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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 investment in responsible 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 the summer of 2015, the GEM program has successfully carried out 14 research activities that include 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 collaborators as the program advances.

Summary

This activity report summarizes accomplishments of the GEM 2 Hudson-Ungava surficial activities focused on northeast Quebec and west central Labrador. These activities are 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 year's activity report published by McClenaghan et al. (2014). The study area is underlain by Precambrian rocks of the New Quebec Orogen and southern Core Zone. Surficial sediment and landforms include thin veneers of glacial sediment (till), thicker glacial deposits of ribbed and streamlined sediment, small esker systems, and glacial lake deposits in low lying areas.

The overall objective of these activities is to produce new regional geoscience data including surficial geology, and geochemistry and radiometric maps to support natural resource exploration and responsible resource development in the Hudson-Ungava region. Activities include surficial and bedrock mapping, till geochemistry and indicator mineralogy, lake sediment geochemistry, geochemical database management and gamma ray spectrometry studies.

Surficial mapping led to an improved understanding of the surficial and bedrock geology of the study area and identification of key areas for more focused mapping and sampling in subsequent field seasons. Laboratory work led to improved sample processing and examination techniques for till samples. Data management has facilitated web access to GEM 1 and GEM 2 publications and data.

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Chapter 1 Project overview

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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 flow 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.

An activity report summarizing field and laboratory activities in the first year of the project was published in 2014 (McClenaghan et al., 2014). This open file is the second activity report for the project and focuses on activities for 2015. Bedrock mapping and geochronology activities in 2015 for the south Core Zone are summarized in Sanborn-Barrie et al. (2015).

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 overall objective of the south Core Zone activities is to produce new regional geoscience data and knowledge to support natural resource exploration and responsible resource development. To this end, specific goals and objectives include:

- Document 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;

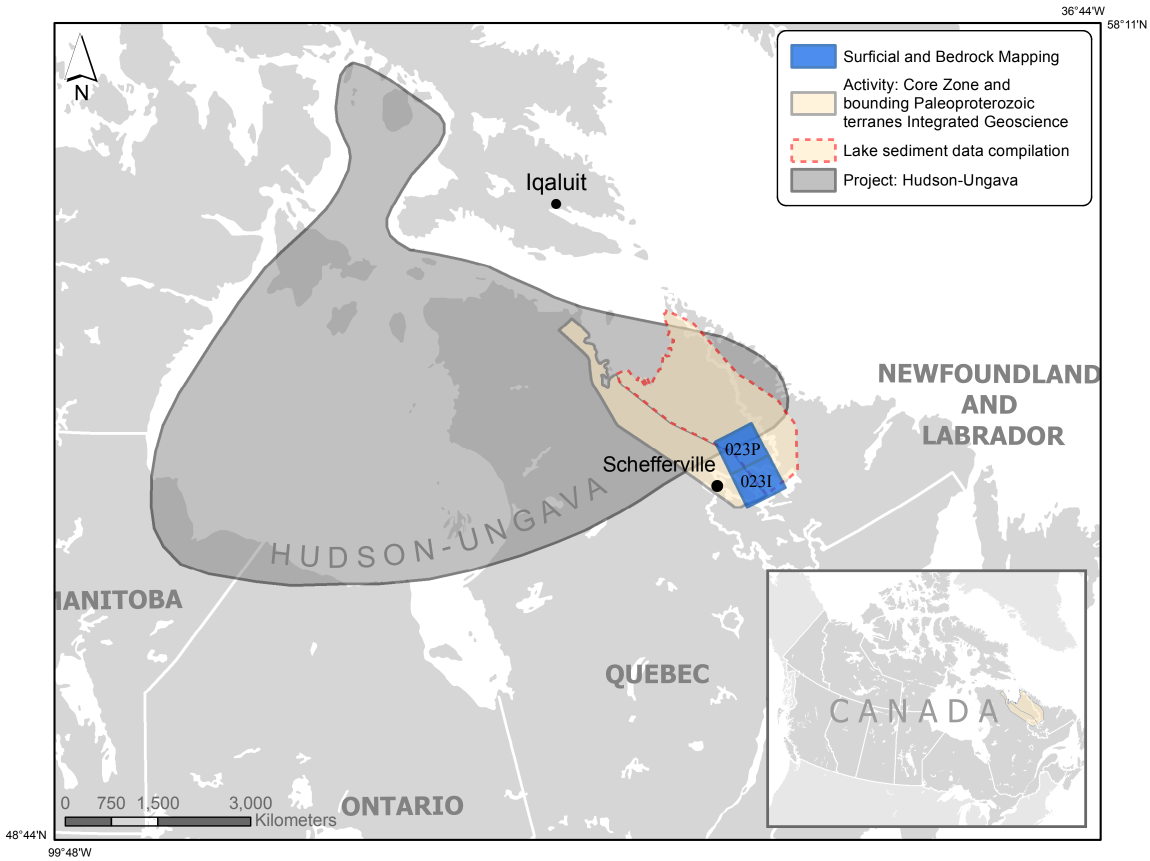

Figure 1.1. Location of the Core Zone and bounding orogens integrated bedrock studies area (beige polygon), south Core Zone surficial and bedrock mapping area (blue box), and the Core Zone lake sediment geochemical data compilation area (red dashed line) within the Hudson-Ungava GEM 2 project area (grey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

Geochemical data and metadata from GEM and other surveys are being stored in the Canadian Database of Geochemical Surveys (CDoGS) (Adcock et al. 2013). The public interface to CDoGS can be found at http://geochem.nrcan.gc.ca. Raw data from several recently published GEM 1 geochemical surveys north of 60° have been imported into the database to complement metadata previously loaded data for all major geochemical surveys carried out under GEM 1.

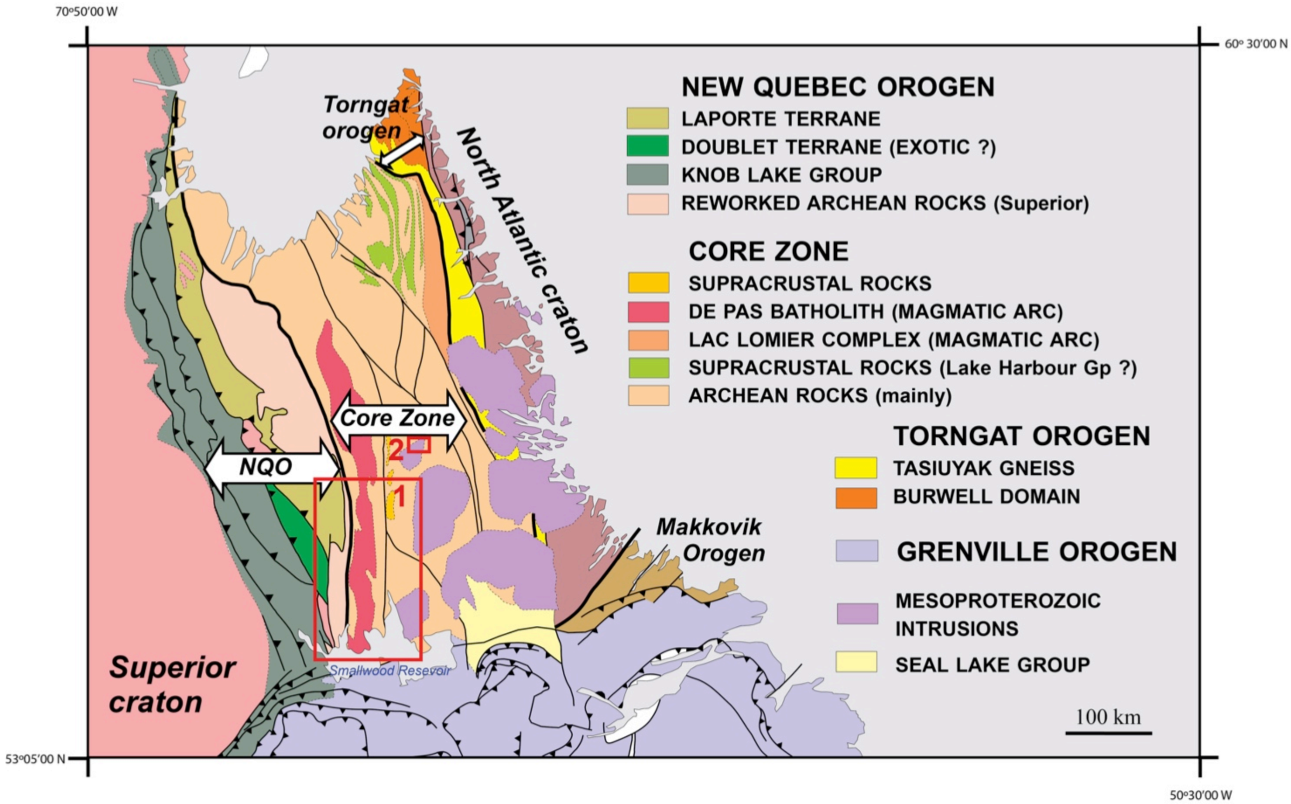

Figure 1.2. Simplified bedrock geological map of the Core Zone and bounding orogens. Boxes show areas visited this summer: 1) south Core Zone surficial mapping; 2) Strange Lake area, Modified after James et al. (2003).

Raw data from 23 legacy GSC lake sediment surveys in Labrador have been imported to benefit current GEM 2 work in that region. For all surveys, the website provides links to spreadsheets and KML maps allowing the user to download the data or view it in Google Earth™. Figure 1.3 shows Zn content in lake sediment data for samples collected in NTS 23G, H, I and J.

Metadata from surveys carried out by the GSC and the Quebec (MERNQ) and Labrador (DNR-NL) provincial geological surveys in the Core Zone and surrounding area have been compiled and will be added to the database. Work will continue to focus on adding more surveys and standardizing the raw data for viewing in Google Earth™. Priority will be given to new survey data for the Hudson-Ungava Core Zone project, as they become available.

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 and Lila Chebab.

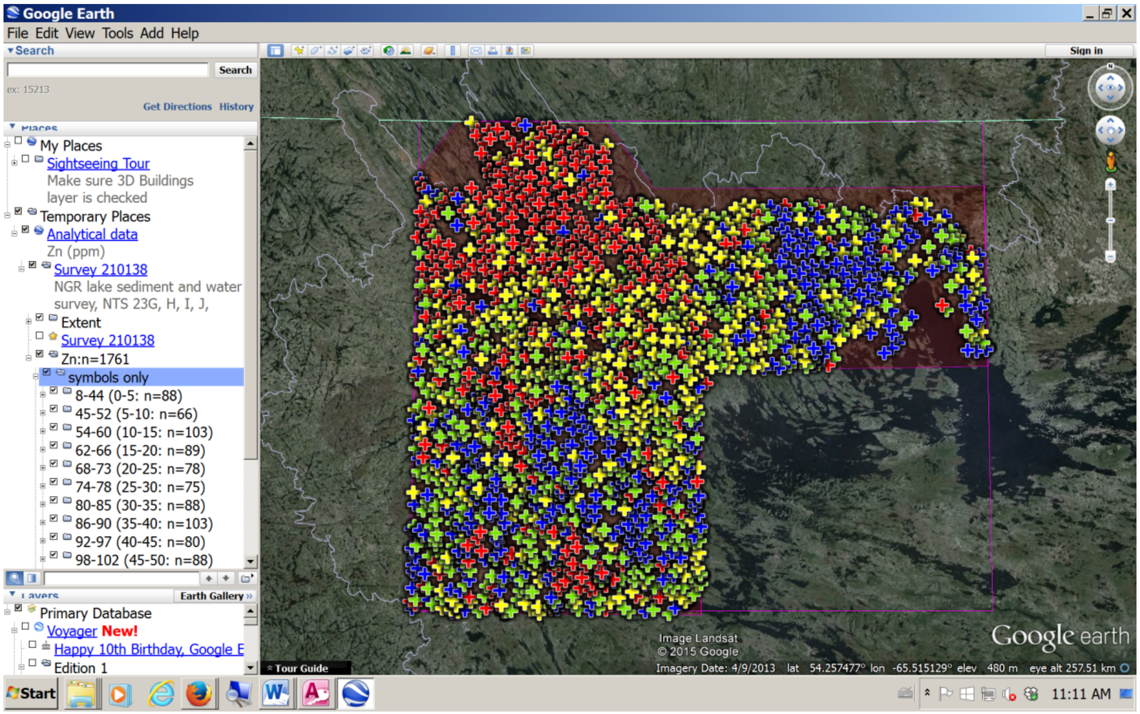

Figure 1.3. Zinc concentration (ppm) in 1761 lake sediments from a GSC survey in Labrador. Zn values are classified by quartile: red crosses indicate highest values, blue lowest.

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Chapter 2 Surficial Mapping

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Introduction

Surficial geological mapping was undertaken during the summer of 2015 as a continuation of the reconnaissance fieldwork conducted in 2014 as part of the GEM 2 Hudson Ungava Core Zone surficial mapping activity. This activity focuses on the composition and properties of surficial sediments located in northern Quebec and Labrador within NTS map sheets 23I and 23P within the Hudson-Ungava region (Fig. 2.1). This report describes the surficial mapping methods and preliminary results from summer 2014 and 2015 for the Woods Lake (NTS 23I) and Lac Résolution (NTS 23P) map areas.

Methodology

Previous fieldwork (McClenaghan et al., 2014) had identified regions of complex ice-flow chronologies, variations in the intensity of glacial erosion, and a multitude of surficial deposit types throughout the region. Glacial sediment samples (i.e., till) were collected with a spacing of approximately 10 to 15 km, depending on the bedrock geology. In regions of prospective bedrock, a tighter sample density was employed. In the northern regions, and at higher elevations, fresh mud-boils were targeted for sample collection at a depth below ~0.2 m, following GSC till sampling protocols outlined by Spirito et al. (2011) and McClenaghan et al. (2013). Outside of regions containing discontinuous permafrost, till samples were collected by digging below the oxidized soil profiles and within the C-horizon. Great care was taken in limiting cross-contamination between sites, including cleaning shovels between sites, and double bagging saturated samples to ensure fines were not lost through desaturation of the sample initiated through vibration from helicopter transport. Specific care was taken to not include any surface organics or surrounding soil horizons and general quality assurance and quality control guidelines outlined by Plouffe et al. (2013) were followed for the processing of samples for indicator mineral study. The majority of the sample sites are located in upland clearings where helicopter landings were practical and safe. For logistical reasons, sample collection in 2015 focused on the northeast portion of NTS 23I and the entire eastern and northern portion of 23P.

At each site two samples were collected: a 10-15 kg sample for indicator mineral analysis; and, a ~3 kg sample for geochemical analysis, textural determinations, Munsell colour determination, and archiving. Where possible, paleo-ice-flow indicators such as striae, glacial-grooves, and other features were measured to assist in determining ice-flow movements and chronologies. Several stations initially visited by previous workers (e.g., Klassen and Thompson, 1990), were also revisited for detailed examination and interpretation.

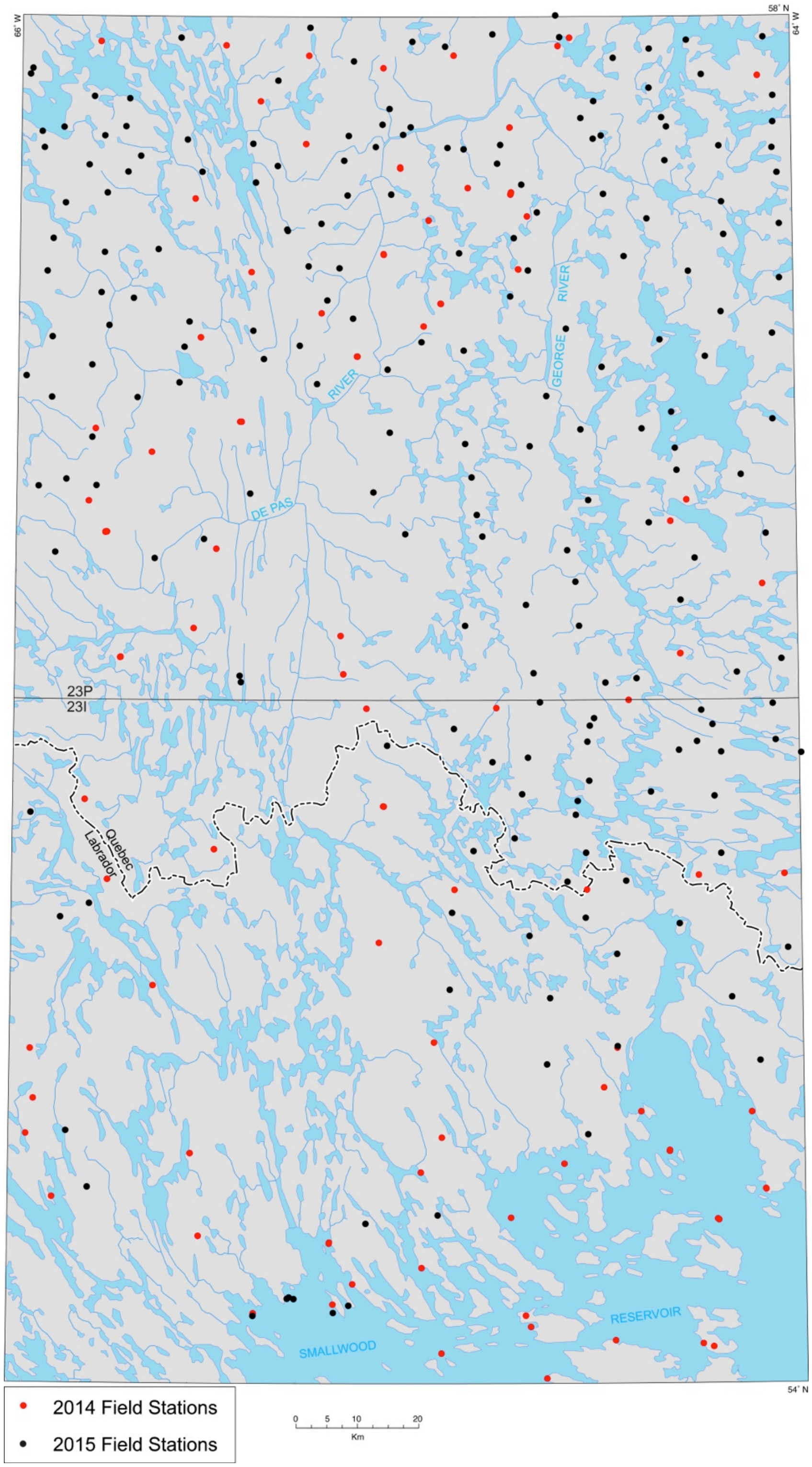

Figure 2.1. Study area with 2014 and 2015 field stations. The study area extends over the Woods Lake (NTS 23I) and Lac Résolution (NTS 23P) map sheets, straddling the Quebec-Labrador border.

Samples of bedrock, boulders and glacial sediments were collected for ^{10}Be cosmogenic analysis to determine age and inheritance to aid in the chronological constraints of the ice flow history and to evaluate the erosional vigour and dispersal of the ice flows (cf., Staiger et al., 2006). These samples were collected along a general east to west transect across the northern portion of NTS map 23P. Optical Stimulated Luminescence (OSL) samples of glaciolacustrine littoral sediments were also collected in the northeast portion of NTS map 23P to better constrain the timing of the earliest phases of glacial Lake Naskaupi, which inundated the northern half of the study area during deglaciation.

Results

Field observations related to surficial geology mapping and ice-flow indicators were made at 204 sites during the 2015 survey (Fig. 2.1), 144 of which were in NTS sheet 23P and the additional 60 sites in NTS map 23I. A total of 137 till samples were collected for heavy mineral analysis, 153 samples were collected for matrix geochemical analysis, five for cosmogenic analysis, and three for OSL dating. Additionally, 109 sites with paleo ice-flow indicators were recorded across the study area indicating a complex sequence of ice-flow trajectories, including an ice-flow reversal in the north-central region of NTS map 23P (Fig. 2.2).

A variety of surficial deposits and landforms were observed during the course of field work. The northern portion of 23P has highland clearings with till veneers, commonly with perched erratics, draped by till blankets infilling the valleys. Three glacial lakes inundated the map area during the retreat of the Laurentide Ice Sheet (LIS): glacial Lake Smallwood in the southeast part of 23I; glacial Lake McLean in the northwest part of 23P; and a larger glacial Lake Naskaupi in the northeast part of 23P (Jansson, 2003). The regions inundated by these glacial lakes are characterized by winnowed till deposits, washed bedrock surfaces, and littoral beach sediments. Meltwater erosion, transport and deposition, including erosion of lateral meltwater channels and deposition of outwash deposits occurred during the downwasting of the LIS. These glaciofluvial landforms and deposits are concentrated in the northern and northeastern portion of the study area. Eskers are found radially along the southern and eastern edges of the map area. Ice-flow indicators show evidence of a complete reversal of ice movement trajectory in the northeastern portion of map sheet (23 I or P), where striations and small-scale landforms show a complete change in ice flow from the west toward the east around the north-central part of the study area, which is underlain by the DePas batholith bedrock (McClenaghan et al., 2014).

Discussion and future work

The landscape of the Woods Lake and Lac Résolution region is the product of a complex glacial history, with multiple ice-flow trajectories and evidence of an ice-flow reversal. No evidence of long-term cold-based glaciation was observed, indicating that all areas were subjected to warm-based glacial flow and erosion at some time during the Quaternary. That observation, however, does not eliminate the possibility of a transition from warm-based flow to cold-based flow during the Wisconsin, which could form relict terrain (c.f., Kleman et al., 1994; Kleman and Hattestrand, 1999), as the Hudson Ice Divide of the Laurentide Ice Sheet occupied part of the study area. Future fieldwork, particularly in the southwest portion of NTS Sheet 23P, and sampling will help decipher the complex glacial history of the region.

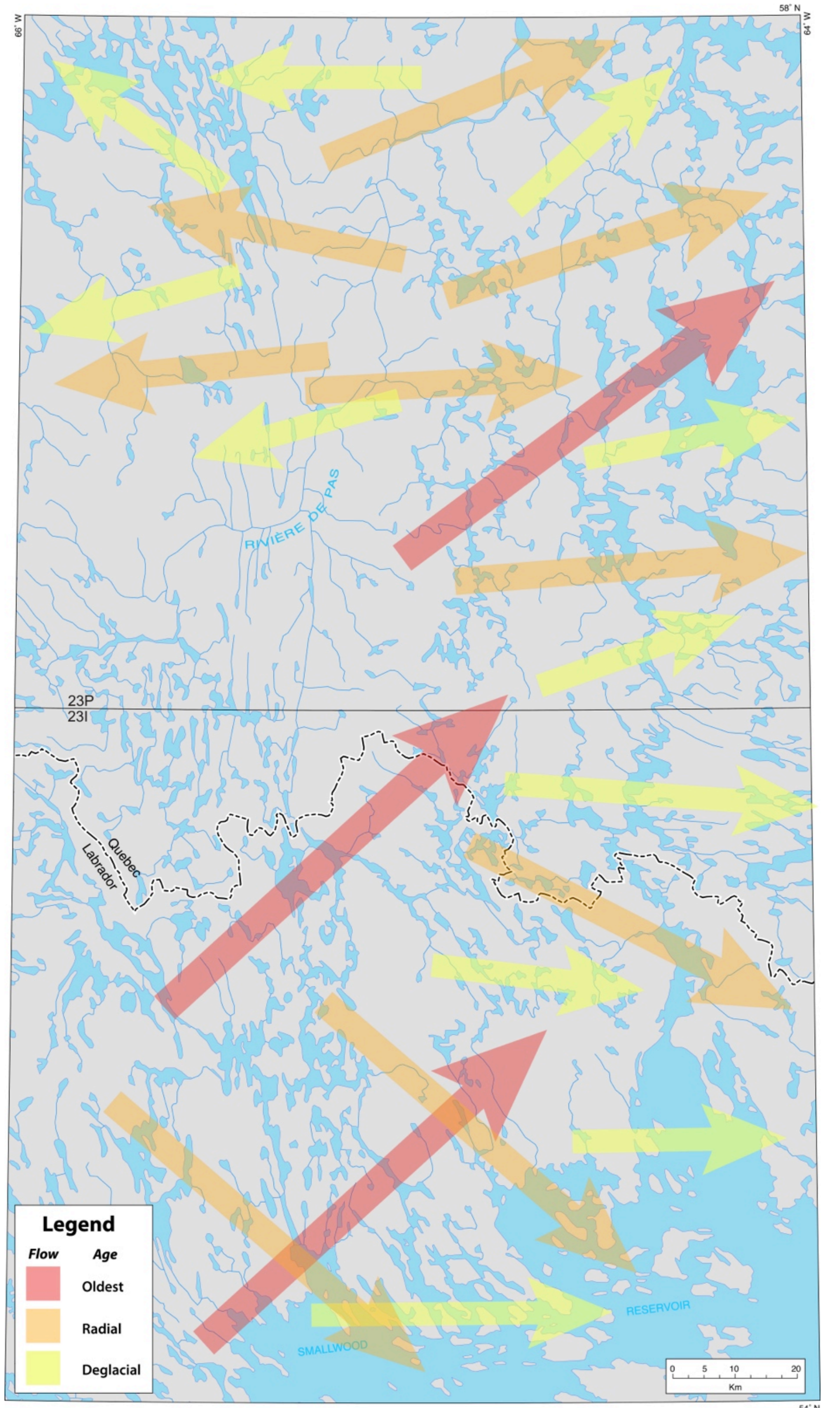

Figure 2.2. Generalized ice-flow chronology in the study area. Red arrows indicate the oldest flow seen in the region, and was likely from the Quebec highlands (cf., Veillette et al., 1999). Orange arrows indicate radial flow from the Labrador ice centre during the main Wisconsin phase of the LIS. Yellow arrows show radial flow from ice centre during deglaciation.

Fieldwork in support of surficial mapping will continue in the summers of 2016, with the objective of producing surficial geology maps at 1:100,000 scale. The first map, 23I/SE is targeted for completion in late 2015.

Acknowledgements

The surficial mapping activity is part of the GEM2 Hudson – Ungava Project, under the scientific leadership of David Corrigan with GSC management support from Rejean Couture and Lila Chebab. This activity is conducted in collaboration with the MERNQ in Val d'Or. This research benefitted from the support of the Polar Continental Shelf Program. We are especially thankful to Mary Sanborn-Barrie (GSC Ottawa) for her background knowledge and insight into the bedrock geology of the study area, and her enthusiastic assistance in the field. Norpaq Aviation provided excellent and professional expediting service. Financial assistance, as part of J. Rice's PhD thesis, was also provided through the Northern Scientific Training Program on behalf of the Canadian Polar Commission. Surficial geological input and satellite imagery was provided by Hugo Dubé-Loubert and Virginie Daubois (MERNQ). Surficial mapping was supported by the Polar Continental Shelf Program. Alain Plouffe (GSC) is thanked for his review of this open file.

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Chapter 3 Lake Sediment Geochemistry

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Introduction

At the outset of this activity it was determined that lake sediment geochemical data sets for areas of Labrador within the Labrador Trough and adjacent Core Zone available from the Newfoundland and Labrador government were not compatible with data for adjacent areas in Quebec. In order to produce seamless geochemical element concentration maps for exploration throughout the study area spanning northwest Labrador and northeast Quebec (Fig. 3.1), aliquots of Labrador lake sediment from archived samples in Ottawa and St. John's were sent to a commercial laboratory for reanalysis using a modified aqua regia digestion similar to that employed by Quebec.

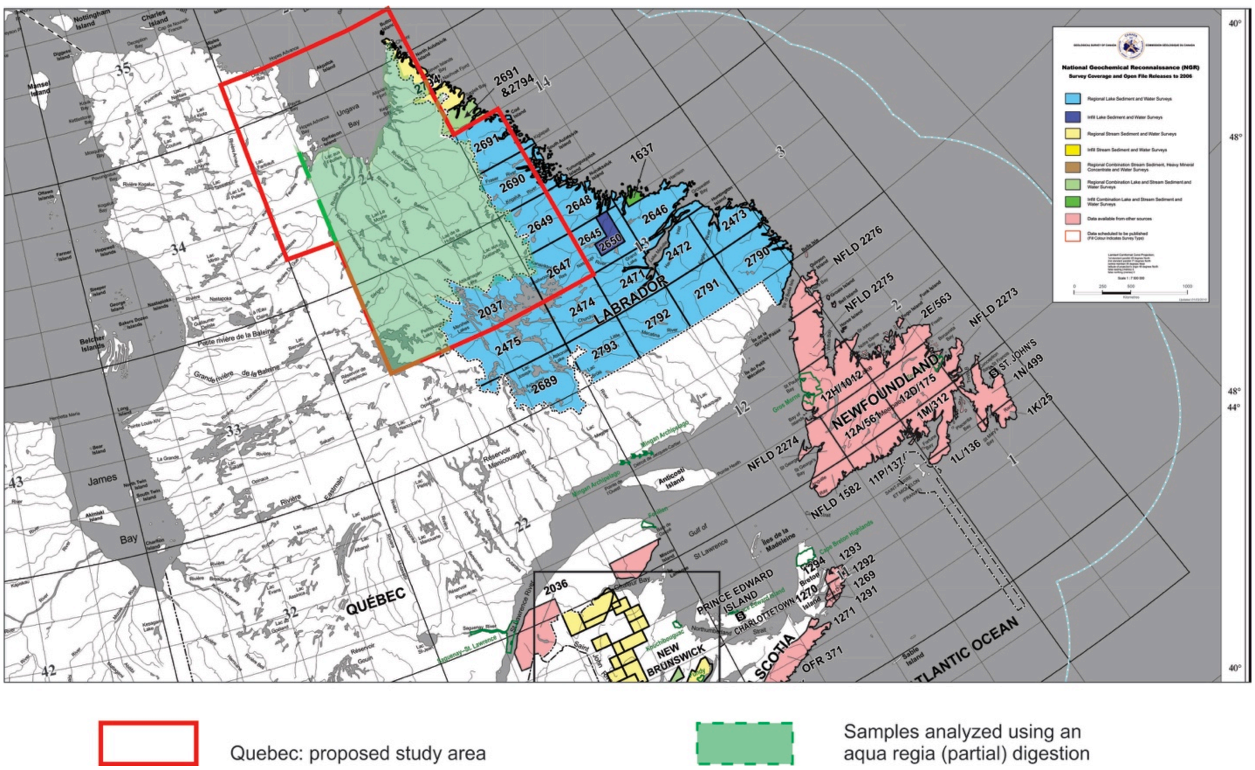

Figure 3.1. Areas of Labrador (blue) within the study area (red line) from which archived lake sediment samples are being reanalyzed by GSC in order to produce an internally consistent database for the entire study area.

Methodology

A subset of 2,484 samples from the GSC Collections at Tunney's Pasture, Ottawa was prepared for analysis and submitted to a commercial laboratory. The lake sediment samples were analyzed for 65 elements by aqua regia/ICP-MS. Geochemical data for lake sediments received from the commercial laboratory were evaluated for analytical accuracy and precision with standard and duplicate samples.

The Geological Survey of Newfoundland and Labrador provided 1 g aliquots for re-analysis from 4,166 of archived GSC samples in their collection stored in St. John's. These samples are being analyzed using the same analytical methods as the GSC samples described above - 65 elements by aqua regia/ICP-MS.

Results

Copper data for 2,484 Labrador lake sediment samples re-analyzed as part of this GEM 2 project and 26,727 Quebec lake sediment samples were contoured separately using the Inverse Distance Weighting (IDW) algorithm in Esri® Arcmap™ 10.1 and plotted to check for visual boundary effects (Fig. 3.2). None were noted.

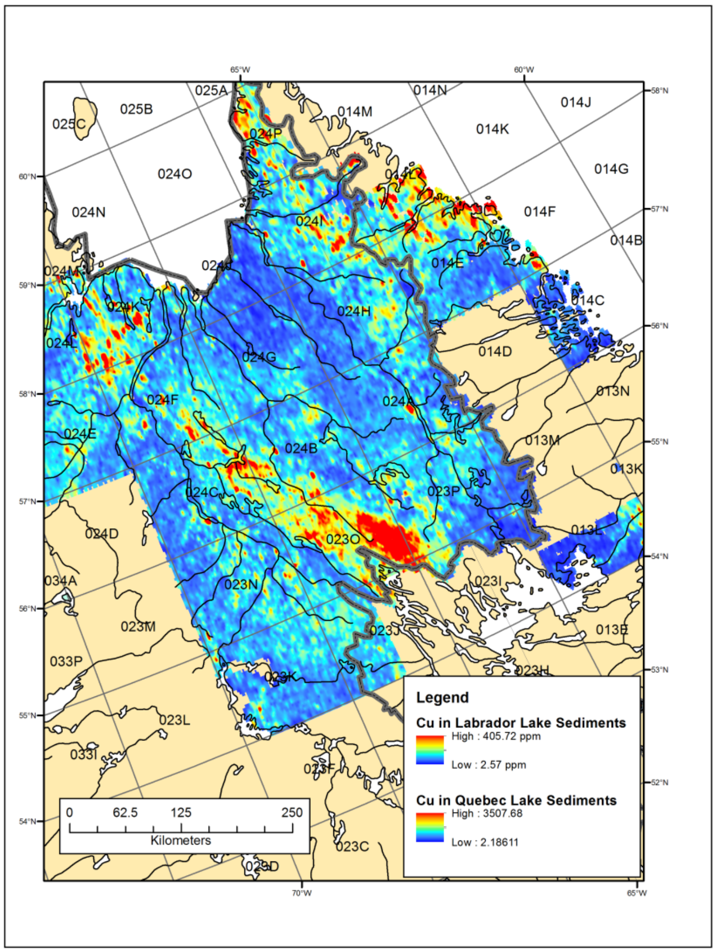

Figure 3.2. Copper concentration in lake sediments for Labrador and Quebec separately plotted as contoured grids to check for boundary effects. Note that there is no visible boundary effect along the border between Quebec and Labrador. The region with elevate copper concentrations (red) in the south-central part of the study area corresponds to the Labrador Trough.

Conclusions
Results from the graphic comparison of copper data from Quebec and Labrador lake sediment samples suggest that the two data sets are compatible and can be used to create geochemical element concentration maps for the entire study area.

Future Work/Next Steps
Geochemical data from aliquots of 4,166 samples held in St. John's are currently being analyzed at a commercial laboratory (Bureau Veritas, formerly Acme Analytical Labs) in Vancouver. When these data are received and checked for accuracy and precision, they will be integrated with the Labrador data already received and compared with the Quebec data set. Assuming a satisfactory comparison by statistical and graphic methods, the two sets of data will be integrated and used to produce seamless element concentration maps for the study area. An open file will be released that will include methods, site data and quality control data.

Acknowledgements
We wish to thank Guillaume Allard, Ministère de l'Énergie et des Ressources Naturelles du Québec, for providing Quebec lake sediment geochemical data and Martin Batterson, Steve Amor, and Chris Finch, Newfoundland and Labrador Geological Survey, for their help obtaining sample materials for re-analysis.

Chapter 4 Gamma-ray spectrometry studies

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Introduction

In recent years, new airborne magnetic and gamma-ray spectrometry coverage of the Core Zone and Labrador Trough areas of northern Quebec has been completed by Géologie Québec with contributions from the GSC, through the GEM program. Airborne gamma-ray spectrometry (AGRS) provides unique and spatially continuous compositional information about surface materials that can be used in various aspects of regional mapping and resource exploration. However, AGRS end-products appear to be only partially utilized during the data integration and interpretation phases of mapping and exploration projects. In order to promote its usage as part of exploration programs in northern Quebec, the significance of AGRS end-products need to be documented in the specific context of the Core Zone and Labrador Trough areas. The specific goal of this activity is therefore to develop an interpretation methodology for airborne gamma-ray spectrometry data for the central Core Zone area. This objective will be achieved by 1) providing case studies for NTS sheets 21I and 23P, to complement surficial mapping activities and indicator minerals studies, and 2) presenting a re-analysis of the GSC's East and West Schefferville airborne surveys of 2009 with an emphasis on discriminating U and Th concentrations anomalies. This new knowledge will support natural resource exploration and responsible resource development by contributing in refined bedrock and surficial geology mapping and by helping to resolve potential geochemical anomalies related to mineral deposits.

Methodology

Airborne gamma-ray spectrometry measurements provide the surface concentrations of Potassium (K), Uranium (U) and Thorium (Th) and are usually presented as maps of their distributions. The physical context and geochemical processes at the surface and the inherent statistical noise of radioactive decay result in a complex spatial distribution. The approach that will be taken here is to reduce the complexity of this spatial distribution for the study areas into a set of *radiometric domains* (Campbell et al., 2007, Fortin et al., 2014). A radiometric domain is heuristically defined as an area of finite extent that presents a distinctive radiometric signature. The objective of domain tracing is then to classify surface features and enhance the readability of gamma-ray spectrometry maps for end-users.

For the selected study areas, NTS 23I and 23P, this exercise of image segmentation will be conducted on the available AGRS imagery. The consistency of the domain tracing process will then be validated in two ways. First, measurements within a given domain should present a Poisson distribution in order to reflect the law of radioactive decay. With this mathematical condition verified, it should also be confirmed secondly, that the variability observed from domain to domain in the airborne data corresponds to a similar geophysical variability in ground level measurements. Therefore, radiometric domains will be ground-truthed by handheld gamma-ray spectrometry to verify the quantitative differences between airborne and ground measurements. Ground gamma-ray spectrometry will be conducted at locations selected to match defined domains and where surficial mapping activities are taking place in order to optimize the productivity of field operations. Till samples collected in 2015 will also be analyzed at the

GSC’s gamma-ray spectrometry laboratory to provide volume concentrations in till of K, U and Th.

A combination of spectrometry measurements, concurrent surficial and bedrock geology field observations, till geochemistry, and indicator mineral analysis will provide a detailed characterization of the geological and radiation environment at each location, and allow for interpretation of linkages to bedrock and surface geology. In turn, this new knowledge could potentially feed back into mapping activities and provide complementary information to the map compilation processes.

The radiometric domains provide local baselines against which readings can be identified as anomalous or else, will define the minimum detectable strength of an expected target. A review of selected mineral deposit types occurring in the area will be conducted in terms of related surface geochemical anomalies, and the implications for ground or airborne detection by gamma-ray spectrometry will be considered.

Results

A compilation of airborne gamma-ray spectrometry data was completed for NTS sheets 23I and 23P using the Schefferville East and Schefferville West surveys from the GSC and the Romanet and George Sud surveys from Géologie Québec. Ternary images were produced where each radioelement concentration is represented by the value of a primary color (Potassium by magenta, Uranium by cyan and Thorium by yellow), and the composite colour mapped is indicative of the relative and absolute concentrations of that radioelement by the colour hue and saturation, respectively (Figure 4.1). Preliminary radiometric domains were traced by a visual inspection of the ternary images to plan locations for targeted ground truthing.

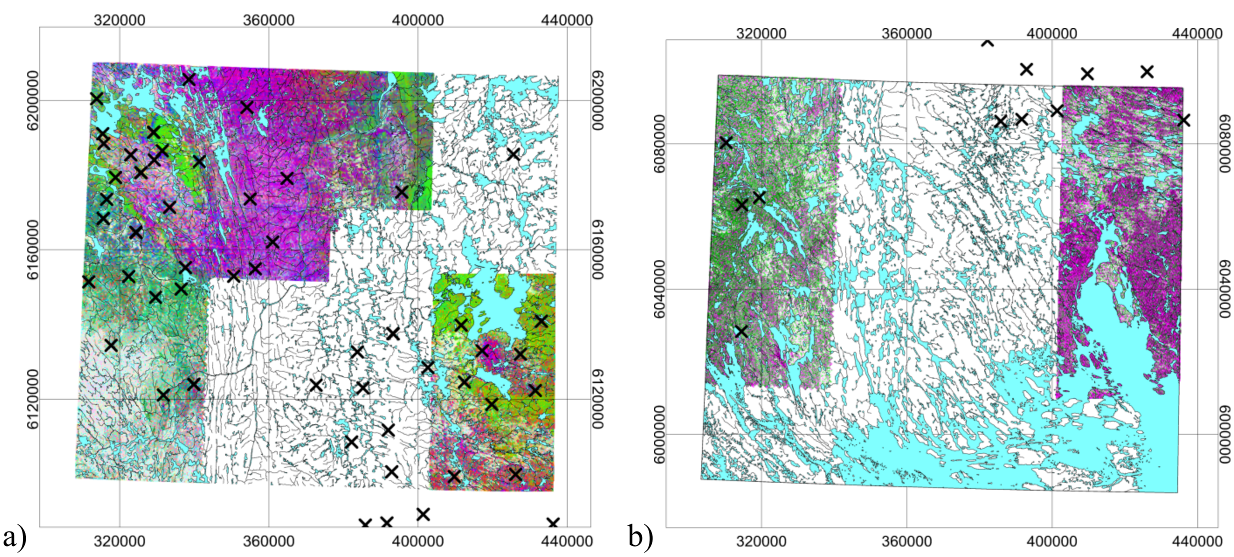

Figure 4.1. Gamma-ray spectrometry ternary images for NTS sheet a) 23I and b) 23P. Coordinates are in NAD83 UTM Zone 20. Black X symbol indicate locations of ground truthing measurements.

During the summer of 2015, field stations were visited and ground gamma-ray spectrometry was collected on bedrock outcrops and/or till substrate. For completeness, spectrometry data was also collected at till sampling sites, outside of airborne radiometric coverage, that were visited for surficial mapping activities. A total of 101 ground spectrometry measurements were acquired. A selected subset of the till samples collected at these sites will also be prepared for analysis at the GSC's gamma-ray laboratory.

Conclusions

A comprehensive database of airborne and ground gamma-ray spectrometry measurements, and upcoming till geochemistry and volumetric radioelements concentrations, has been assembled and will further the development of an interpretation methodology for airborne gamma-ray spectrometry maps in NTS 23P and 23I.

Future works/next steps

Data integration and analysis is ongoing and will reach two goals. First, from the preliminary tracing, final radiometric domains will be defined for NTS 23I and 23P. Then, linkages with bedrock and surficial geology will be investigated. Work on re-processing of the East and West Schefferville surveys will begin when final radiometric domains are defined, as this information will be used a priori for this process.

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