 with weak airborne response • Northern border follows contact of greywacke, shale, biotite schist and quartzofeldspathic gneiss
9	Green	Uranium + thorium K (%) – 0.8 eU (ppm) – 0.6 eTh (ppm) - 3.8	Greywacke, Shale, Biotite Schist	Low	Till blanket	• Similar composition to Domains 5 and 7 • Follows orientation of lake • Separated from surroundings based on strong U and Th response
10	Purple/Blue	Potassium + uranium K (%) – 0.9 eU (ppm) – 0.4 eTh (ppm) – 2.5	Greywacke, Shale, Biotite Schist	High	Till veneer and till blanket	• Similar composition to Domain 2, separated based on higher U contents • Follows a topographic high • Sediment cover gets thicker in western arm
11	Blue	Potassium + uranium K (%) – 0.8 eU (ppm) – 0.6 eTh (ppm) – 2.7	Greywacke, Shale, Biotite Schist	Intermediate	Till blanket	• Similar to Domain 12, differentiated based on higher K content
12	Cyan	Uranium K (%) – 0.8 eU (ppm) – 0.8 eTh (ppm) – 3.2	Greywacke, Shale, Biotite Schist	Intermediate	Till blankets and bedrock outcrop	• Located in SW part of the study area • Delineated based on high U only content