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R.C. Paulen, I.R. Smith, S.J.A. Day, G.W. Hagedorn, R.D. King and M.D. Pyne

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GEM2 Southern Mackenzie Surficial Activity 2017 report of activities: surficial geology and heavy mineral studies in southern Northwest Territories

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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 the 2017 field season, 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.

Activity Summary

This report summarizes accomplishments of the Southern Mackenzie Surficial activity that is focused in the southern Northwest Territories. This research is being carried out in collaboration with the Northwest Territories Geological Survey, the University of Waterloo and Memorial University. The report outlines field methods and field observations regarding the regional surficial geology and reconstruction of glacial history based on detailed mapping of palaeo ice-flow indicators and stratigraphy. It also discusses regional multi-media heavy mineral sampling transects that are being used to better understand long-distance glacial dispersal of indicator minerals and to potentially delimitate regions of previously unknown mineralization in the Paleozoic platform of the Western Canada Sedimentary Basin.

The overall objective of this research activity is to produce new regional geoscience data including surficial geology, geochemistry and indicator mineral maps to support natural resource exploration and responsible resource development in the southern Mackenzie corridor. Fieldwork in 2017 builds upon earlier research conducted by the Northwest Territories Geological Survey (Watson, 2011a; Watson, 2011b) and by the Geological Survey of Canada in GEM-1 (Oviatt et al., 2015; McClenaghan et al., in press). Field research in 2017 led to an improved understanding of the regional surficial geology of the study area and identified key areas for more focused mapping and sampling in subsequent field seasons.

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Matt Pyne: GIS and data management matt.pyne@canada.ca

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Chapter 1 Project Overview

Roger C. Paulen and I. Rod Smith

Introduction

Understanding of the Quaternary geological framework is essential to the exploration success in glaciated, drift-covered terrain. Surficial mapping, targeted surficial geology studies, and till and stream sediment sampling for geochemistry and heavy mineral indicators were initiated in 2017 between 114°W longitude near Fort Resolution to 124°W longitude, east of the Liard River, and from 60°N latitude along the Northwest Territories – Alberta provincial border to 62°N latitude. This region encompasses an area bordering western Great Slave Lake. This field activity was conducted as part of the Southern Mackenzie Surficial Activity, in the GEM-2 Mackenzie Project area (Figure 1.1). This activity was targeted as a region with no prior surficial geology maps and is, in part, a follow-up to GEM-1 Quaternary research in the Pine Point region conducted in 2010-2011 which successfully defined indicator mineral methods that are suitable for Mississippi Valley-type (MVT) Pb-Zn exploration and documented multiple phases of ice flow that impacted the southern Great Slave Lake region (Rice et al., 2013; Oviatt et al., 2015; McClenaghan et al, in press).

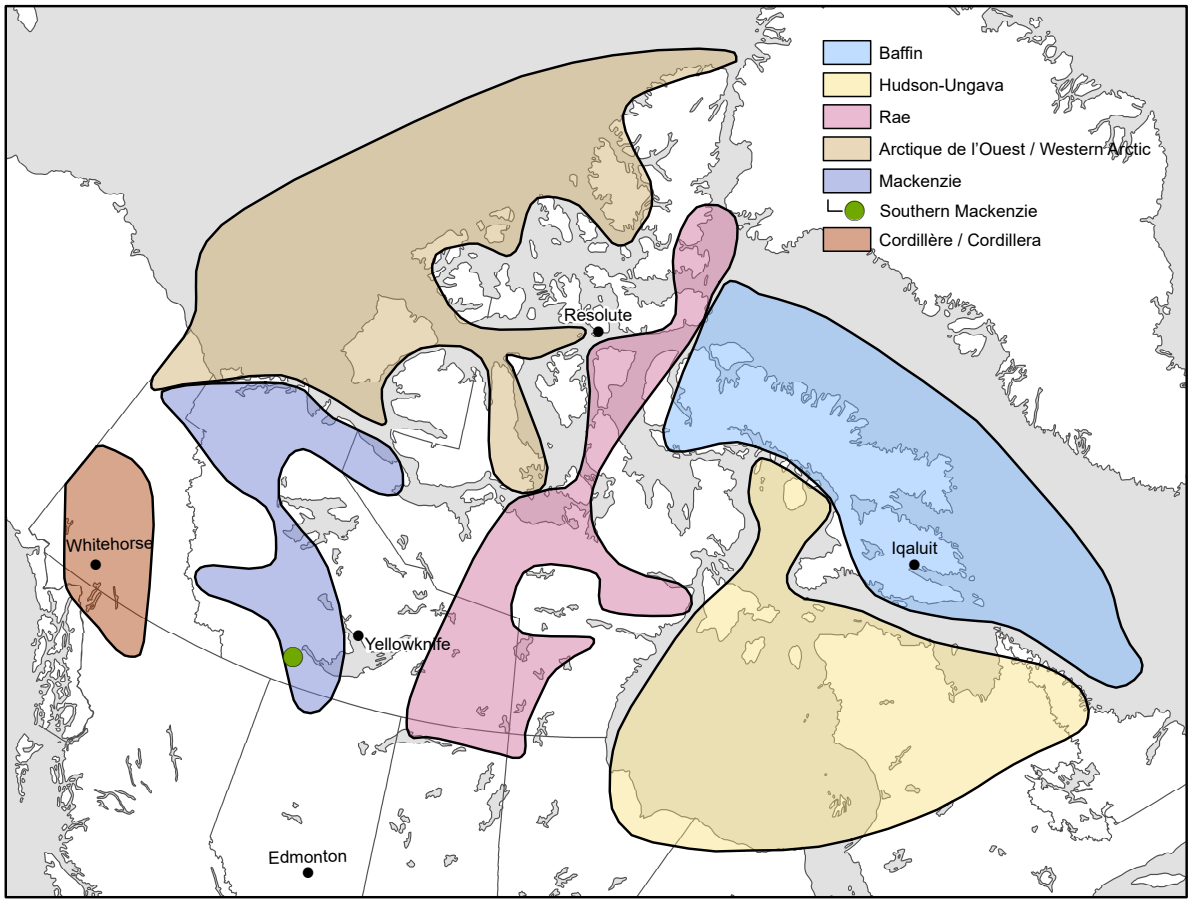

Figure 1.1. Location of the Mackenzie Project area in northwest Canada (purple polygon) and Southern Mackenzie Surficial Activity field location, represented by the green dot.

Rationale and background

Research conducted during a Geological Survey of Canada (GSC) Targeted Geoscience Initiative (TGI) project investigating the potential for MVT mineralization in northern Alberta and the Great Slave Plain of southern Northwest Territories (Hannigan, 2006a) produced a mineral prospectivity map showing MVT mineralization potential in the carbonate platform in the southwest Great Slave Lake region (Figure 1.2; Hannigan, 2006b).

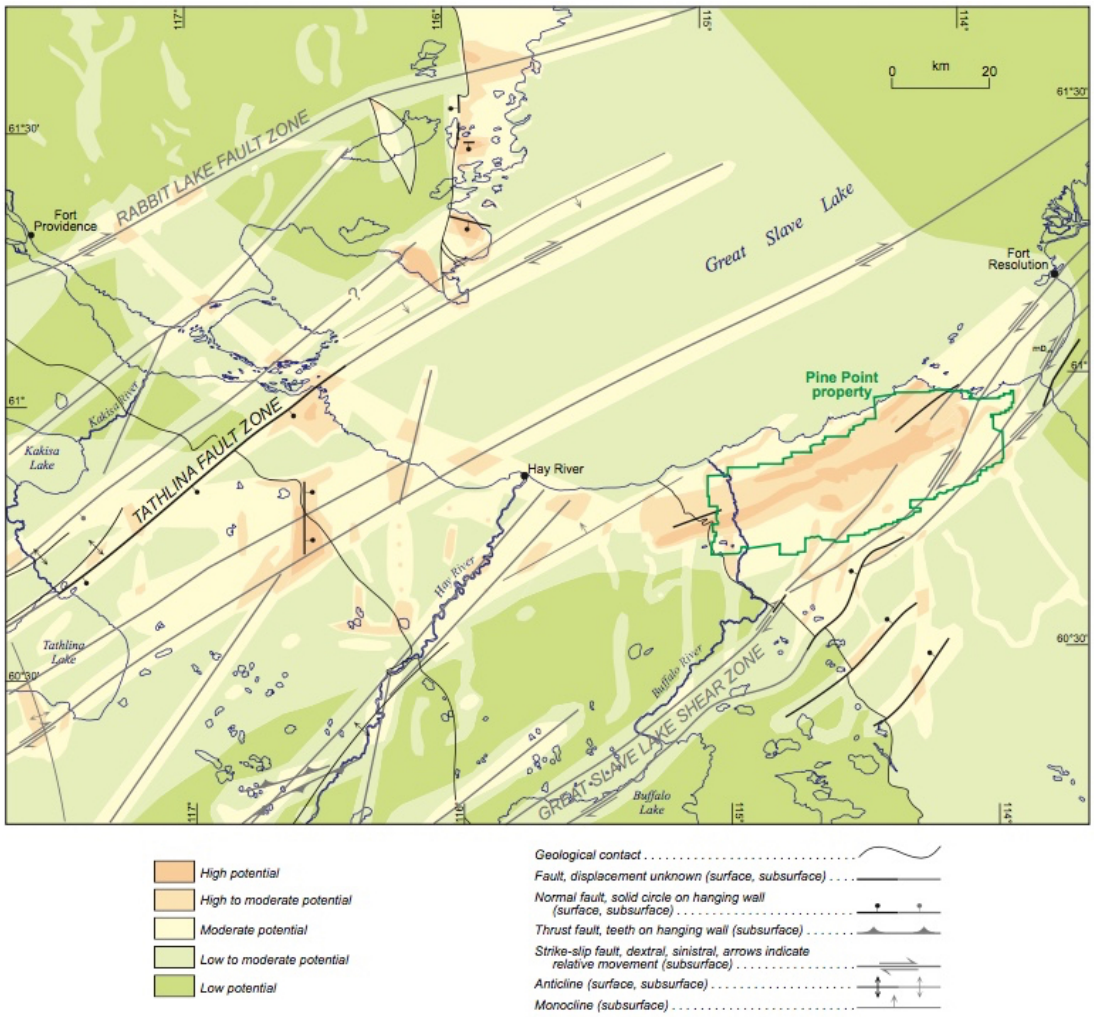

Figure 1.2. Mineral prospectivity map of the Pine Point district, with ratings for the potential to host MVT mineralization (from Hannigan, 2006b, p. 339).

Concurrent to Hannigans's investigations, atwo-year reconnaissance-scale stream and glacial sediment sampling project, funded by Geoscience BC and the GSC in northeast British Columbia published elevated values of Pb and Zn in till and stream sediment samples collected in the northeast corner of their study area (McCurdy et al., 2007), adjacent to the Northwest Territories and Alberta borders (Figure 1.3). The GSC, under the Northern Resource Development Program (2003-2007) and the Alberta Geological Survey also funded a surficial mapping and reconnaissance-scale till sampling program in northwest Alberta that led to the discovery of a large sphalerite dispersal train (Plouffe et al., 2006; Paulen et al., 2011) in the Zama Lake

lowlands (Figure 1.4). Historically, the Cretaceous sedimentary rocks of the Western Canada Sedimentary Basin, renowned for their hydrocarbon resources, have seldom been considered to have potential to host base metal mineralization (MacQueen, 1997).

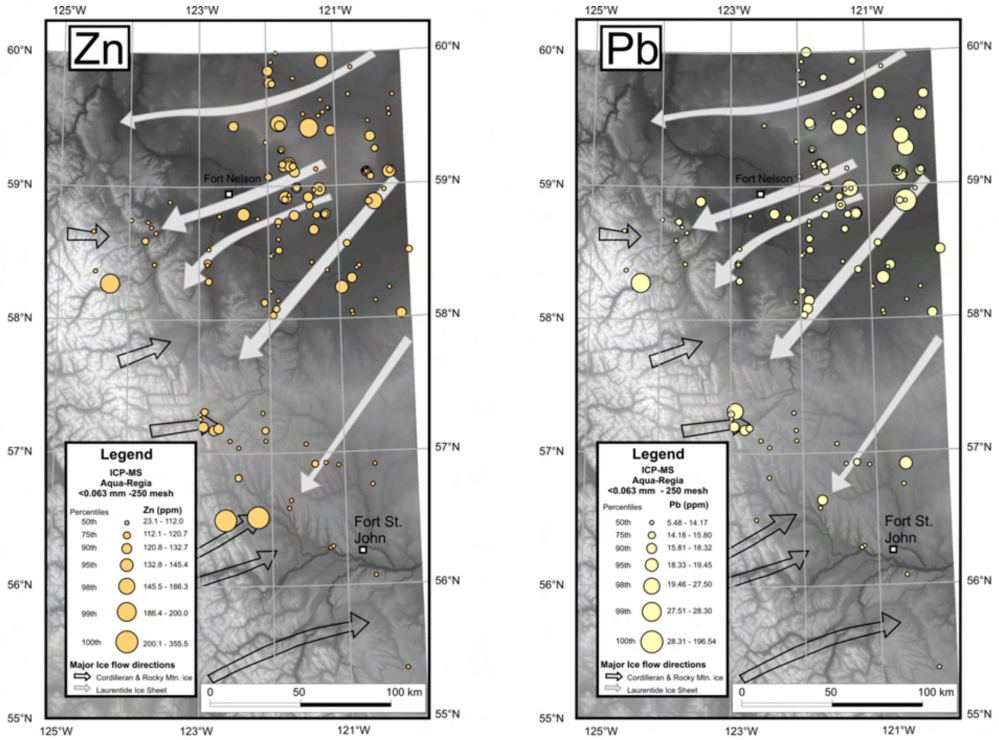

Figure 1.3. Zinc (Zn) and lead (Pb) concentrations in the silt and clay-sized fraction (–250 mesh, <0.063 mm) of till in northeast British Columbia, as measured by inductively coupled plasma mass spectrometry (ICP-MS) with aqua regia digestion. The light arrows indicate ice-flow trajectories from the Laurentide Ice Sheet and the dark arrows indicate ice-flow directions from the Cordilleran Ice Sheet (from McCurdy et al., 2007, p. 368).

These results in neighbouring terrain, in part, prompted the inclusion of a program of heavy mineral sampling of till and stream sediments within the Protect Area Strategy (PAS) studies that were conducted in the Sambaa K'e (Trout Lake) region (Watson, 2011a) and Ka'a'gee Tu (Kakisa) region (Watson, 2011b). The results from Sambaa K'e were quite surprising, with elevated indicator mineral counts of sphalerite, galena and chalcopyrite in till samples overlying Paleozoic carbonate and Cretaceous sediments (Figure 1.5). Recently, exploration in the Łue Túé Sụlái candidate Protected Area (Jean Marie River region) by Olivut Resources discovered kimberlites (Watson, 2013; Pitman, 2014).

The identified mineral potential and results of various heavy mineral surveys, coupled with the paucity of surficial maps and relevant information to support future infrastructure needs along the majority of Northwest Territories all-season highways, was the impetus to conduct surficial mapping, to decipher the glacial and deglacial history, to document the glacial stratigraphy and to conduct heavy mineral studies in the southern Northwest Territories for this GEM-2 activity.

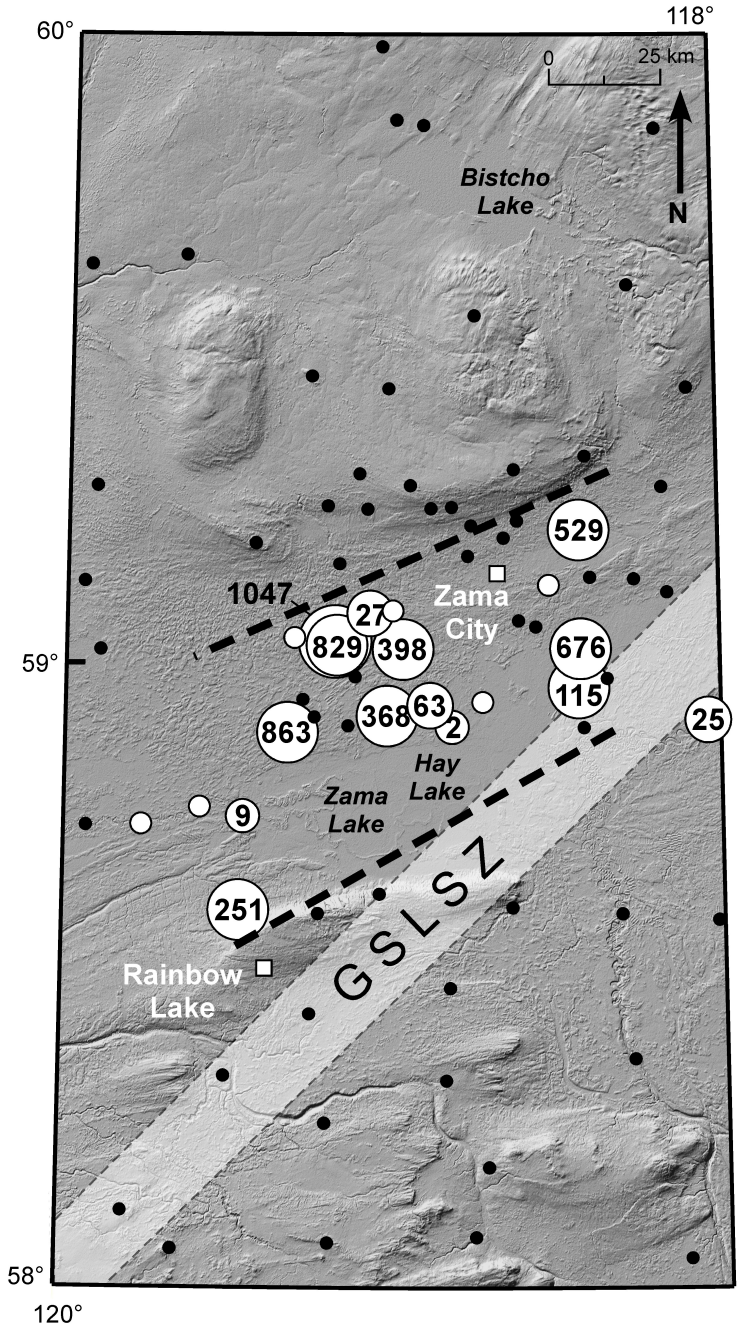

Figure 1.4. Number of sphalerite grains in the 0.25-0.5 mm heavy mineral fraction of 30 kg till samples and the resultant dispersal train (bounded by the thick black dashed lines) recovered from till samples in northwest Alberta. Small white circles represent a single grain; small solid black circles indicate samples with no sphalerite (modified from Plouffe et al., 2008). The outlined white zone marks the approximate location of the Great Slave Lake shear zone (GSLSZ; Eaton and Hope, 2003) projected to surface (modified from Paulen et al., 2011).

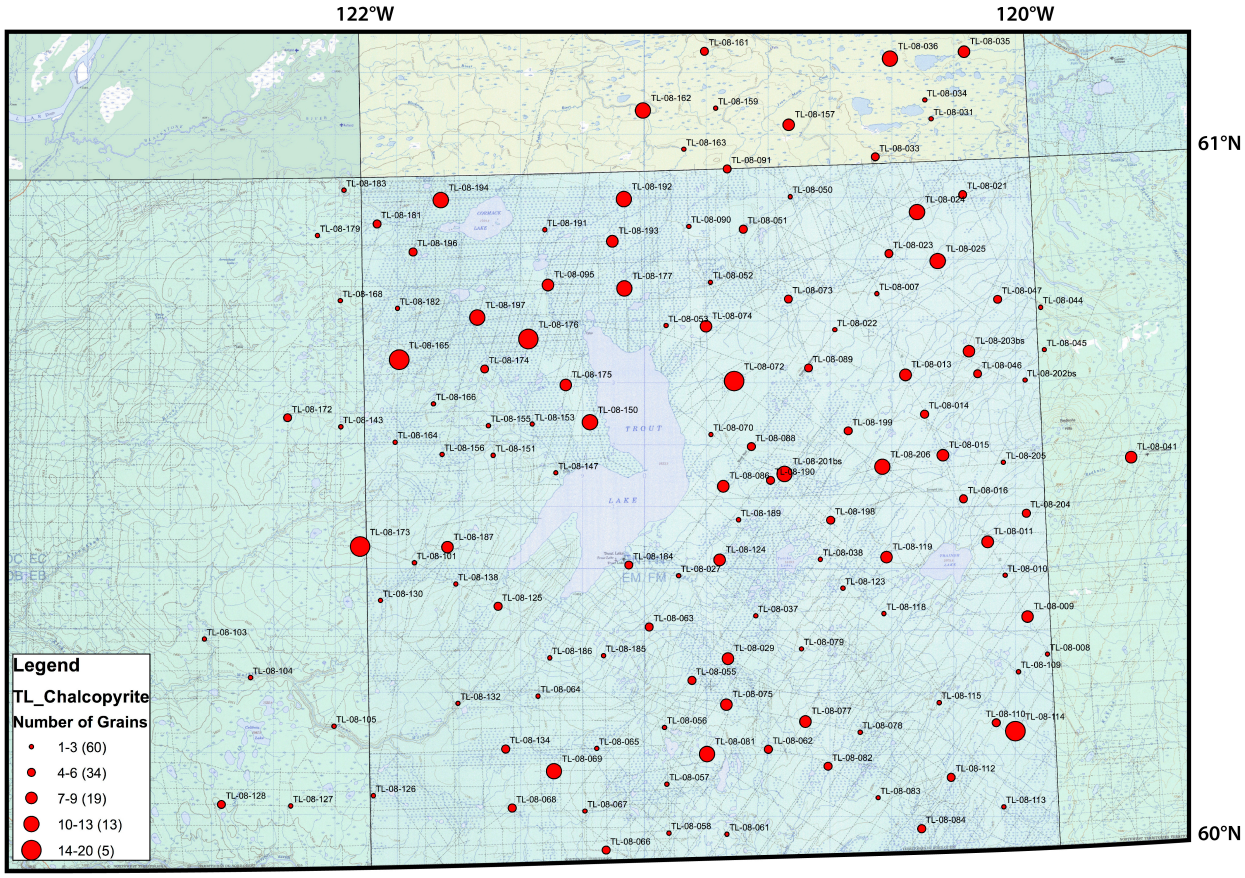

Figure 1.5. Chalcopyrite grain counts from till samples collected in the Trout Lake PAS survey plotted on the NTS Topographic base (data plotted from Watson, 2011a). There are no known mineral sources attributed to these elevated grain counts in the glacial sediment.

Scientific questions

Recently, the Northwest Territories Geological Survey donated all the base metal indicator mineral grains that had been picked from heavy mineral concentrates of till samples collected from the three Protected Area Strategy (PAS) surveys to the GSC for this present project. There are several samples in the Sambaa K'e and Ka'a'gee Tu survey areas with indicator mineral grain counts of sphalerite exceeding 50 or more grains, and more than 15 grains of chalcopyrite. These areas are at least 200 km or more from the only known Pb-Zn mineral deposit, the Pine Point district, and there are no known occurrences of Cu (i.e., chalcopyrite - $CuFeS_2$) in the region. Further study of these donated mineral grains, augmented by additional till sampling and surficial mapping provide insight on the following scientific question. Is the presence of these indicator minerals in the glacial sediments indicative of potential unknown sulphide mineralization up-flow (east) from the PAS sample surveys, or are we seeing evidence of long-distance glacial transport from the Pine Point Pb-Zn district? If the latter is true, what are the implications for such long-distance glacial transport on the interpretation of indicator mineral surveys conducted elsewhere in northern Canada?

Goals and objectives

The main objectives of the GEM-2 Southern Mackenzie Surficial Activity are to provide a glacial and post-glacial historical framework required for interpreting the nature and transport history of surficial sediments, and to collect till and stream sediment samples at targeted sites for provenance studies and mineral potential evaluation. Our goals also fulfill the larger mandate of the GEM Program, namely the completion of the mapping coverage of northern Canada. The three NTS sheets currently undergoing surficial mapping in this GEM-2 activity are NTS 85C (Tathlina Lake), 85F (Fallaise Lake) and 85G (Sulphur Bay), and comprise conspicuous surficial geology and terrain knowledge gaps in the southern Northwest Territories (Figure 1.6, large map attached to this report).

Figure 1.6. (Large map accompanying this report). Summary of till samples collected during the course of surficial mapping and heavy mineral studies for this research activity, between 114°W longitude near Fort Resolution to 124°W longitude, east of the Liard River, and from 60°N latitude along the Northwest Territories – Alberta provincial border to 62°N latitude. Previous work by provincial and federal projects in British Columbia (yellow), Alberta (blue) and Northwest Territories PAS Surveys (pink) are indicated.

Acknowledgments

These surficial research activities are part of the GEM-2 Mackenzie Project, with GSC management support from Carl Ozyer, Glen Stockmal and Paul Wozniak at GSC Calgary. Assistance with all aspects of fieldwork was cheerfully provided by J. Plakholm (Carleton University). M. Francis (GSC Calgary) provided excellent project support. Peter Redvers of the K'atlodeeche First Nation is thanked for his support and communication throughout the early stages of this field activity. Helicopter support was provided by Great Slave Helicopters through the partnership with Denendeh Helicopters. The experience and steady hand of pilot Joe Marsh was greatly appreciated. While conducting helicopter work in the study area, excellent assistance in the field was provided Irene Graham (Kátł'odeeche First Nation), Darcy Simba (Ka'a'gee Tu First Nation) and Henry Sabourin (Deh Gah Got'ie Koe First Nation). Information and samples from the Pine Point deposits and overburden thicknesses is gratefully acknowledged from Stanley Clemmer and Marten King of Pine Point Mining Limited (formerly Darnley Bay Resources Limited). M.B. McClenaghan (GSC Ottawa) is thanked for her review of this report.

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Chapter 2 Surficial Mapping

I. Rod Smith, Roger C. Paulen, Grant W. Hagedorn and Matt D. Pyne

Introduction

Surficial geology mapping and sediment sampling is being conducted in support of the reconstruction of regional ice flow histories and drift geochemical surveys (see Chapter 3). The surficial geology maps will also provide an understanding of surface materials, wetland (bog and fen) extents, and potential granular aggregate resources and have broad application and importance to issues of environmental assessment, sustainability, and resource development. A goal of this project is to produce 1:100 000 scale maps for each of the four quadrants in NTS map sheets 85C (Tathlina Lake) and 85F (Falaise Lake) and the northwest and southwest quadrants in 85G (Sulphur Bay). Grant Hagedorn will compile one of the 1:100 000 map sheets as part of his M.Sc. thesis. The focus area of mapping comprises a conspicuous gap in the existing regional surficial geology map extents (Figure 2.1), and coincides with areas traversed by arterial highways #1, #2 and #3 (see Figure 1.6, large map attached to this report), and the traditional territories of the Kátł'odeeche, Ka'a'gee Tu and Deh Gáh Got'ie Koe First Nations. Mapping and sediment sample collection was initiated in 2017, and will continue through the 2018 and 2019 field seasons.

Quaternary Glacial History

The study area in southwestern Northwest Territories was inundated by the Laurentide Ice Sheet (LIS) during the late Wisconsinan glaciation (~24-10 ^{14}C ka BP; Dyke and Prest, 1987; Dyke, 2004). Predominant glacially streamlined landforms (flutings and drumlins) indicate a southwest ice flow across the study area, while around Pine Point (70 km east of Hay River town site) bedrock striae (Oviatt et al., 2015) and clast fabric measurements (Rice et al. 2013) record at least 3 trajectories: earliest to the southwest (230°), intermediary to the northwest (300°) and a final west-southwest (250°) flow. During deglaciation, retreating ice became increasingly topographically confined and prominent lobes extended south and west down the Hay and Mackenzie river valleys, respectively. Ice retreated from the study area between 11-10 ^{14}C ka BP (Figure 2.2; Dyke, 2004). Blockage of regional drainages and impoundment within glacioisostatically depressed basins led to the formation of a series of glacial lakes (Mackenzie, Peace, Great Bear) that eventually merged along the retreating ice margin to form the expansive glacial Lake McConnell (Figure 2.2; Lemmen et al., 1994). By 8.5 14C ka BP, as LIS meltwater discharge into the Mackenzie drainage basin waned, glacial Lake McConnell had shrunk to form three disconnected basins (Great Bear, Great Slave and Athabasca; Figure 2.2). Drainage of these expanded basins continued largely through a process of decantation by glacioisostatic uplift (Lemmen et al., 1994; Smith, 1994).

Methods

Field research was conducted by truck along existing roads, borrow pits and bedrock quarries, and by Jet Ranger helicopter from June 27 – August 3, 2017. A wildlife monitor from each of the three First Nation communities (Kátł'odeeche (Hay River), Ka'a'gee Tu (Kakisa), Deh Gáh Got'ie Koe (Fort Providence)) accompanied the helicopter crew when we were working in their traditional territory. Five main activities were undertaken this past summer: 1) collect till samples for indicator mineral and geochemical analysis, 2) observe and interpret surficial

geology providing ground truthing for air photograph mapping, 3) examine and record stratigraphy where exposed in natural (stream cut, slump headwalls) and artificial (borrow pit and quarry wall) exposures, 4) record indicators of paleo-ice flow directions from bedrock erosional indicators (e.g., striae, grooves) and clast fabric measurements in till, and 5) collect sand samples from aeolian dunes for optically stimulated luminescence (OSL) dating.

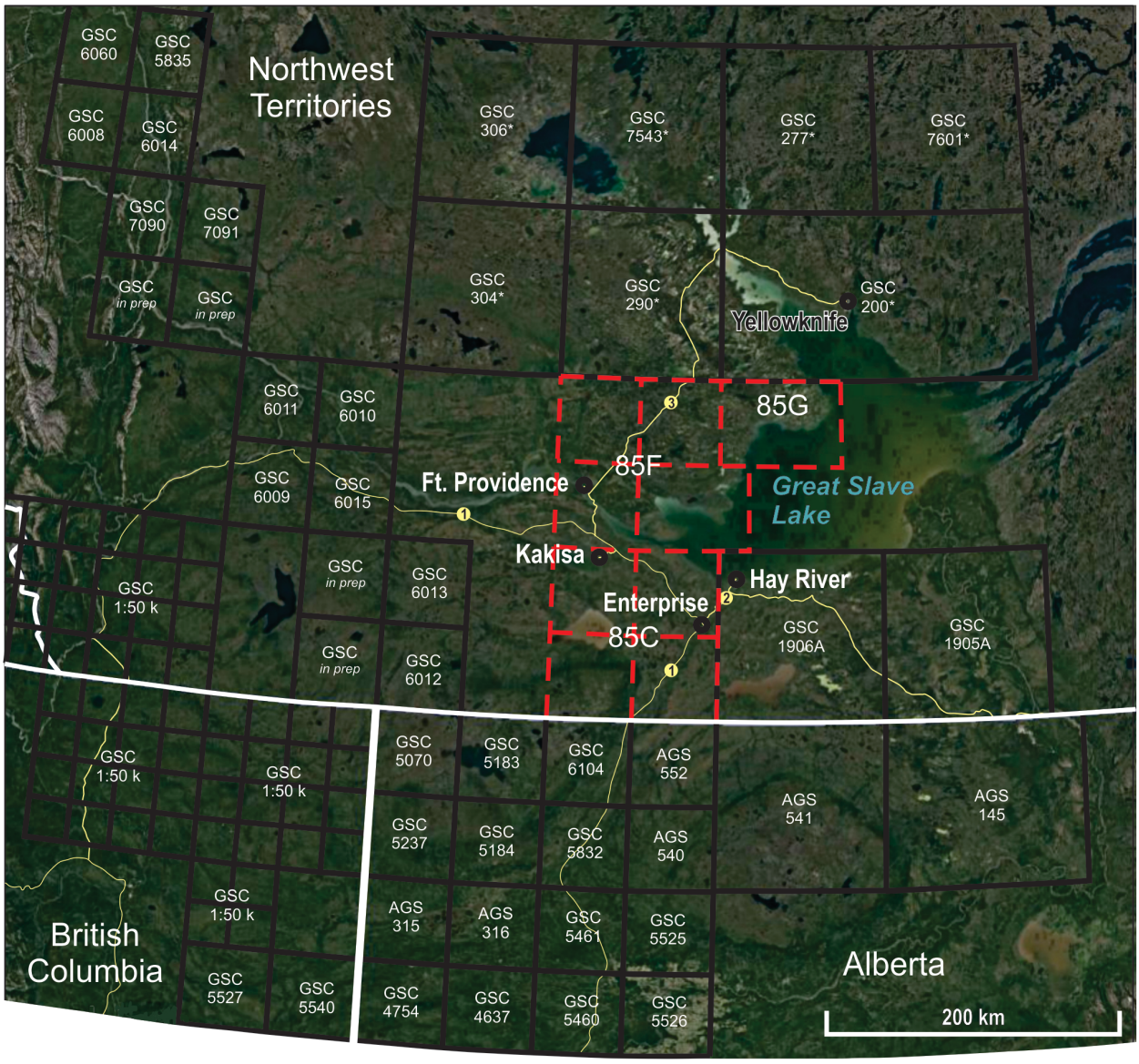

Figure 2.1. Study area of the GEM2 – Southern Mackenzie Mapping project, outlining the areas of intended surficial geology mapping (red dashed lines) and existing regional surficial geology map coverage (1:50 000; 1:100 000 and 1:250 000 scales). Note, published map numbers north of the area of focussed mapping that are marked by an asterisk (*) denote digital remote predictive maps with limited ground control.

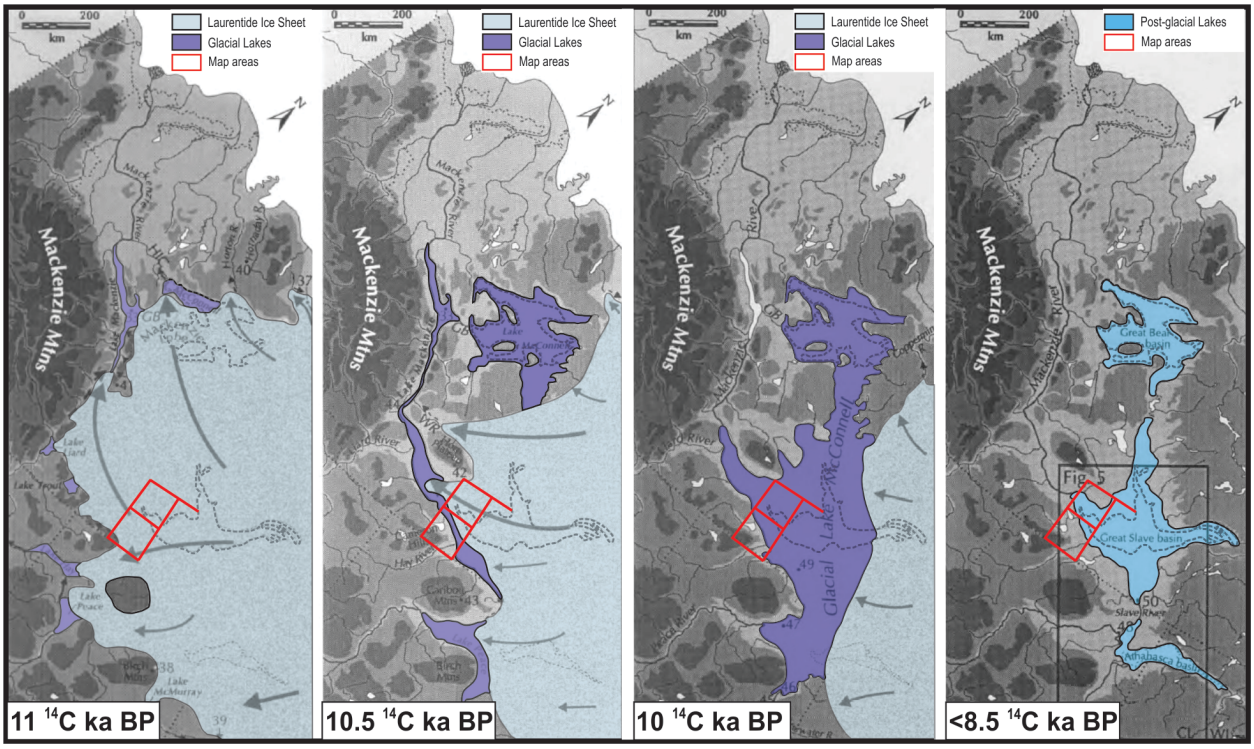

Figure 2.2. Depiction of the retreat of the late Wisconsinan Laurentide Ice Sheet from the study area and the formation and drainage of glacial Lake McConnell. Extent of surficial geology mapping outlined in red (modified from Lemmen et al. 1994).

Till sampling

Till samples were collected at a 10-15 km spacing in the northern half of map 85B (Pine Point area), and throughout map 85C (see large PDF map). These two map areas were the principal focus of field activities this past summer. Additional till sample collection followed a westward trend along the Kakisa River in map 85D and along Highway 1 in 85 E. A two-day reconnaissance assessment of terrain in 85F saw weather-restricted helicopter collection of 3 samples west and east of the highway, and a 10-15 km interval of samples (n=9) collected along Highway 3 which bisects the map sheet. Field conditions throughout the study area, chiefly the prevalence of expansive fens and bogs, restricted helicopter access, and thick organic and glaciolacustrine sediment cover also made access to till difficult or untenable in many areas. Forested terrain, particularly those populated by jack pine and larger aspen and white spruce were recognized as the most probable sites for recovering till samples. While extensive networks of historical seismic lines (dating from the 1960s through the mid-1980s) criss-cross much of the field area, the vegetative regrowth within these prevented their use as helicopter landing sites and access points. Instead, bogs in proximity to forested terrain were typically used, but required a hover exit and the felling of several smaller saplings to be laid as struts upon the ground which the helicopter could then land on and shut down.

Till sample collection and quality control guidelines followed established GSC protocols (Spirito et al., 2011; McClenaghan et al., 2013; Plouffe et al., 2013). Hand shovels were used to dig small holes (60-150 cm deep) below the depth of oxidized soil profiles and into the underlying parent material (till) Ck-horizon. Designated sampling shovels, which were treated to remove all

surface coatings, and then heat tempered were used to dig the base of the hole and for actual sample collection in order to reduce potential of metallic contamination. Two samples were collected at each site. The first constituted an indicator mineral sample, and depending on the sand content, comprised either a clean, plastic 3.5 gallon pail (~20 kg; used for higher sand content tills), or a clean, plastic 5 gallon pail (~30 kg; used for more clay and silt-rich tills). The second sample collected was 3-5 kg of sediments for geochemical analysis, textural determinations, Munsell colour, loss on ignition (LOI), Chittick analysis, and archiving.

OSL dating

Samples of aeolian dune sands were collected from three sites for OSL dating following the procedures outlined by Aitken (1998), Duller (2004) and Lian and Roberts (2006). Pits were dug with shovels at the crest of prominent dune ridges to a depth of 1.5 m. A 2 ½ inch diameter, 30 cm long, black PVC-plastic tube with a cap on one end was then hammered horizontally into the dune. Sand was then dug from around the far end of the tube to allow a second cap to be inserted. Depth of sample collection and azimuth of the tube were recorded, and the end caps were secured with duct tape. Samples were shipped for processing and analysis to Dr. Lian's laboratory at University of the Fraser Valley, Abbotsford, BC.

Results

Field observations relating to surficial geology were made at 189 locations during the 2017 field season. These included 137 sites where till samples were collected for base metal and other indicator minerals, and geochemical analysis. Following established protocols (McClenaghan, 2011; Plouffe et al., 2013), 148 heavy mineral sample pails (including blanks, spiked and duplicate samples) were submitted to Overburden Drilling Management Ltd (ODM) for processing and heavy mineral identification and picking. A total of 159 samples (including blanks and standards) were submitted for geochemical analysis (Lithium borate fusion (5 g sample of <0.063 µm material) and Aqua Regia (30 g sample of <0.063 µm material); Spirito et al., 2011).

Paleo-ice flow measurements were recorded at 26 stations. Striae are absent on most exposed (weathered) limestone bedrock surfaces, but can occasionally be revealed when the overlying sediment cover is carefully removed/swept away (Figure 2.3a). West of Enterprise, individual and cross-cutting striae and groove directions rotate from 220° to 264° (mirroring those documented by Oviatt et al. (2015) further to the east). Isolated cases of striated limestone trending 313-331° were also recorded. Small (decimetre to metre-scale) *en echelon* whale-back bedrock p-forms were observed on outcrop surfaces along Highway 1, and typically had form/long axis-parallel striae on their stoss sides indicating a subglacial, flow-parallel formation (Figure 2.3b).

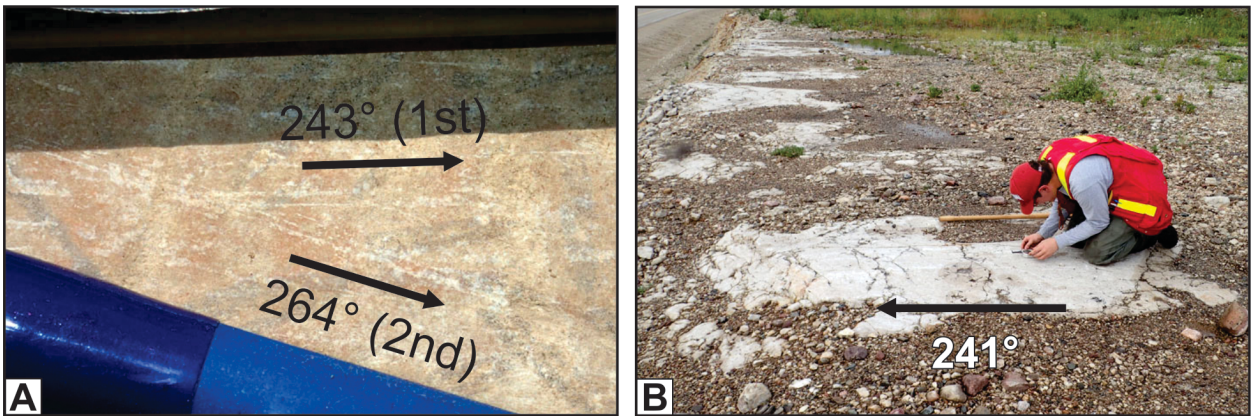

Figure 2.3. Paleo-ice flow indicators. A) Cross-cutting striae (bordered by two pens) indicating a westward-rotation of ice flow. B) En echelon bedrock whale-back p-forms and striae indicating flow at 241°. (photos, I.R. Smith).

A majority of the study area is situated in a broad, low-relief plain, formed over gently westward-dipping Phanerozoic bedrock (Okulitch, 2006) that is extensively blanketed by till, glaciolacustrine sediments, organic deposits, and in places aeolian sand sheets and dunes (Figure 2.4a; Lemmen 1998a, b; Wolfe et al., 2009). Outcrops of bedrock are rare, other than where exposed in stream cuts and slumps along the margins of the Cameron Hills (Figure 2.4b), and along the prominent Devonian limestone escarpment upon which Highway 1, heading west from Enterprise, was built (Figure 2.4c). In the vicinity of the Pine Point deposit, till thickens from 1 m in the east, to >25 m in the west (Lemmen, 1990; Rice et al., 2013), while across the mapping area, interpretations of seismic shothole drillers' logs (Smith and Lesk-Winfield, 2010a) identify extensive till blankets and undifferentiated drift thicknesses of 8 - >16 m. Areas within the bounds of glacial Lake McConnell (Figure 2.2) exhibit variable reworking of till, producing flights of sorted sand and gravel beach deposits and finer-grained littoral/benthic sediments that range up to 5 m thick, but average <2 m (Lemmen, 1990). The generally flat terrain in the study area seems to have limited the degree of wave-wash induced erosion (Lemmen, 1990; Smith, 1994), and in many areas of eastern map sheet 85F and central 85C, there is a conspicuous surface scattered boulder lag (Figure 2.4d) sitting atop <50 cm of glaciolacustrine sediments/washed till, suggesting that much of the fines have been winnowed from the till and either redeposited into more benthic regions of the glacial/post-glacial lake or discharged down the Mackenzie River. Thicknesses of peat underlying extensive fen and bogs estimated from seismic shothole drillers' logs (n=210; Smith and Lesk-Winfield, 2010b) range up to 9.1 m, and average 2.76 m although this measure is considered an overestimate as shothole drillers typically did not report thicknesses ≤1 m.

The prominent Cameron Hills in the southwest part of map sheet 85C are remarkable for parallel fields of flutings (225° then 245°; Figure 2.5a) that point to fast-flowing ice streams crossing the area that were unconstrained by topography (Margold et al., 2015). Individual mega-flutings (up to 1.5 km wide, 30 km long) may have numerous narrower parallel flutings superimposed atop them. In northwestern Cameron Hills, thick (>40 m) sequences of southwest-trending, boulder-gravel glaciofluvial outwash, overlying and interbedded with diamicts (Figure 2.5b) point to a dynamic ice margin abutting the northern and eastern margins of the hills.

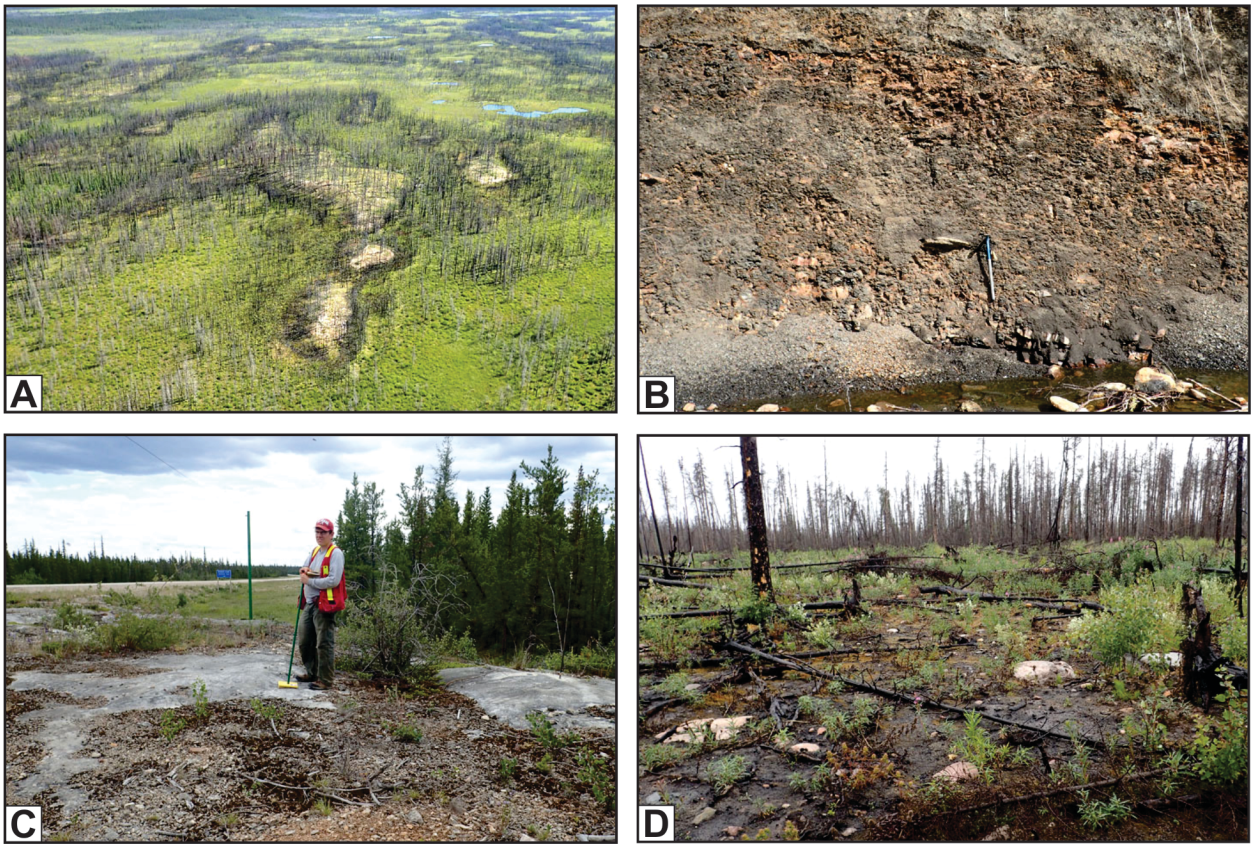

Figure 2.4. Different terrain units from the field area. A) Prominent parabolic and longitudinal dune ridges east of Kakisa Lake sampled for OSL dating. Paleo-wind flow is towards the viewer at 220°. Darkened outlines reflect extensive forest fires in 2013. B) Shale outcrop (lower Cretaceous Scatter Fm.) exposed along Cameron River north of Cameron Hills; geological pick in center of photo is 75 cm long. C) Outcrop of upper Devonian Twin Falls Fm. limestone along Highway 1, west of Enterprise, NT. D) Scattered boulder lag in eastern map 85F, produced by winnowing of till within the bounds of glacial Lake McConnell, and the expanded post-glacial Great Slave basin. (photos, I.R. Smith)

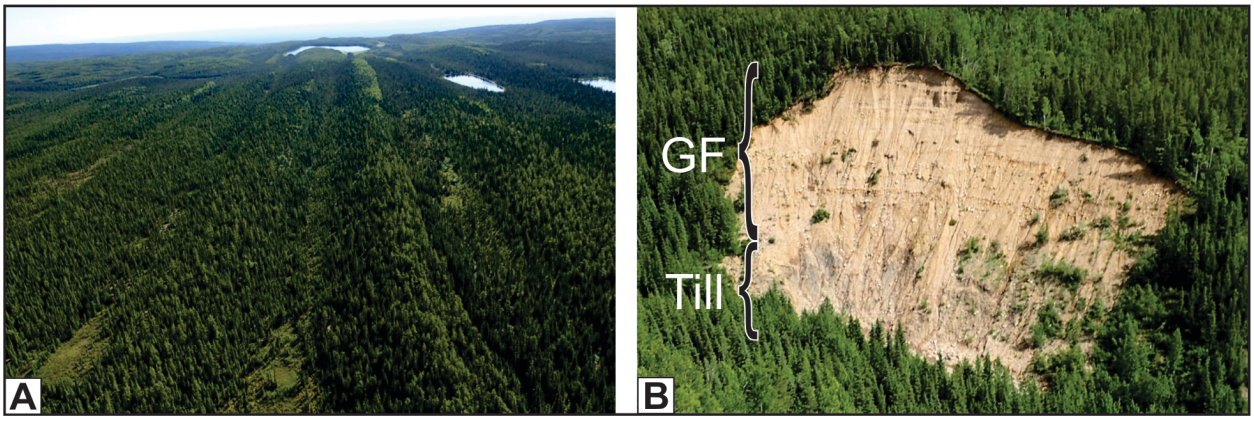

Figure 2.5. Cameron Hills, southwestern map 85C. A) Prominent glacial flutings (245° azimuth). Photo shows one larger flute with 4 superimposed parallel narrower flutes. B) Glaciofluvial boulder-gravel outwash (30 m thick) overlying dark clay-rich till (8 m of exposed section). (photos I.R. Smith)

The field area is situated within the zone of sporadic discontinuous permafrost (Heginbottom et al., 1995), and permafrost-related thermokarst ponds are widespread. Other permafrost-related landforms such as ice wedges were not seen. A number of sites dug in areas of bog, glaciolacustrine sediments, and marginally-forested terrain exposed frozen ground at shallow depths (<50 cm). In one case this frozen layer was thin enough to punch through, suggesting that some of these sites have merely encountered a seasonal frozen layer. Elsewhere it is considered likely that shallow permafrost was encountered, most commonly beneath thicker organic blankets.

Discussion and Future Work

The Southern Mackenzie field area records the late Wisconsinan inundation by the Laurentide Ice Sheet, its retreat, and formation and eventual decantation of glacial Lake McConnell. Sections exposed along the edges of past mining pits in the Pine Point area identify the existence of 3 distinct tills and flow directions (Rice et al., 2013; Oviatt et al., 2015). Exposed sections in the present field area reveal no more than two till units at any one site. It remains to be determined if these tills can be correlated based on indicator minerals, geochemistry, pebble lithologies, clast fabrics, and bedrock striae records.

As a first field season, exceptional weather and a skilled helicopter pilot greatly facilitated access and recovery of a regionally coherent set of till samples in map areas 85B, C, and along the Kakisa river in 85D, and reconnaissance sampling in 85F and 95B, G, and H. Processing of these samples for heavy minerals and geochemistry should identify areas that additional field investigation and sampling will be required in the summer 2018 field season. Till sampling throughout map 85F will be a priority for summer 2018, as will ground-truthing in support of surficial geology mapping activities throughout the field area.

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Chapter 3 Heavy Mineral Dispersal Studies

Roger C. Paulen, Robert King, I. Rod Smith and Stephen J.A. Day

Introduction

The goal of the heavy mineral dispersal studies is to gain a better understanding of glacial dispersal from the world-class Pine Point MVT district, under varying subglacial conditions. Such conditions would include long-term glacial accretion of till in the thicker till deposits encountered in the study area (Rice et al., 2013), complex glacial dispersal patterns (Oviatt et al., 2015; McClenaghan et al., in press), and long-distance dispersal by former ice stream tracts (Margold et al., 2015). Sulphide indicator minerals of interest include galena, chalcopyrite, sphalerite and arsenopyrite and collectively are being examined along two major transects (Figure 3.1).

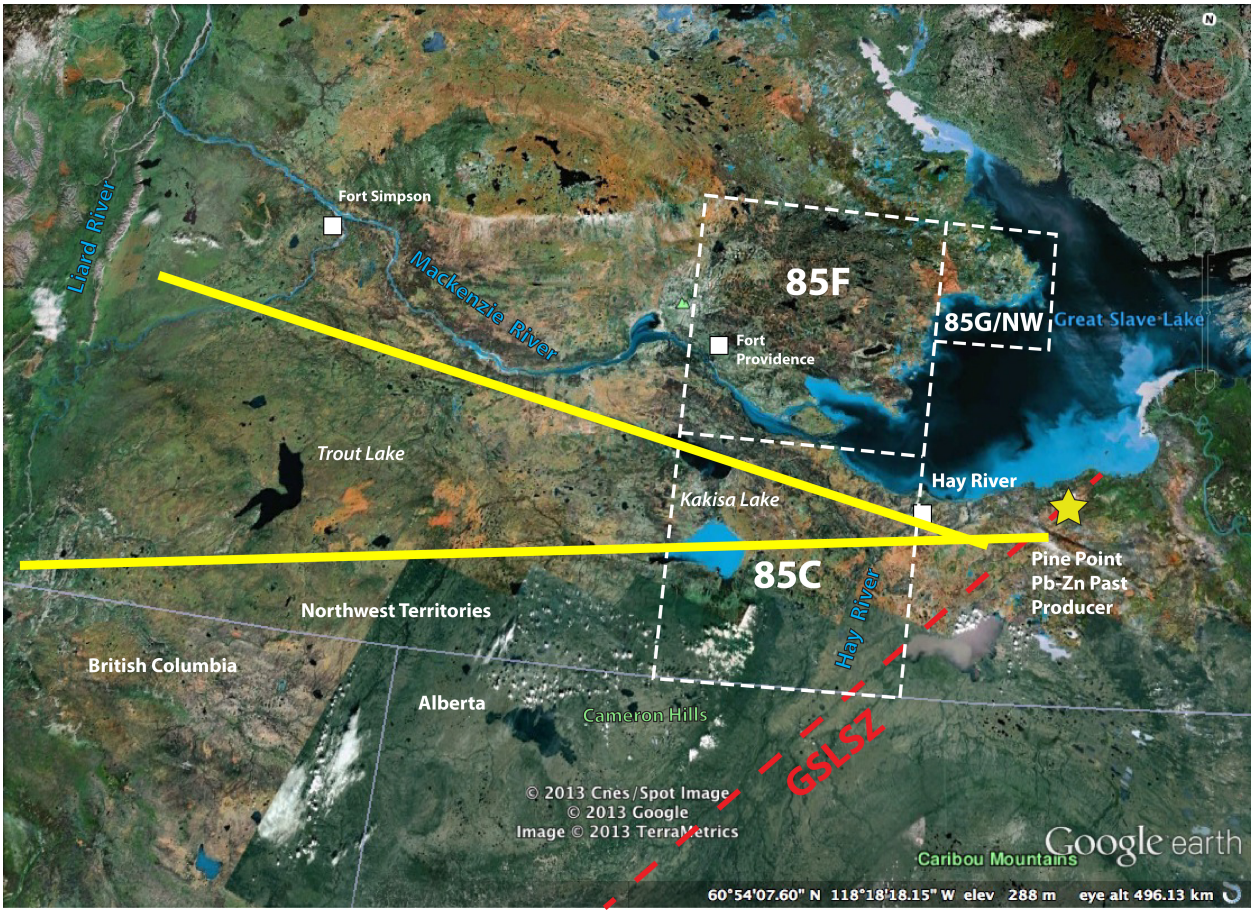

Figure 3.1. Heavy mineral activity study area. The NTS areas outlined in white represent the surficial mapping activity from which heavy mineral grains will be incorporated with samples collected along the two yellow transect lines. These lines represent generalized phases of Laurentide Ice Sheet flow and their potential dispersal patterns from the Pine Point MVT district (yellow star).

The objectives are to collectively gather and study:

- the existing archives of all the sulphide indicator minerals collected during the PAS surveys, donated to this GEM-2 activity by the Northwest Territories Geological Survey;
- incorporate the analytical data from GEM-1 dispersal research conducted at Pine Point
- a subset of the samples collected during the course of surficial mapping with this GEM-2 activity in NTS 85C (Tathlina Lake) and 85F (Falaise Lake);
- samples collected up ice, overlying, immediately down ice and along two major transects in excess of 400 km west of the past producing Pine Point MVT district.

Indicator mineral grains will be subjected to multiple analyses to characterize their mineralogy, major-element chemistry and trace-element chemistry. Additional analyses by laser-ablation inductively-coupled-plasma mass-spectrometry (ICP-MS) and isotopic fingerprinting are planned to determine what the potential source mineralization could be.

Data sources

The main sulphide indicator minerals to be examined in this activity include chalcopyrite, galena, sphalerite and arsenopyrite. There are 142 sample sites with picked grains of sulphide minerals from the Sambaa K'e (Trout Lake) PAS survey (Watson, 2011a). There are 45 sample sites with picked grains of sulphide minerals from the Ka'a'gee Tu (Kakisa Lake) PAS survey (Watson, 2011b). There are two samples containing chalcopyrite from the Łue Túé Sụlái (Jean Marie River region) PAS survey (Watson, 2013).

There are analytical data (mineralogical and isotopic) from grains collected from till samples in the Pine Point MVT district that were analyzed from glacial dispersal research conducted under the Tri-Territorial Indicator Mineral Project in GEM-1 (Oviatt et al., 2013). This data will augment data analyzed during this GEM-2 activity.

Bulk (20 kg and 30 kg) till samples were collected during field activities in 2017. Till samples collected east of the Hay River and within 100 km of the western margin of the Canadian Shield were typically of a silty-sand matrix. Therefore, approximately 20 kg of material was collected. Till samples west of the Hay River ranged from having a sandy-silt matrix over the Paleozoic carbonate bedrock to a clayey-silt matrix over the Cretaceous sedimentary bedrock and therefore approximately 30 kg of material was collected for indicator mineral recovery. The sample protocols were the same as those established for the surficial mapping surveys (Spirito et al., 2011; Plouffe et al., 2013), and are also described in Chapter 2 of this report. It is difficult to predict if most of the samples will contain sulphide indicator minerals, but negative results will still be significant for spatially defining mineralization potential with respect to the indicator minerals recovered from the PAS surveys. The heavy mineral data sources are summarized in Table 3.1 and the entire heavy mineral sample coverge is shown in Figure 1.6 (see large map attached to this report).

Sample Collection Area (NTS map sheets)	Data Source	Samples
085A Klewi River up ice of Pine Point District	GEM-2 Southern Mackenzie Surficial	1
085B Buffalo Lake Pine Point District	GEM-1 Pine Point Dispersal (Oviatt et al. 2013)	15
085B Buffalo Lake Pine Point District	GEM-2 Southern Mackenzie Surficial	40
085C Tathlina Lake	GEM-2 Southern Mackenzie Surficial	44
085D Kakisa River	GEM-2 Southern Mackenzie Surficial	8
085E Mills Lake	GEM-2 Southern Mackenzie Surficial	9
085F Falaise Lake	GEM-2 Southern Mackenzie Surficial	19
095B	GEM-2 Southern Mackenzie Surficial	10
095G	GEM-2 Southern Mackenzie Surficial	1
095H	GEM-2 Southern Mackenzie Surficial	5
Sambaa K'e (Trout Lake) 085D, 095A, B, H	PAS survey (Watson, 2011a)	142
Ka'a'gee Tu (Kakisa) 085C, D, E, F	PAS survey (Watson, 2011b)	45
Łue Túé Sụlái (Jean Marie River) 095H6, H7	PAS survey (Watson, 2013)	2

Table 3.1. Summary of historical till samples and heavy mineral data sources and those collected this past summer that will be utilized in this activity. Additional sample collections are planned in summer 2018.

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Chapter 4 Stream Sediment Geochemistry and Heavy Minerals

Stephen J.A. Day and Robert D. King

Introduction

A stream sediment and water study was initiated under the GEM2 Mackenzie Project, Southern Mackenzie Surficial Activity, in the Hay River – Kakisa Lake area of southern Northwest Territories (Figure 1.1, Chapter 1 of this Report of Activities). This study aims to address the scientific question: "*Is there potential for carbonate-hosted Pb-Zn deposits hidden beneath the thick glacial overburden between Hay River and Kakisa Lake/Fort Providence*?"

Non-renewable resource assessments carried out by the Northwest Territories Geological Survey (NTGS) in the Trout Lake (Watson, 2011a), Kakisa Lake (Watson, 2011b) and Jean Marie River (Watson, 2013) areas indicate the presence of sphalerite and galena grains in the heavy mineral fraction of numerous till samples collected. Significant sphalerite and galena grain counts occur over a broad area of up to nearly 400 km west of the past-producer Pine Point lead-zinc mine. In collecting bulk stream sediment samples, for their heavy mineral indicator content, the goal is to better understand any possible link between the sphalerite and galena grains and the Pine Point deposit.

Both stream sediments and waters are products of the environment in which they are found. Erosion and weathering of nearby bedrock and surficial deposits (predominately glacial till), provide sediment which interacts with flowing water producing the streambed and banks. Drainage morphology and hydrology, as well as the physical properties of the sediment, dictate the nature and distribution of sediments. Sphalerite, galena and numerous other indicator minerals (IM) are found in the heavy mineral concentrate (HMC) fraction of sediments. The mineral exploration industry and government geological surveys have successfully employed similar sampling programs in their search for knowledge regarding the mineral prospectivity of areas of interest (cf., Friske and Hornbrook, 1991).

Field activities for this study were carried out in July 2017 and were based in Hay River, NT. Roughly half of the sample sites were road accessible and were visited by truck, while a helicopter was used to reach more remote sites (Figure 4.1).

Methodology

Prior to commencing fieldwork, potential sample sites were preselected to ensure a reasonable coverage of samples within a set budget. Bulk stream sediment, silt sediment, and water samples were collected from 31 sites, resulting in 32, 23 and 32 field samples respectively. Figure 4.2 illustrates the field equipment used and samples collected at a typical stream bulk sediment and water site.

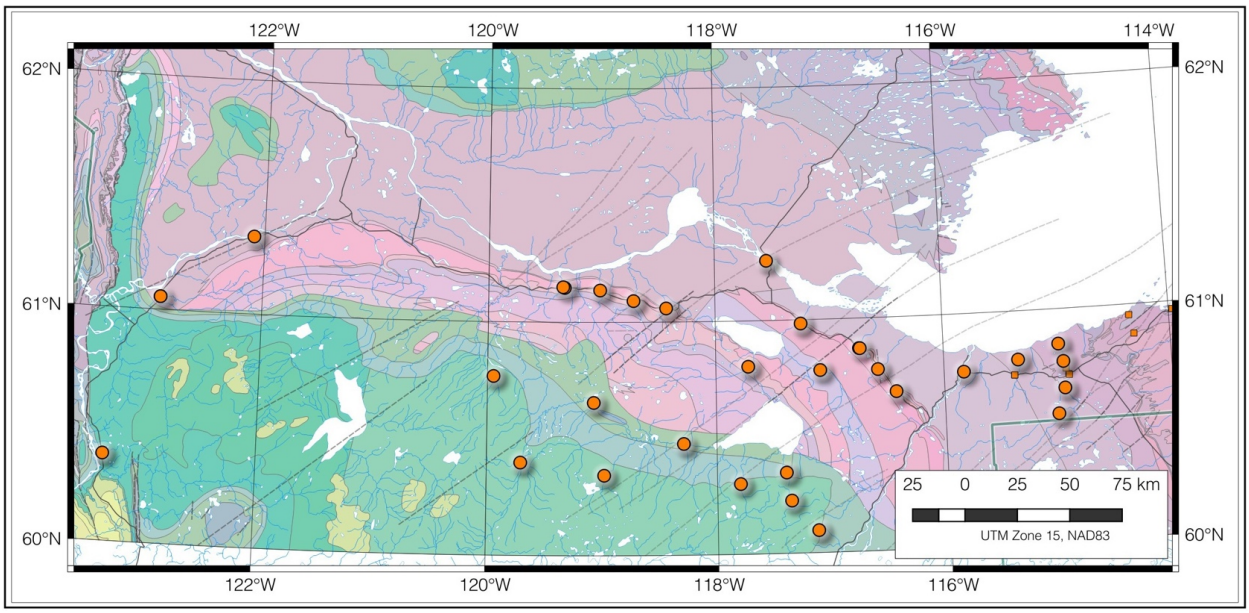

Figure 4.1. Stream sediment sample locations; orange dots represent sites where bulk sediment, silt sediment and water samples were collected in 2017 (n=31), small orange squares show 4 sites sampled in 2010 as part of a previous study.

Ideally, at every stream sample site, an on-site (0.45µm) filtered water sample, a grab sample of silt-sized sediment, and a wet-sieved bulk sediment sample are collected. Water samples will be analysed to obtain their trace- and minor-element concentrations as well as measurements for pH, conductivity and alkalinity. Silt sediment samples will have the <177µm fraction analysed by aqua regia/ICP and 4-acid/ICP. The (<2mm field-sieved) bulk sediment samples are to be further processed to obtain the HMC fraction, from which indicator minerals –including sphalerite and galena will be counted and representative grains will be picked from each sample. Indicator mineral grains of interest will be analysed to obtain their chemistry and isotopic compostion which will assist in determining bedrock source and mineral potential.

Site-specific field observations, including GPS location and photographs were recorded using a customised FileMaker Go data entry form running on an iPad. Navigation to and between sites was managed using applications running on the same iPad.

Samples collected as part of this activity followed the GSC's former National Geochemical Reconnaissance (NGR) programme's standard set of sample collection and analytical techniques, in order to ensure consistent and reliable results regardless of the area, date of the survey or the analytical laboratory used (Friske and Hornbrook, 1991).

Results

At the time of publication, all samples collected during the 2017 fieldwork have been submitted for sample processing and subsequent mineralogical and geochemical analyses. Preliminary analytical and mineralogical data is not expected to begin arriving until late in 2017, with a complete dataset not expected until early 2018.

Figure 4.2. Field gear used and samples collected at a typical bulk stream sediment and water site. 1) two 60 ml water samples (filtered on site with 0.45 µm filter), 2) YSI Professional Plus multi-parameter water meter, 3) silt-size stream sediment sample (~ 2kg wet), 4) #10 mesh (2mm) sieve, 5) gold pan with weigh scale, 6) steel shovel, 7) bulk stream sediment (12+kg of ≤2mm sediment), 8) #2 mesh (10mm) sieve, 9) bucket with extra supplies (silt bags, bulk sediment bags, water bottles, etc.), 10) bucket lined with pre-labeled sample bag (not yet stretched tightly about the bucket opening).

Conclusions

The field component of this study was successfully undertaken. Once the mineralogical and analytical data are complete, then data compilation, interrogation and interpretation will proceed.

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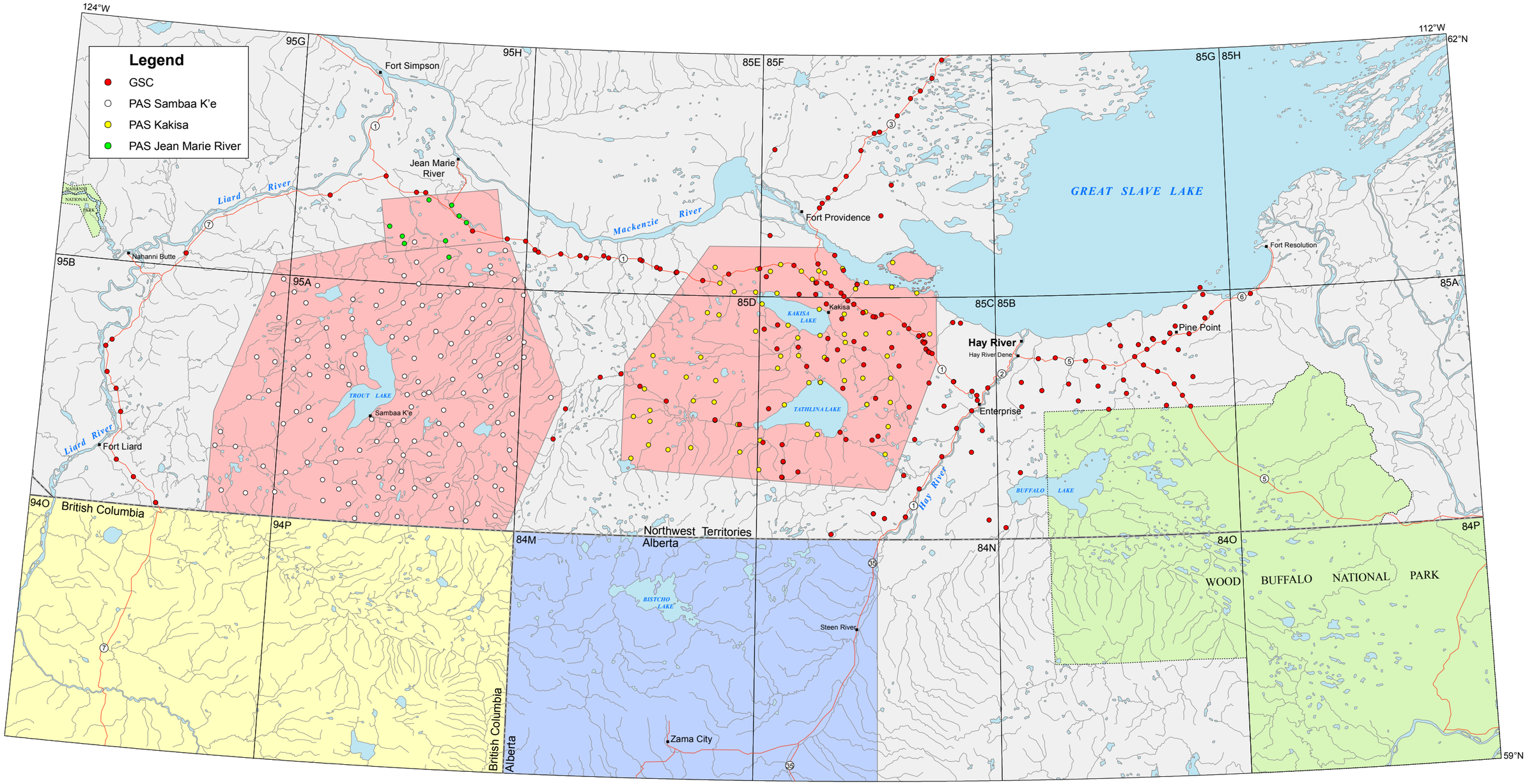

Figure 1.6. Summary of till samples collected during the course of surficial mapping and heavy mineral studies for this research activity, between 114°W longitude near Fort Resolution to 124°W longitude, east of the Liard River, and from 60°N latitude along the Northwest Territories – Alberta provincial border to 62°N latitude. Previous work by provincial and federal projects in British Columbia (yellow), Alberta (blue) and Northwest Territories PAS Surveys (pink) are indicated.