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GEM-2 Southern Mackenzie Surficial activity 2018 report: surficial geology and heavy mineral studies in southern Northwest Territories

R.C. Paulen, I.R. Smith, and S.J.A. Day
(editors)

2019

Canada

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Permanent link: https://doi.org/10.4095/313419

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Recommended citation
Paulen, R.C., Smith, I.R., and Day, S.J.A. (ed.), 2019. GEM-2 Southern Mackenzie Surficial activity 2018 report: surficial geology and heavy mineral studies in southern Northwest Territories; Geological Survey of Canada, Open File 8477, 70 p. https://doi.org/10.4095/313419

Publications in this series have not been edited; they are released as submitted by the author.

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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, publicly available, regional-scale geoscience knowledge in Canada's North.

During the 2018 field season, research scientists from the GEM program successfully carried out 18 research activities, 16 of which will produce an activity report and 14 of which included fieldwork. Activities applied a variety of geological, geochemical, and geophysical methods. 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 recent accomplishments of the Southern Mackenzie Surficial activity that is focused in the southern Northwest Territories. The report outlines fieldwork conducted in summer 2018 on the regional surficial geology and reconstruction of glacial history based on detailed mapping of palaeo ice-flow indicators and stratigraphy. It also discusses regional heavy mineral for stream sediment and till samples (Day et al., 2018; King et al., 2018). These new data are being used to better understand glacial dispersal of indicator minerals and to identify new potential mineral exploration targets in regions with previously unrecognized subcropping bedrock 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 maps, and geochemical and indicator mineral data and maps to support natural resource exploration. Fieldwork in 2018 built upon the 2017 field program (Paulen et al., 2017) and earlier research conducted by the Geological Survey of Canada in GEM-1 (Oviatt et al., 2015; McClenaghan et al., 2018; Rice et al., in press). Field research in 2018 led to an improved understanding of the regional surficial geology and glacial history of the study area and provided information essential to complete the surficial mapping and related studies.

This publication is a compilation of papers that describe various research activities supported by the Southern Mackenzie Surficial activity. This research is carried out in collaboration with external partners and supports several student thesis projects at four universities. The papers in this report highlight progress over the past year in surficial mapping, indicator mineral research and the glacial history and dynamics of the western sector of the Laurentide Ice Sheet.

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References

Day S.J.A, Paulen R.C., Smith I.R. and King R.D. 2018. Heavy-mineral and indicator-mineral data from stream sediments of southwest Northwest Territories: new potential for undiscovered mineralization; Geological Survey of Canada, Open File 8362. doi:10.4095/306587

King, R.D., Piercey, S.J., and Paulen, R., 2018. In situ, microanalytical sulphur and lead isotopic compositions of sulphide indicator minerals from surficial sediments in southwestern Northwest Territories; Geological Survey of Canada, Open File 8449. doi:10.4095/311247

McClenaghan, M.B., Paulen, R.C., and Oviatt, N.M., 2018. Geometry of indicator mineral and till geochemistry dispersal fans from the Pine Point Mississippi Valley-type Pb-Zn district, Northwest Territories, Canada; Journal of Geochemical Exploration, v. 190, p. 69-86. doi:10.1016/j.gexplo.2018.02.004

Oviatt, N.M., Gleeson, S.A., Paulen, R.C., McClenaghan, M.B., and Paradis, S., 2015. Characterization and glacial dispersal of indicator minerals associated with the Pine Point Mississippi Valley-type (MVT) district, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 52, p. 776-794. doi:10.1139/cjes-2014-0108

Paulen, R.C., Smith, I.R., Day, S.J.A., Hagedorn, G.W., King, R.D., and Pyne, M.D., 2017. GEM2 Southern Mackenzie Surficial Activity 2017 report: surficial geology and heavy mineral studies in southern Northwest Territories; Geological Survey of Canada, Open File 8322. doi.org:10.4095/306090

Rice, J.M., Menzies, J., Paulen, R.C., and McClenaghan, M.B. in press. Microsedimentological evidence of vertical fluctuations in subglacial stress from the northwest sector of the Laurentide Ice Sheet, Northwest Territories, Canada; Canadian Journal of Earth Sciences, accepted. doi:10.1139/cjes-2018-0201

Project Overview

Roger C. Paulen[1], I. Rod Smith[2] and Steve J.A. Day[1]

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Introduction

Understanding of the Quaternary geological framework is essential to 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 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 targeted a region with no prior surficial geology maps. It is also, in part, a follow-up to GEM-1 Quaternary research in the Pine Point region (2010-2011) that successfully demonstrated indicator mineral methods suitable for Mississippi Valley-type (MVT) Pb-Zn exploration and documented three phases of ice flow that impacted the southern Great Slave Lake region (Rice et al., 2013; Oviatt et al., 2015; McClenaghan et al, 2018).

Scientific questions

For this GEM-2 activity, the Northwest Territories Geological Survey donated all the base metal indicator mineral grains that had been picked from heavy mineral concentrates of till samples previously collected from the three Protected Area Strategy (PAS) surveys in the southern Northwest Territories and first reported on by Watson (2011a, 2011b, 2013). There are several samples in the Sambaa K'e and Ka'a'gee Tu surveys with indicator mineral grain counts exceeding 50 grains of sphalerite, and >15 grains of chalcopyrite. These areas are at least 200 km from the only known Pb-Zn mineralization, the Pine Point Mining District, and there are no known occurrences of Cu mineralization (i.e., chalcopyrite - CuFeS2) in the region. Further study of these donated mineral grains, augmented by additional till sampling and surficial mapping in the current study, provide insight on the following scientific question: Is the presence and relative abundance of sphalerite, galena and chalcopyrite grains in the glacial sediments indicative of potential unknown base metal mineralization in the Paleozoic bedrock of the Western Canada Sedimentary Basin?

Goals and objectives

The rationale and background to this GEM-2 Southern Mackenzie Surficial activity are outlined in Paulen et al. (2017). Previous identification of diamond potential in the region by Pittman (2014) and Poitras et al. (2018), results of previous heavy mineral surveys (Watson, 2011a, 2011b, 2013), and the paucity of surficial geology maps and relevant information required to support infrastructure development, was the impetus for this GEM-2 activity.

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Paulen, R.C., Smith, I.R., and Day, S.J.A., 2019. Project overview; in GEM-2 Southern Mackenzie Surficial Activity 2018 report: Surficial Geology and Heavy Mineral Studies in Southern Northwest Territories, (eds.) R.C. Paulen, I.R. Smith and S.J.A. Day; Geological Survey of Canada, Open File 8477, p. 34-42., p. 3–6. http://doi.org/10.4095/313420

The main objectives of this activity are to provide the 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 (Fig. 1.2, see large map appended at the end of this report). Our goals also fulfill the larger mandate of the GEM Program, namely completion of the mapping coverage of northern Canada. The three NTS sheets currently undergoing surficial mapping in this GEM-2 activity are NTS 85-C (Tathlina Lake), 85-F (Fallaise Lake) and 85-G (Sulphur Bay), and comprise conspicuous surficial geology and terrain knowledge gaps in the southern Northwest Territories (Fig. 1.3, map attached at the end of this report).

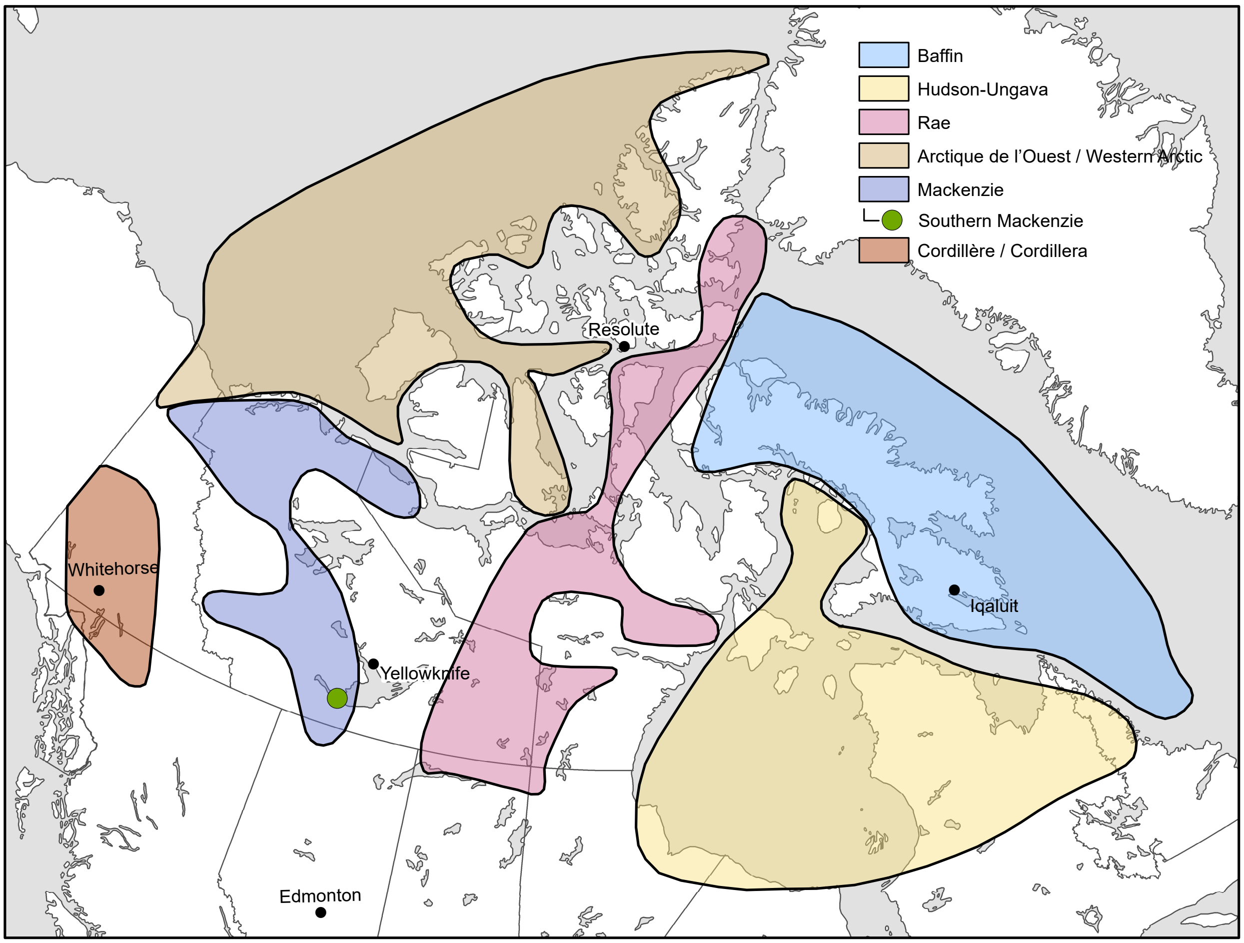

Figure 1.1. Location of the Mackenzie Project area in northwest Canada (purple polygon) and Southern Mackenzie Surficial activity field location, represented by the green dot.

Figure 1.2. (Large map accompanying this report). Location of till samples collected during surficial mapping and heavy mineral studies by this research activity (2017-2018). Previous related mapping and sampling activities conducted by provincial and federal projects are shown for British Columbia (yellow), Alberta (blue) and Northwest Territories (pink - PAS indicator mineral surveys).

Figure 1.3. (Large map accompanying this report). Current status of surficial map coverage in the southwest Northwest Territories (yellow), northeast British Columbia (pink) and northwest Alberta (blue). The large gap on the west side of Great Slave Lake comprises the surficial mapping area to be completed by the GEM-2 Southern Mackenzie Surficial activity (CGM = Canadian Geoscience Map).

Acknowledgments
These surficial research activities are part of the GEM-2 Mackenzie Project, with GSC management support from Carl Ozyer and Paul Wozniak at GSC Calgary. Assistance with all aspects of fieldwork was cheerfully provided by Matt Pyne (GSC Ottawa) and GEM-2 funded students Grant Hagedorn (University of Waterloo), Robert King (Memorial University) and Jamie Sapera (Brock University). GIS and field database support provided by Matt Pyne and Christine Deblonde (GSC Calgary). Marlene Francis (GSC Calgary) and Danielle Marquette (GSC Ottawa) provided project support. Logistical equipment support for fieldwork was provided by Technical Field Support Services, Polar Continental Shelf Program (Project 058-18). Abigail Alty and Kate Clark (GSC Ottawa) facilitated engagement with the local First Nations and Métis Nations within our operational field area. Dehcho Grand Chief Herb Norwegian is thanked for providing an opportunity at short notice to meet with him and members of the Dehcho Renewable Resource Council to further clarify the goals and objectives of this research activity. Peter Redvers of the Kátł'odeeche First Nation is thanked for his support and communication throughout the development stages of the field program. Helicopter support was provided by Great Slave Helicopters through their partnership with Denendeh Helicopters. Bob Head, of Digaa Enterprises Limited (Fort Providence) provided support for accessing stratigraphic sections along the Mackenzie River by jet boat. Michael Vandell of the Deh Gáh Got'ie First Nation is gratefully acknowledged for being a valuable connection to the local communities, and for his skill as a jet boat pilot; his knowledge of the upper Mackenzie River was beneficial to our research. Assistance in the field and wildlife monitoring out of Fort Providence was provided by James Nadli and Alan Farcy (Deh Gáh Got'ie First Nation). Pat Martel (Kátł'odeeche First Nation) is thanked for his assistance with fieldwork in the Cameron Hills. Fieldwork at Pine Point was conducted safely with wildlife monitoring provided by Tom Unka (Denínu Kųę First Nation) and John Delorma (Fort Resolution Métis Nation). The provision of information, samples and overburden thickness data from recent drill cores in the Pine Point mining district by Stanley Clemmer, Marten King and Konstantin Lesnikov of Pine Point Mining Limited (Osisko Metals Incorporated) is gratefully acknowledged. M.B. McClenaghan (GSC Ottawa) is thanked for her review of this report. This research was conducted under Northwest Territories Scientific Research Licence No. 16226.

References

McClenaghan, M.B., Paulen, R.C., and Oviatt, N.M., 2018. Geometry of indicator mineral and till geochemistry dispersal fans from the Pine Point Mississippi Valley-type Pb-Zn district, Northwest Territories, Canada; Journal of Geochemical Exploration, v. 190, p. 69-86. doi:10.1016/j.gexplo.2018.02.004

Oviatt, N.M., Gleeson, S.A., Paulen, R.C., McClenaghan, M.B., and Paradis, S., 2015. Characterization and glacial dispersal of indicator minerals associated with the Pine Point Mississippi Valley-type (MVT) district, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 52, p. 776-794. doi:10.1139/cjes-2014-0108

Paulen, R.C., Smith, I.R., Day, S.J.A., Hagedorn, G.W., King, R.D., and Pyne, M.D., 2017. GEM2 Southern Mackenzie Surficial Activity 2017 report: surficial geology and heavy mineral studies in southern Northwest Territories; Geological Survey of Canada, Open File 8322. doi.org:10.4095/306090

Poitras, S.P., Pearson, D.G., Hardman, M.F., Stachel, T., Nowell, G.M., and Cairns, S., 2018. Evidence for a 200 km thick diamond-bearing root beneath the Central Mackenzie Valley, Northwest Territories, Canada? Diamond indicator mineral chemistry from the Horn Plateau and Trout Lake regions; Mineralogy and Petrology, published online: https://doi.org/10.1007/s00710-018-0641-4

Rice, J.M., Paulen, R.C., Menzies, J., McClenaghan, M.B. and Oviatt, N.M. 2013. Glacial stratigraphy of the Pine Point Pb-Zn mine site, Northwest Territories. Geological Survey of Canada, Current Research, 2013-5, p. 1-14. doi:10.4095/292184

Watson, D.M., 2011a. Sambaa K'e Candidate Protected Area Phase II Non-renewable Resource Assessment – Minerals, Northwest Territories, Parts of NTS 085D, 095A, B, H; Northwest Territories Geoscience Office, NWT Open File 2010-08.

Watson, D.M., 2011b. Ka'a'gee Tu Area of Interest, Phase II Non-renewable Resource Assessment – Minerals, Northwest Territories, Parts of NTS 85C, 85D, 85E and 85F; Northwest Territories Geoscience Office, NWT Open File 2011-001.

Watson, D.M., 2013. Non-Renewable Resource Assessment (Minerals): Łue Túé Sųlái Candidate Protected Area, NTS 095H6 & 095H7; Northwest Territories Geoscience Office, NWT Open File 2013-03.

Surficial Geology and Drift Isopach Mapping

I. Rod Smith[1], Roger C. Paulen[2], Christine Deblonde[1], Grant W. Hagedorn[3], Robert D. King[4] and Matt D. Pyne[2]

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Introduction

In this second year of fieldwork (Paulen et al., 2017), the surficial geology mapping and sediment sampling program expanded the geographical area of operations largely throughout map areas NTS 85F (Falaise Lake) and 85G (Sulphur Bay; Fig. 2.1). Additional samples and site investigations were conducted in NTS 85C (Tathlina Lake) to fill in sampling gaps from summer 2017, and to further investigate aspects of the surficial geology. Field investigations of surficial geology, ice-flow history, and the collection of till samples for indicator minerals and matrix geochemistry were conducted almost exclusively by helicopter because of the remoteness of the terrain. Ground-truthing and sample collections will be used to aid aerial photograph interpretations of the regional surficial geology and the production of 1:100 000 scale maps in each of these three areas. The field research undertaken this past summer was conducted in or around the traditional territories of the Deh Gáh Got'ie Koe, Ka'a'gee Tu, Kátł'odeeche, West Point, and Denínu Kųę First Nations, and the Fort Providence, Hay River and Fort Resolution Métis Nations.

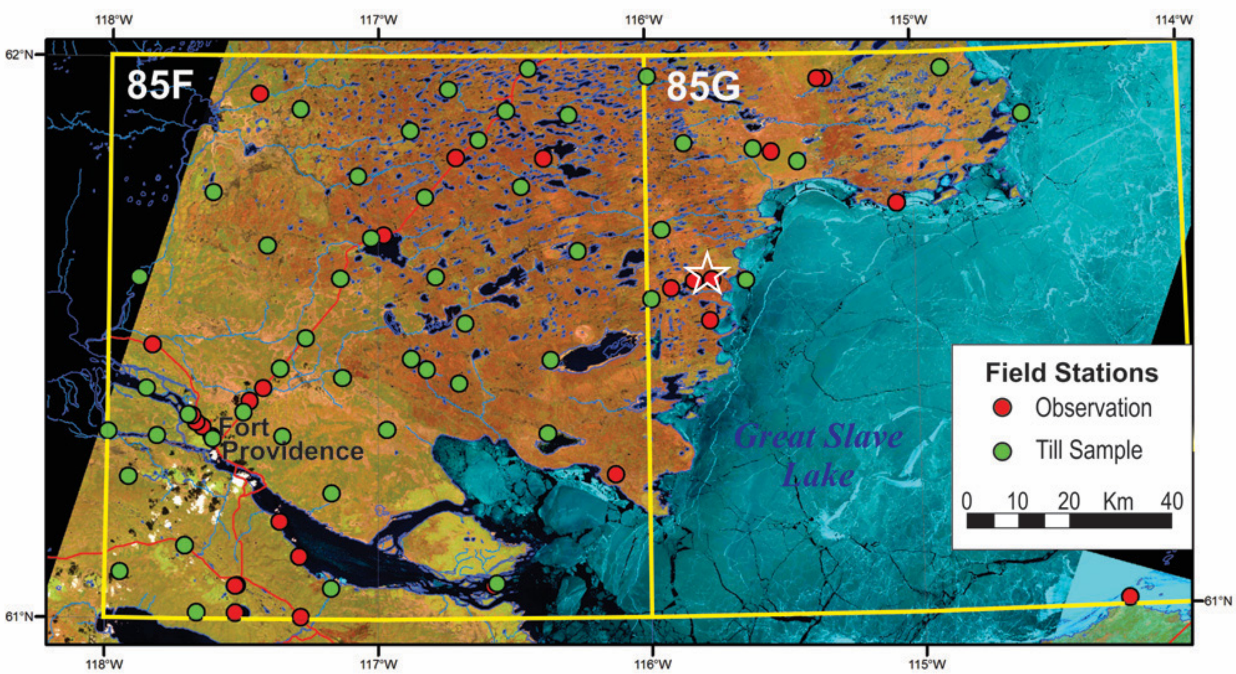

Figure 2.1. Landsat-8 imagery base map of the principal 2018 summer surficial geology field area (NTS maps 85F and G), Fort Providence, Northwest Territories region. Observation and till sample sites for heavy mineral and geochemical surveys over the two summers of fieldwork (2017, 2018) are depicted. The white star indicates the location of the former Qito mineral exploration claim.

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Smith, I.R., Paulen, R.C., Deblonde, C., Hagedorn, G.W., King, R.D., and Pyne, M.D., 2019. Surficial geology and drift isopach mapping; *in* GEM-2 Southern Mackenzie Surficial Activity 2018 report: Surficial Geology and Heavy Mineral Studies in Southern Northwest Territories, (eds.) R.C. Paulen, I.R. Smith and S.J.A. Day; Geological Survey of Canada, Open File 8477, p. 7-16. http://doi.org/10.4095/313421

Quaternary Glacial History

A review of the Quaternary glacial history of the study area was previously discussed by Smith et al. (in Paulen et al., 2017), to which the reader is referred. Of particular note to the two map areas of focus this past summer (85F and G), was the formation and retreat of glacial Lake McConnell, which would have completely inundated both map areas (Fig. 2.2). Glacial Lake McConnell formed within an isostatically depressed basin along the eastward retreating margin of the Laurentide Ice Sheet between ~10 to 8.5 ^{14}C ka BP (Dyke, 2004; Lemmen et al., 1994). By 8.5 ^{14}C ka BP, meltwater from the Laurentide Ice Sheet no longer flowed into the Mackenzie drainage basin and glacial Lake McConnell shrunk to form three separate basins (Great Bear, Great Slave and Athabasca; Fig. 2.2). Largely as a consequence of decantation by glacioisostatic uplift, each of the basins progressively shrank to their modern limits (Lemmen et al., 1994; Smith, 1994). In a national-scale surficial geology map compilation (Fulton, 1995), the southern half of map area 85F is indicated to be covered by fine-grained glaciolacustrine sediments, while its north half and all of northwestern 85G is covered by fluted, till blanket.

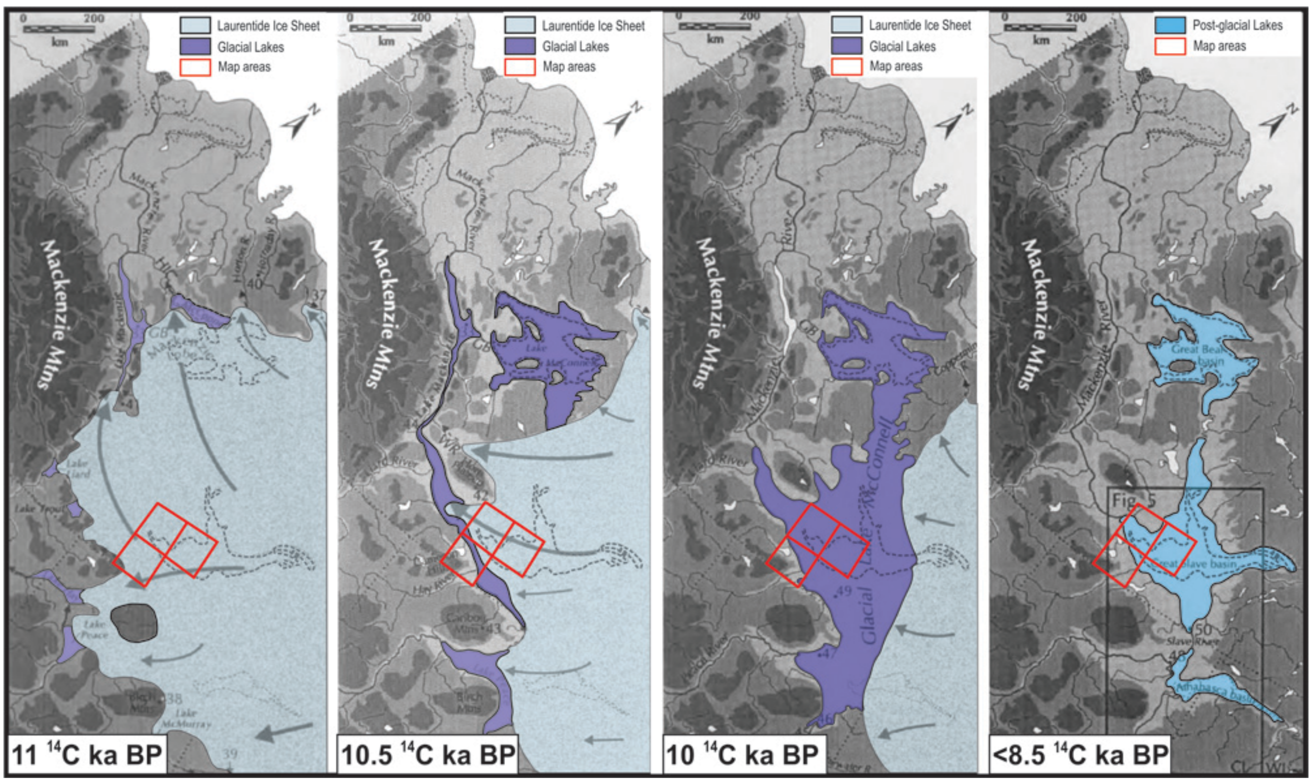

Figure 2.2. Retreat of the Late Wisconsinan Laurentide Ice Sheet from the study area and the formation and drainage of glacial Lake McConnell (modified from Lemmen et al., 1994). Area of surficial geology mapping outlined in red. Dashed grey line underlying the red boxes indicates present day Great Slave Lake.

Drift Isopach Reconstructions and Implications for Mineral Exploration

The term "drift" collectively describes all unconsolidated sediments overlying bedrock, and includes the likes of till, glaciolacustrine, fluvial, eolian, and organic matter (bogs and fens). Within the Southern Mackenzie Surficial activity study area, there is wide variability in the thickness of drift. It ranges from zero, where bedrock is exposed along the rim of the Devonian platform carbonates traversed by Highway 1, to sites within some of the reef and platform carbonate karst collapse structures around Pine Point that exceed 100 m (K. Lesnikov, Pine Point Mining Ltd., pers. comm., 2018). Understanding the nature and distribution of this drift cover is significant for many reasons.

Where drift is shallow, there may be a more dynamic/direct interaction between surface processes or development activities and underlying groundwater and lateral aquifer diffusion, particularly when underlain by a relatively impermeable bedrock. By comparison, thicker drift may more broadly integrate meteorological and potential surface contaminant inputs into deeper, regional aquifer systems, with slower outward diffusion. Thickness of drift can also affect the depth and relative stability of permafrost. In general, water saturated drift has a much lower thermal diffusivity (the ratio of thermal conductivity to volumetric heat capacity) than that of bedrock (Gold and Lachenbruch, 1973; Smith, 1993). Areas of thicker, saturated drift are therefore likely to retain both greater depths of freezing and be less responsive to changes in surface air temperature and related environmental parameters.

Thicknesses of drift specifically derived from glacial deposition (e.g., till) can be used to deduce former glacier-bed processes (cf., Evans, 2018). In areas where the Laurentide Ice Sheet flowed up-slope, it can be expected that under compressive flow, the glacier would have more actively quarried and entrained bed materials (sediments and/or bedrock), leading to thinner drift. On down-slopes, or in the lee of obstacles such as prominent bedrock steps, extending flow would lead to greater deposition and accumulation of drift (Boulton, 1974, 1996). While this simple "steady-state" flow model may hold for much of the area immediately south of Great Slave Lake, the presence of extensive flutings and mega-scale glacial lineations (MSGL; Clark et al., 2003) in northern and central 85F and 85G, and over much of the upper Cameron Hills (85C), are evidence of past ice streams. Where such landforms occur, it can be expected that significant deformation, ploughing, and entrainment of subglacial debris occurred such that drift thicknesses are more reflective of glacial bed processes, and are largely independent of topography (cf., King et al., 2009; Stokes et al., 2013).

Of particular significance to drift prospecting and the study of mineral dispersal is the understanding that the thickness and distribution of drift can be critical to determining where glaciers may have been in direct contact with bedrock, and where thicker, pre-existing drift cover may have capped underlying bedrock, inhibiting direct contact and quarrying of mineralized bedrock. Similarly, where drift overlying bedrock is thin, indicator minerals recovered from surface till samples are more likely to be locally derived. In areas of thicker drift, the dispersal plume of indicator minerals becomes more and more diffuse as material is deposited and then re-entrained and admixed with further sediments downflow (cf., McClenaghan and Paulen, 2018; Fig. 2.3).

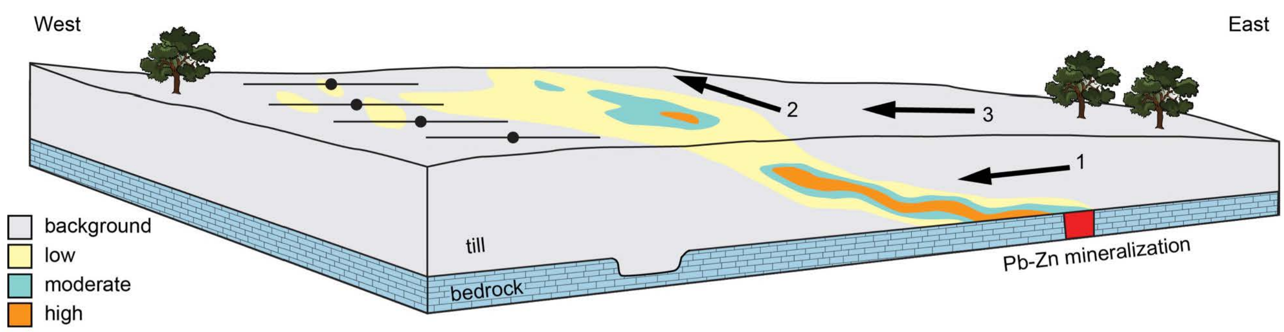

Figure 2.3. Conceptual model illustrating how indicator mineral traces of mineralized bedrock extend and diffuse down-glacier flow of the outcrop source. The concentration of indicator minerals rise vertically and diffuse laterally as the till cover progressively accretes and undergoes shifts in glacier flow direction (figure reproduced from McClenaghan et al., 2018).

Methods

Till Sampling

Samples of till were collected throughout the 85F and 85G study areas at an approximate 10-15 km spacing. Sample sites were accessed almost exclusively by helicopter, and landing areas were found often with great difficulty in former forest burn sites, or along the margins of bogs, fens and lakes. Till sample collection and quality control guidelines followed established GSC protocols (Spirito et al., 2011; McClenaghan, et al., 2013; Plouffe et al., 2013). Holes were dug using hand shovels 60-140 cm, until unoxidized soil profiles within the underlying parent material (till) Ck-horizon were reached. Specially selected and treated sampling shovels were used in order to reduce potential metallic contamination, and vigorously cleaned between each sample site to avoid potential carry-over contamination. Two samples were collected at each site. The first constituted a 19 litre (5 gallon) plastic pail of till (~25 kg) which was designated for heavy mineral concentrate (HMC) processing according to the methodology outlined by McClenaghan (2011). The second was a 3 to 5 kg bag of sediment for geochemical analysis, particle size determinations, Munsell colour, loss on ignition (LOI), Chittick (carbonate) analysis, and archiving.

Drift Isopach

Three sources of data are available for reconstructing drift thickness in the study area (Fig. 2.4). The greatest abundance of records (n=15,043; Fig. 2.4) relate to seismic shothole drillers' logs (Smith and Lesk-Winfield, 2010; Smith, 2015). Averaging 18.6 m deep, these records provide simple stratigraphic logs, that delineate: (i) absolute drift thickness (e.g., 0-8 m clay, gravel, rocks; 8-20 m shale; drift thickness = 8 m; n=3684), (ii) minimum estimates of drift thickness (e.g., 0-20 m clay, sand, gravel; drift thickness >20 m; n=8811), or (iii) maximum estimates of drift thickness (e.g., 0-20 m clay, rocks, shale; drift thickness <20 m; n=2548). A second set of lithostratigraphic records comes from diamond drill holes from regional mineral exploration activities (n=993; Fig. 2.4). These records are principally derived from Mineral Exploration Assessment Reports stored by the Northwest Territories Geological Survey on their NT_GoData web application (e.g., Carter, 1980; Turner et al., 2002). While these drill logs tend to give the most accurate measurements of drift thickness, they typically contain no or little lithostratigraphic descriptions of the drift materials themselves. The final set of records are derived from petroleum well logs (n=116; Janicki, 2005). These well logs also typically have little in the way of lithostratigraphic characterization of the drift and, if reported, simply convey the thickness of drift overlying the upper bedrock contact. In some cases, these records appear suspect, and may instead relate to casing depths, rather than exact drift thicknesses (Smith and Lesk-Winfield, 2010).

The diamond drill hole exploration records typically report the presence and thickness of overlying Hay River shale when present. The seismic shothole driller's logs can be used cautiously to identify where underlying bedrock is shale, sandstone, or limestone (carbonate). Using the two records together, it may be possible to identify areas or channels of preferential glacial erosion where all the shale has been removed. Combining this information with ore-mineral indicator data (cf., Day et al. 2018), may further help to identify potential bedrock source areas and glacial dispersal trajectories.

Results

Field observations of the surficial geology were made at 72 ground stations in map areas 85F and 85G during the 2018 field season (see Figure 1.2 at the end of this report). From these sites, 54 till samples were collected for recovery of base metal and other indicator minerals, and for matrix geochemical analysis. These samples add to the 28 ground stations and 17 samples collected in these same map areas in the 2017 field season (Paulen et al., 2017). All till samples have been submitted to Overburden Drilling Management Limited (ODM) for processing and heavy mineral identification and picking. Geochemical and isotopic analysis of recovered kimberlite (diamond) indicator mineral (KIM) grains will proceed subsequently through the University of Alberta, Arctic Resources

Laboratory. Any sphalerite ((Zn,Fe)S) and galena (PbS) grains recovered from the till samples will be included in the research of King (see Chapter 6 of this report).

Much of the central, eastern and northern parts of the study area (85F and 85G) are heavily fluted, indicating a southwestern ice flow direction. These southwest flutes appear overprinted on a prior northwestern flow. Iceberg scours are most prominent in 85G and the southern and eastern parts of 85F, but occur throughout the study area, including those regions dominated by flutings. The iceberg scours relate to inundation by glacial Lake McConnell and the retreat of a calving ice-contact margin. Scours are typically aligned NW-SE, likely reflecting katabatic wind flow direction to the southeast off the retreating LIS. The study area has very little topographic relief, and bogs and fens abound in this low-lying, poorly drained terrain. Where peat accumulations are thicker, frozen ground was frequently encountered at shallow depths (<30 cm). It is unknown if this simply represents seasonally frozen ground that had yet to thaw, or whether it occurred within a seasonally developing active layer overlying discontinuous permafrost. Morphologies of large (>1 km diameter) raised peat plateaux and pervasive raised peatlands with sparse stunted black spruce trees suggest the presence of underlying, discontinuous permafrost. Abundant relict and active thermokarst ponds, particularly in areas of fine-grained glaciolacustrine sediment cover, illustrate locally degrading permafrost.

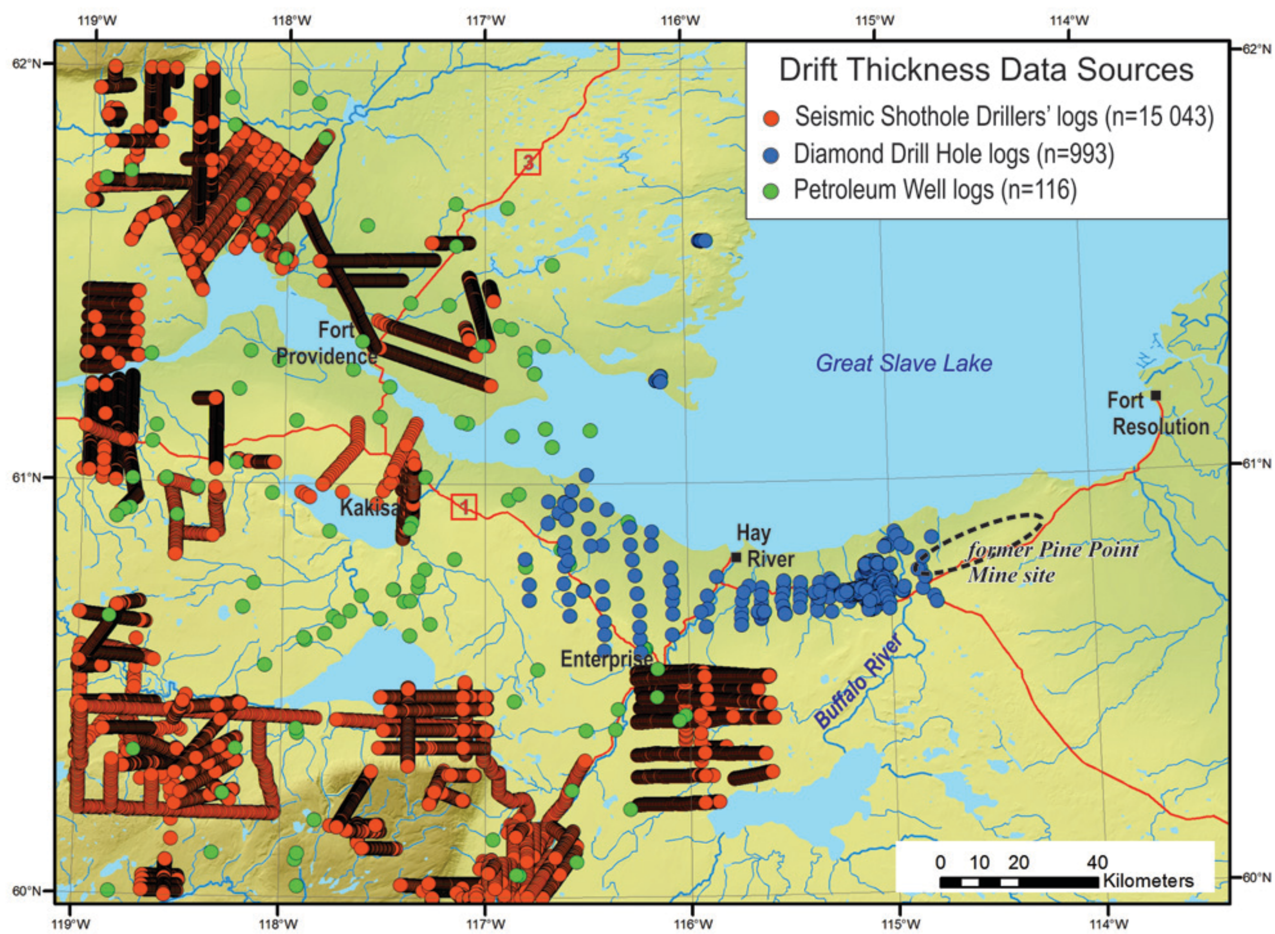

Figure 2.4. Distribution of different drill log records used to create a regional drift thickness (isopach) map.

While all of the study area in the two map sheets was inundated by glacial Lake McConnell (Fig. 2.2), the distribution of glaciolacustrine sediments is neither ubiquitous nor thick in most areas. The most prevalent sediment assemblage associated with glacial Lake McConnell is a winnowed till lag of cobbles and boulders lying at surface. Typically this lag overlies no more than 50 cm of reworked till, and often as little as 10 cm of material. The absence of accumulations of fines over much of the central, northern and western parts of map area 85F, suggests that the majority of fines have been deposited elsewhere, or were discharged down the proto-Mackenzie River. Thicker accumulations of silt and sand deposits were found extending 20 km north of the Mackenzie River, and bordering the western shores of Great Slave Lake. Thick sand deposits and a characteristic pattern of shallow, relict and active thermokarst lakes are found in northwestern 85G, and are interpreted as evidence of littoral (shallow water) glaciolacustrine/lacustrine deposition.

One locality in central 85F (61°41.5'N; 116°59.2'W) preserves an esker-subaquatic fan complex (Fig. 2.5). It is interpreted that the eskers formed beneath a retreating grounded ice sheet whose western margin was situated within (ice-contact) glacial Lake McConnell. Where the esker channels emerged at the base of the ice sheet, fan deposits were formed (Fig. 2.5; cf., Dowdeswell et al., 2015). The landform exhibits two main eskers, the largest and highest (~15-20 m relief) of which is at the north end of the landform and is where the local communication and fire watch towers are situated. Sections exposed in former gravel pit operations within the largest esker reveal an inverse grading and concentration of large boulders (0.5-3 m in diameter) near and at the top of the esker ridge. This inverse grading may relate to increasing discharge flow velocities as the subglacial conduit filled and the effective channel depth narrowed, or the progressive depletion of debris-rich ice, and the winnowing of fines as meltwater continued to drain through the channel (cf., Shaw, 1972). Interestingly, while the subaqueous fan and esker ridges are criss-crossed by iceberg scours, areas immediately outside the esker/subaquatic fan complex do not have, or did not preserve, similar iceberg scours. The differences in elevation are slight (10-15 m), suggesting perhaps that minor glaciolacustrine lake elevations locally controlled depth of iceberg scouring, either immediately after the subaquatic fan landform was created, or later as the ice sheet retreated and the level of glacial Lake McConnell was declining.

The only bedrock outcrops identified in the study area occur in proximity to the western shore of Great Slave Lake and include Presquile dolomite in the Middle Devonian Elk Point Group (Okulitch, 2006), and also the site of the former Qito mineral exploration claim (Lane, 1980) where cubic galena crystals were observed in the bedrock (Fig. 2.6). Lower Devonian Mirage Point Formation argillaceous sediments (Okulitch, 2006) outcrop at Gypsum Point and their distinctive red rocks can be seen in glacial sediments throughout NTS 85G. No striae or other glacial flow direction indicators were preserved on the generally deeply weathered bedrock surfaces.

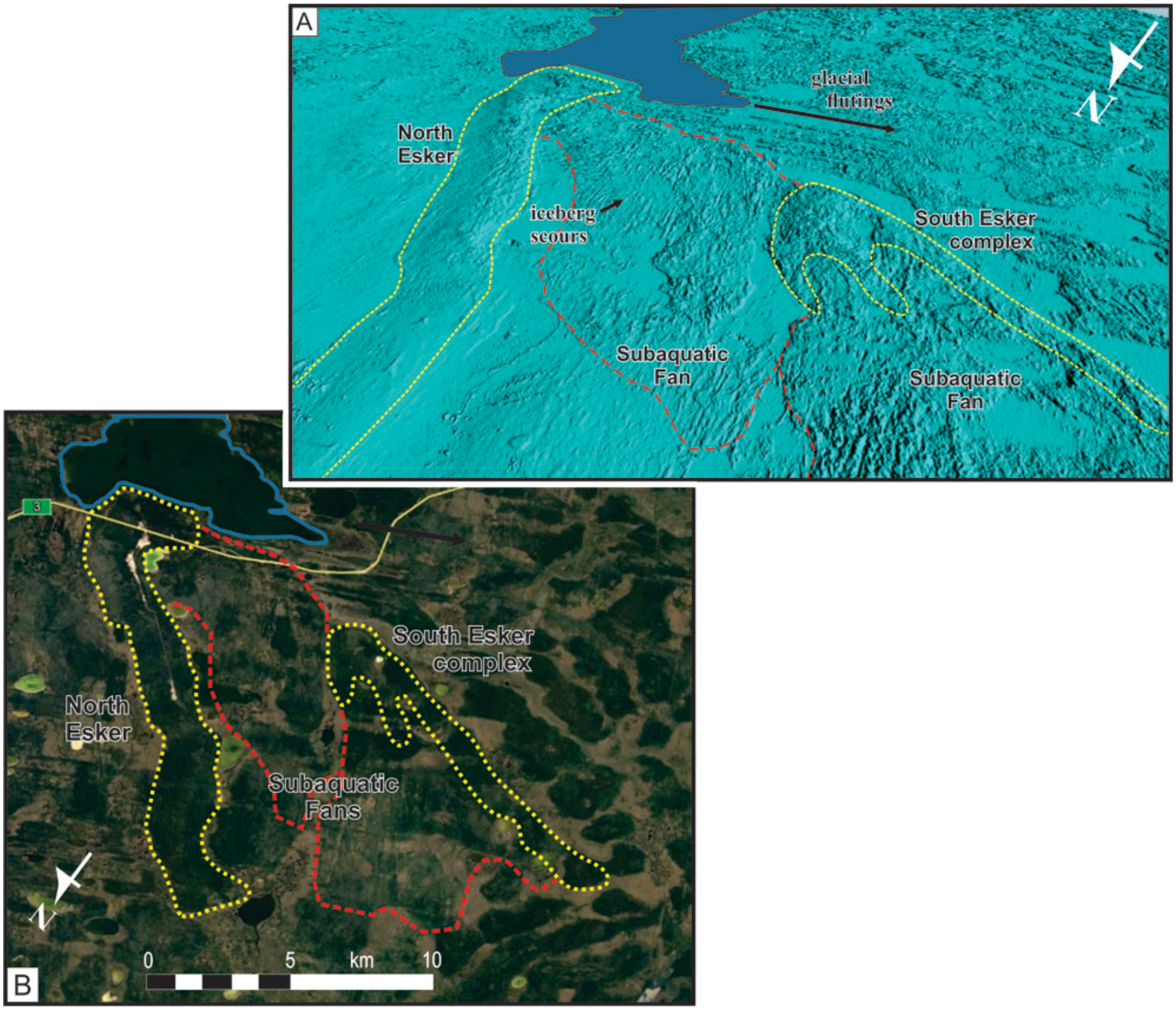

Figure 2.5. Esker and subaquatic fan complex, NTS 85F. (A) Oblique view looking west on an ArcticDEM image base. Flow of eskers and fans was towards the viewer. Glacial flutings aligned southwest, and predate (overlain by) esker-fan complex. (B) Google Earth plan view image of the same site.

Future Work

The GEM-2 Southern Mackenzie Surficial activity has now completed its surficial geology-related field mapping and till sample collection work. Focus is now on continuing processing and analysing samples, and the production of 1:100 000 scale surficial geology maps throughout map sheets 85C and 85F, and 1:250 000 scale for 85G. We are encouraged by the results of the 2017 stream sediment survey (Day et al., 2018), and hope that till samples collected in the summer of 2018, combined with those collected in 2017, will further refine our understanding of regional indicator mineral dispersal and mineral prospectivity of the southern Northwest Territories.

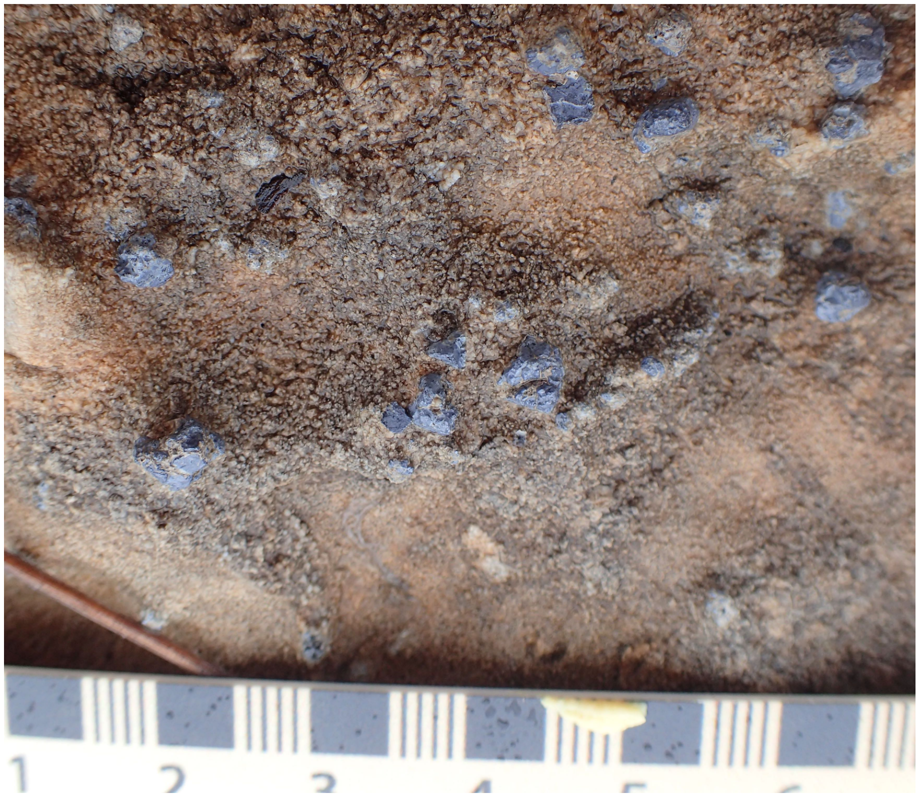

Figure 2.6. Cubic galena crystals on the weathered dolomite surfaces at the former Qito exploration claim (scale in cm).

References

Boulton, G.S., 1974. Process and patterns of glacial erosion; *in* Glacial Geomorphology, (ed.) D.R. Coates; State University of New York, Binghamton, p. 41-87.

Boulton, G.S., 1996. Theory of glacial erosion, transport and deposition as a consequence of subglacial sediment deformation; Journal of Glaciology, v. 42, p. 43-62.

Carter, K.M., 1980. Assessment Report: Geological, Geochemical and Geophysical report for the Hay West Exploration program; Assessment Report 081224, Northwest Territories Geological Survey.

Clark, C.D., Tulaczyk, S.M., Stokes, C.R., and Canals, M., 2003. A groove-ploughing theory for the production of mega-scale glacial lineations, and implications for ice-stream mechanics; Journal of Glaciology, v. 49, no. 165, p. 240-256.

Day, S.J.A., Paulen, R.C., Smith, I.R., and King, R.D., 2018. Heavy-mineral and indicator-mineral data for stream sediments in southwest Northwest Territories: new potential for undiscovered mineralization; Geological Survey of Canada, Open File 8362. doi:10.4095/306587

Dowdeswell, J.A., Hogan, K.A., Arnold, N.S., Mugford, R.I., Wells, M., Hirst, J.P.P., and Decalf, C., 2015. Sediment-rich meltwater plumes and ice-proximal fans at the margins of modern and ancient tidewater glaciers: observations and modelling; Sedimentology, v. 62, p. 1665-1692. doi: 10.1111/sed.12198

Dyke, A.S., 2004. An outline of North American deglaciation with emphasis on central and northern Canada; *in* Quaternary Glaciations – Extent and Chronology, Part II, (eds.) J. Ehlers and P.L Gibbard; Developments in Quaternary Science, 2B; Elsevier, Amsterdam, p. 373-424.

Evans, D.J.A. 2018. Till: a glacial process sedimentology. John Wiley & Sons Ltd., 390 p.

Fulton, R.J., 1995. Surficial materials of Canada; Geological Survey of Canada, "A" Series Map 1880A, scale 1:5 000 000. doi:10.4095/

Gold, L.W. and Lachenbruch, A.H., 1973. Thermal Conditions in Permafrost: a review; *in* Proceedings of the Second International Conference on Permafrost, Yakutsk, USSR, North American Contribution, Washington, DC: National Academy of Sciences, p. 3-25.

Hannigan, P.K., 2006. Introduction; *in* Potential for Carbonate-hosted Lead-Zinc Mississippi Valley-type Mineralization in Northern Alberta and Southern Northwest Territories: Geoscience Contributions, Targeted Geoscience Initiative; (ed.) P.K. Hannigan; Geological Survey of Canada, Bulletin 591, p. 9-39. doi:10.4095/222883

Janicki, E. 2005. Northwest Territories Formation Tops, 60-68° North. Northwest Territories Geoscience Office, Open Report 2005-006.

King, E.C., Hindmarsh, R.C.A., and Stokes, C.R., 2009. Formation of mega-scale glacial lineations observed beneath a West Antarctic ice stream; Nature Geoscience, v. 2, p. 585-588. doi:10.1038/NGEO581

Lane, R.W., 1980. Assessment report for program of geological investigation of soil geochemical and geophysical (I.P.) anomalies undertaken on Qito claims 2, 9, and 74, Mackenzie M.D., Northwest Territories; Assessment Report 081238, Northwest Territories Geological Survey.

Lemmen, D.S., Duk-Rodkin, A., and Bednarski, J.M., 1994. Late glacial drainage systems along the northwestern margin of the Laurentide Ice Sheet. Quaternary Science Reviews, v. 13, p. 805-828.

McClenaghan, M.B., 2011. Overview of common processing methods for recovery of indicator minerals from sediment and bedrock in mineral exploration; Geochemistry: Exploration, Environment, Analysis, v. 11, p. 265-278. doi:10.1144/1467-7873/10-IM-025

McClenaghan, M.B. and Paulen, R.C., 2018. Application of Till Mineralogy and Geochemistry to Mineral Exploration; *in* Past Glacial Environments, 2nd Edition; (eds.) J. Menzies and J.J.M. van der Meer; Elsevier, p. 689-751.

McClenaghan, M.B., Plouffe, A., McMartin, I., Campbell, J.E., Spirito, W.A., Paulen, R.C., Garrett, R.G., and Hall, G.E.M., 2013. Till sampling and geochemical analytical protocols used by the Geological Survey of Canada; Geochemistry: Exploration, Environment, Analysis, v. 13, p. 285-301. doi:10.1144/geochem2011-083

McClenaghan, M.B., Paulen, R.C., and Oviatt, N.M. 2018. Geometry of indicator mineral and till geochemistry dispersal fans from the Pine Point Mississippi Valley-type Pb-Zn district, Northwest Territories, Canada; Journal of Geochemical Exploration, v. 190, p. 69-86. doi:10.1016/j.gexplo.2018.02.004

Okulitch, A.V., (compiler), 2006. Phanerozoic Bedrock Geology, Slave River, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Open File 5281, scale 1:1 000 000. doi:10.4095/222163

Paulen, R.C., Smith, I.R., Day, S.J.A., Hagedorn, G.W., King, R.D., and Pyne, M.D., 2017. GEM2 Southern Mackenzie Surficial Activity 2017 report: surficial geology and heavy mineral studies in southern Northwest Territories; Geological Survey of Canada, Open File 8322. doi:10.4095/306090

Plouffe, A., McClenaghan, M.B., Paulen, R.C., McMartin, I., Campbell, J.E., and Spirito, W.A., 2013. Processing of glacial sediments for the recovery of indicator minerals: protocols used at the Geological Survey of Canada; Geochemistry: Exploration, Environment, Analysis, v. 13, p. 303-316. doi:10.1144/geochem2011-109

Shaw, J., 1972. Sedimentation in the ice-contact environment, with examples from Shropshire (England); Sedimentology, v. 18, p. 23-62.

Smith, D.G., 1994. Glacial Lake McConnell: paleogeography, age, duration and associated river deltas, Mackenzie River basin, western Canada; Quaternary Science Reviews, v. 13, p. 829-843.

Smith, I.R., 2015. Seismic shothole drillers' lithostratigraphic logs: unearthing a wealth of regional geoscience information in northwestern Canada; GeoResJ, v. 6, p. 21-29. doi:10.1016/j.grj.2015.01.005

Smith, I.R. and Lesk-Winfield, K., 2010. Drift isopach, till isopach, and till facies reconstructions for Northwest Territories and northern Yukon; Geological Survey of Canada, Open File 6324, 1 .zip file. doi:10.4095/261783

Smith, M.W., 1993. Climate Change and Permafrost; in Canada's cold environments, (eds.) H.M French and O. Slaymaker; McGill Queen's University Press, Montréal, QC, p. 291-311.

Spirito, W.A., McClenaghan, M.B., Plouffe, A., McMartin, I., Campbell, J.E., Paulen, R.C., Garrett, R.G., and Hall, G.E.M., 2011. Till Sampling and Analytical Protocols for GEM Projects: from field to archive; Geological Survey of Canada, Open File 6850. doi:10.4095/300281.

Stokes, C.R., Spagnolo, M., Clark, C.D., Ó Cofaigh, C., Lian, O.B., and Dunstone, R.B., 2013. Formation of mega-scale glacial lineations on the Dubawnt Lake Ice Stream bed: 1. size, shape and spacing from a large remote sensing dataset. Quaternary Science Reviews, v. 77, p. 190-209. doi:10.1016/j.quascirev.2013.06.003

Turner, W.A., Pierce, K.L., and Cairns, K.A., 2002. Great Slave Reef (GSR) Project Drillhole Database. A compilation of the drillhole locations, drill logs, and associated geochemical data for the Great Slave Reef joint venture project: Interior Platform, Northwest Territories, Canada (NTS 85B11 to 14); NWT Open Report 2002-001, C.S. Lord Northern Geoscience Centre, Yellowknife, NT.

Surficial Geology Constraints on Laurentide Ice Sheet Reconstruction in the Southern Northwest Territories

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Introduction

Paleo-ice sheet reconstructions define ice flow directions, ice margin positions, glacial lake levels, and other aspects of ice dynamics. The Laurentide Ice Sheet (LIS) last advanced into western Canada during the Late Wisconsin (24-10 ka BP), and at its maximum ice extent (~21 ka BP) covered the majority of Canada (Dyke, 2004). Many continental-scale LIS reconstructions have been completed and are useful for defining general ice-flow and margin locations (cf., Dyke and Prest, 1987; Dyke, 2004; Tarisov and Peltier, 2004; Margold et al., 2018), but for mineral exploration applications, region- and site-specific information is required. A knowledge gap in detailed- and regional-scale understanding of the LIS exists over its western margin in the southern Northwest Territories area surrounding southwestern Great Slave Lake.

Previous glacial reconstructions in southern Northwest Territories indicate a general westward flow toward a coalescent LIS – Cordilleran Ice Sheet (CIS) margin, parallel to the mountain front (Dyke and Prest, 1987). Further refinement of glacial flow history is provided by Rice et al. (2013) and Oviatt et al. (2015), who through bedrock striae and till clast fabric analyses, concluded that three major flow phases affected the region: the oldest to the southwest (230°); followed to the northwest (300°), and finally to the south-southwest (250°). Based on optical dating ages (Wolfe et al., 2004; Oviatt and Paulen, 2013), Great Slave Lake's southwestern shore is estimated to have been ice- and glacial lake-free by ~11.5 ka BP. The LIS in this area retreated in contact with proglacial lakes that grew in size and coalesced to form glacial Lake McConnell which inundated the study area. Shortly after ~ 9 ka BP, LIS meltwater no longer fed westward into the glacial Lake McConnell basin, and the lake progressively isostatically decanted (Fisher and Smith, 1994; Lemmen et al., 1994; Dyke, 2004).

The southern Northwest Territories region has been identified as prospective for lead-zinc mineralization (Hannigan, 2006). However, limited understanding of the erosional and depositional influence that the Late Wisconsin glaciation had on the landscape hinders mineral exploration. A better understanding of ice-flow history and sediment deposition can help mineral exploration by deciphering dispersal patterns that may have been impacted by multiple ice-flow directions (Rice et al., 2013; Oviatt et al., 2015; McClenaghan et al., 2018).

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Hagedorn, G.W., Paulen, R.C., Smith, I.R., Ross, M., Neudorf, C.M., and Lian, O.B., 2019. Surficial geology constraints on Laurentide Ice Sheet reconstruction in the southern Northwest Territories; *in* GEM-2 Southern Mackenzie Surficial Activity 2018 report: Surficial Geology and Heavy Mineral Studies in Southern Northwest Territories, (eds.) R.C. Paulen, I.R. Smith and S.J.A. Day; Geological Survey of Canada, Open File 8477, p. 17-26. http://doi.org/10.4095/313422

The goal of this research is to use a wide array of data to create a detailed LIS reconstruction over NTS sheets 85C, 85F and 85G, at the southwestern shore of Great Slave Lake (Fig. 3.1; Paulen et al., 2017). Methods include erosional bedrock ice-flow indicators measurements, clast fabric analysis, glacial sedimentology, geochronology, and geomorphological and surficial geology mapping. Each method provides distinct information about ice flow chronology and deglaciation, that when combined, allows for a holistic reconstruction of the western LIS.

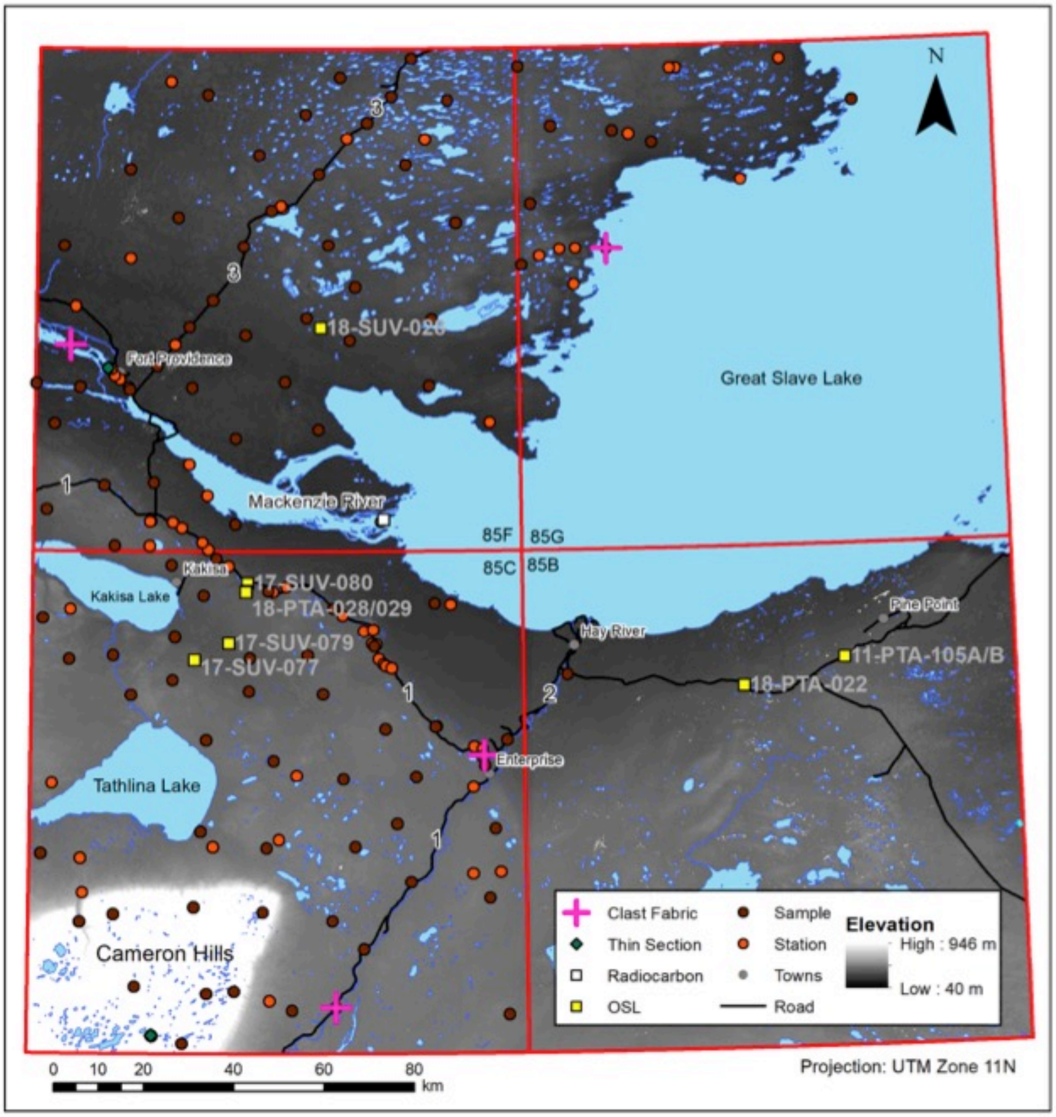

Figure 3.1. Sample sites throughout the study area. Note some locations have multiple sample types.

Methods

Bedrock Erosive Features

Debris embedded in the base of flowing glaciers act as erosive tools as the glacier moves across bedrock outcrops. As a result, bedrock outcrops are eroded and polished, leaving multiple ice movement direction indicators (Rea et al., 2000; McMartin and Paulen, 2009). Bedrock erosive features are particularly useful in deciphering multiple ice-flow directions where cross-cutting and overprinting of older forms are present. Bedrock outcrops are rare within the study area, due to an extensive Quaternary sediment cover. Furthermore, exposed bedrock is soft Paleozoic carbonates, which tend to weather and erode easily, reducing preservation potential of erosional features. At prospective bedrock outcrops, specifically sites where the bedrock was protected by thin sediments, the overlying sediment layer was carefully removed and the exposed bedrock surface brushed and cleaned with water. The orientation of striations, grooves, and larger p-forms were recorded as ice-flow indicators. Measurements were obtained at 52 sites, totaling 66 observations.

Clast Lithology Counts

The 2–32 mm clast (pebble) fraction of 160 till samples was separated for lithological identification and provenance analysis. The pebbles were then acid washed and split into equal volumes. The clasts of one split (n≈300) were classified into 23 different lithological categories based on the local bedrock geology. Results will be incorporated with regional pebble lithology counts previously conducted in the Kakisa Protected Area Strategy (PAS) survey (Watson 2011; Plakholm, 2018). See Plackholm et al. Chapter 7 of this report for full details. This information will help determine till provenance and consequently flow direction during till deposition (Trommelen et al., 2013).

Clast Fabrics

Elongated clasts in till tend to align parallel to the main direction of shear and thus provide useful information about the subglacial stress conditions during till formation (Benn, 2004). Till clast fabric measurements included clast long axis azimuth and dip inclination. The strength and orientation of clast fabrics can be analyzed by plotting the data on a lower hemisphere stereonet and by calculating eigenvalues (S1, S2, S3) and eigenvectors (V1, V2, V3). The first eigenvector (V1) of relatively strong fabrics (S1 > 0.5) is typically used to infer ice flow direction at time of till deposition. To complete a clast fabric a clean till face was dug and 50 clasts with a minimum 2:1 a-axis (longest) to b-axis (perpendicular to a-axis) ratio were excavated. Once removed, an aluminum knitting needle was placed in the cavity to represent the clast long axis and dip which were measured for fabric analysis (cf., Benn, 2004). A till clast fabric was completed at each of four selected sites.

Till Thin Sections

Till thin sections are slices of a larger oriented till block. A total of four samples for thin section preparation were collected throughout the study area. To collect these samples, a fresh vertical till face was cleaned and a metal box (75mm x 55mm x 40mm) was inserted with the 75 mm side oriented parallel to the vertical face. Once completely filled with in-situ till, the depth, orientation, and dip of the box was recorded. The box was then carefully removed, cavities within the box filled with medium-grained sand, and then tightly packed to reduce disturbance of the till block during transport. Thin section boxes were processed at Brock University where they were impregnated with epoxy resin, and cut to reveal the structures of the sediment under microscope (cf., Rice et al., 2014). Till thin section slides are used to determine characteristics like grain orientation, compaction, structure, and grain shear which identify basal ice conditions and flow directions (Hart, 2017).

Stratigraphy

Stratigraphic information important for understanding the temporal changes in ice sheet erosive/depositional conditions (Menzies et al., 2017). Stratigraphic exposures in the study area are concentrated along the Mackenzie River. Otherwise, rare vertical exposures of sediments were found in borrow pits, quarries and road cuts. This past summer, extensive exposures of glacial and glaciolacustrine stratigraphy were investigated along the Mackenzie River channel, accessed by boat. Field methods at stratigraphic sections included description of major units and their sedimentological characteristics such as grain size, sorting, colour, and compaction. All sites were documented photographically. Additional regional stratigraphic data are available from seismic shothole drillers' log records (Smith and Lesk-Winfield, 2010), and from mineral exploration diamond drill hole records (see Smith et al., Chapter 2, this report). Different stratigraphic logs will be used to assess extents and thickness of different sedimentary units.

Geochronology
Optical dating of eolian and beach sands in addition to radiocarbon dating of organic macrofossils will be applied to constrain the timing of deglaciation and glacial lake history in the study area. Four sand samples collected in 2018 were submitted to the University of Fraser Valley (UFV) to undergo optical dating age determination following the methods of Neudorf et al. (2015) and Wolfe et al. (2018). To collect these samples, 30 cm long, 2” diameter black PVC tubes were hammered horizontally into a vertical section of exposed sand in one beach ridge and several eolian dunes. When full of sand, the tube was excavated and both ends capped to prevent light exposure before transport to UFV for processing. Optical dating was performed on these samples to determine when the sand was last exposed to sunlight, providing a burial age. Optical dating ages from eolian sediments provide a minimum age of deglaciation as dunes form after the landscape is ice and glacial lake free (cf., Munyikwa et al., 2011). Beach sand optical dating ages will constrain the age of glacial Lake McConnell (cf., Hickin et al., 2015) at a specific elevation or lake phase. Two optical ages from eolian dunes along the southern part of Great Slave Lake by Oviatt and Paulen (2013) and four samples collected during the 2017 field season (Paulen et al., 2017) will also be included within this research.

One peat sample was collected at a site where a thick deposit of peat directly overlies till. The sample’s organic macrofossil content and species composition is being assessed at PALEOTEC Services in Ottawa. Suitable fragments of organic material will then be selected for AMS radiocarbon dating at the André E. Lalonde AMS Laboratory in Ottawa. Altogether, the resultant ages will be useful in validating interpretation of ice sheet margins and further constraining deglaciation in the western portion of the LIS.

Surficial Mapping
Landforms are created by a multitude of erosional and depositional glacial processes (Ely et al., 2016; Menzies et al., 2017). Therefore, landform mapping across ancient ice sheet beds provides information on ice-flow directions, and are used to infer basal ice sheet conditions (Evans et al., 1999). Other landforms record former positions of the ice margins and features of the proglacial environments such as glacial lake shorelines and eolian dunes. Landforms throughout the study area are mapped in several ways. Landforms and streamlined landform long axes are digitized and recorded using the 5 m resolution ArcticDEM imagery (Polar Geospatial Center, 2017) and through stereo aerial photograph interpretation. The two methods are then integrated to obtain information about landform orientations, elongation of subglacial landforms, as well as landform associations. Landforms mapped include moraines, meltwater channels, beach ridges, iceberg scours, crevasse ridges, eskers, outwash fans, flutings, and mega-scale glacial lineations (MSGL).

Surficial geology maps document the nature and spatial distribution of features that formed in different environments and provide important detailed information useful for geological reconstructions. Surficial geology will be mapped using stereo aerial photographs (1:60,000 scale) and ArcticDEM imagery, and ground-truthed with observational data collected during fieldwork in 2017 and 2018. Completed maps will be published at 1:100 000 scale.

Preliminary Results
Preliminary results are consistent with previously identified westward ice flow directions and eastward ice margin retreat based on bedrock erosive features, till clast fabrics, pebble lithologies, and landforms in the region (Dyke, 2004; Rice et al., 2013; Oviatt et al., 2015). The 66 bedrock erosive observations show ice-flow trajectories ranging from 200° to 5°. Pebble lithology counts have been partially completed and the results and interpretations are found in Chapter 7 of this report. Overall Canadian Shield clasts present in till samples are consistent with a westward ice-flow across the study

area during the last glaciation. More detailed data analysis will work to establish the sequence of ice flow events using erosive overprinting/crosscutting relationships and stratigraphic correlations with clast fabric measurements and till thin sections.

The stratigraphic analysis along the Mackenzie River has so far revealed two till units below a thin cap of glaciolacustrine sediment. A stratigraphic log from one site is presented in Figure 3.2. Overall, the contact between the two till units is undulating and shows shear deformation extending into the lower till. The till contact also has lodged boulders, mostly contained in the upper till unit, with planed tops that are striated giving a sense of ice-flow direction for the upper till unit. The contact between the till and overlying glaciolacustrine sediments is sharp. A two-till stratigraphy was also observed at three sites along a 15 km stretch of the Mackenzie River, around Fort Providence. At all three sites, till samples were collected to study their composition and provenance, facilitating till correlations.

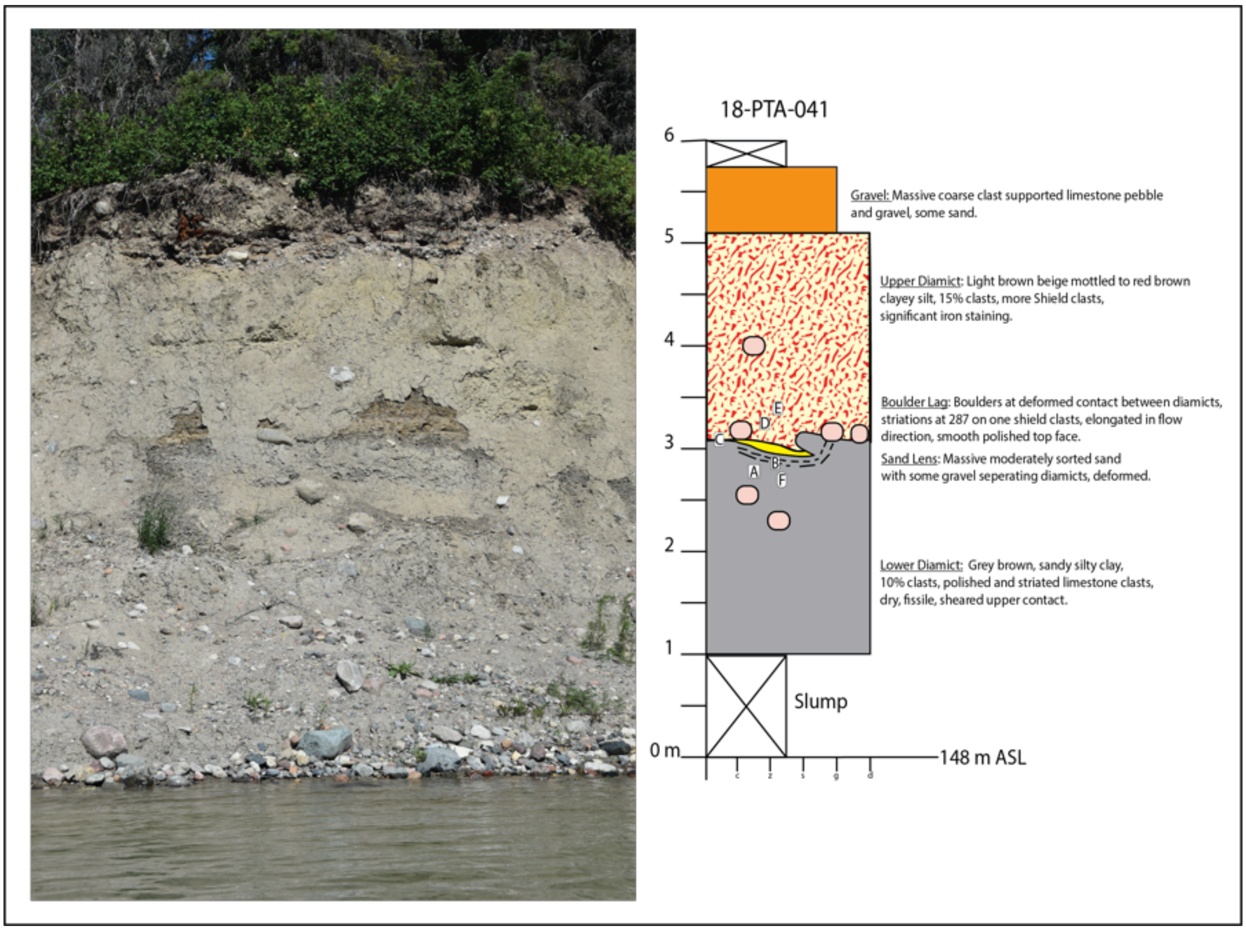

Figure 3.2. Stratigraphic log for site 18-PTA-041 on the north bank of the Mackenzie River, east of Fort Providence, NT. Micromorphology samples are indicated by square boxes (A, B, C, D) and till samples are in circles with sample number indicated as letter (i.e., 18-PTA-041-A). Similar stratigraphy to this site was observed along a 15 km stretch of the Mackenzie River.

Three optical ages from samples collected in 2017 are tightly clustered and correlate well with optical dating ages from surrounding sites, confirming dune forming processes occurred around 10.5 ka ago (Wolfe et al., 2004; Oviatt and Paulen, 2013; Table 3.1). Eolian dunes require both the local retreat of the LIS, and local drainage of glacial Lake McConnell to expose coarse-grained glaciolacustrine and beach sands. The ages from eolian dunes conform to previous ice-free timing estimates in the region. The optical dating ages from samples collected at a beach ridge in northern NTS 85-C will be important for further contextualizing the eolian optical dating ages. The age of the beach ridge is expected to be older than that of the eolian sediments pushing the timing of deglaciation back. The radiocarbon age from the peat sample collected in the Mackenzie River valley will also provide a minimum age of modern Great Slave Lake water levels.

Table 3.1. Optical dating samples and ages for the southwest Northwest Territories (refer to Figure 1 for locations).

Sample Number[1]	Media	Optical age (Corrected Age, ka)[2]
11-PTA-105A	Eolian Dune	11.1 ± 1.1
11-PTA-105B	Eolian Dune	10.5 ± 0.9
17-SUV-077	Eolian Dune	10.5 ± 0.6
17-SUV-079	Eolian Dune	9.9 ± 0.6
17-SUV-080	Eolian Dune	10.8 ± 0.7
18-PTA-022	Eolian Dune	To be determined
18-PTA-028	Beach Ridge	To be determined
18-PTA-029	Beach Ridge	To be determined
18-SUV-028	Eolian Dune	To be determined

[1] Optical ages for samples 11-PTA-105A, -105B are from Oviatt and Paulen (2013). All others are from this study.
[2] Sample ages were corrected for anomalous fading of electrons out of the crystal lattice.

Landform analysis is in the early stages. Nonetheless, several observations have been made. Notably, mega-scale glacial lineations (MSGLs) occur on the Cameron Hills in the southwestern part of the study area. The MSGLs are grouped into two orientations recording two ice flow directions. First, a south-southwest flow is recorded along the southeastern margin of the Cameron Hills that is cross-cut by a prominent set oriented to the southwest. On the northeastern part of the Cameron Hills, a smaller convergent, southeast ice flow is recorded by smaller flutings (Figs. 3.3 and 3.4a). Extensive shorelines have also been observed throughout the study area, and are best developed below the large bedrock escarpment that runs along Highway 1 in NTS 85C (Fig. 3.4b). Shorelines vary in prominence and spacing throughout the study area, indicating variable regression rates, slope, sediment availability, and effective fetch during glacial Lake McConnell's history. Associated with the glacial lake, extensive iceberg scours have also been observed throughout much of northern NTS 85C, southern, central and eastern 85F and northwestern 85G (Fig. 3.4c). These scours were originally identified as anomalous lineaments by Craig (1965). Finally, a large wave-washed moraine sequence has been observed running parallel to glacial Lake McConnell shorelines (Fig. 3.4d). Originally identified further south as the Snake River moraine by Lemmen et al. (1994), the ridges continue in the study area's southern portion. Further work identifying landforms will be completed integrating the detailed ArcticDEM imagery to identify lower relief features on the landscape.

Future Work

A detailed paleo-ice reconstruction for the western margin of the LIS is lacking over the NTS sheets 85C, 85F, and 85G. Using a variety of data on depositional/erosive landscape morphologies, glacial sediment composition and structure, and material depositional ages, paleo-ice flow directions and margins of both the LIS and glacial Lake McConnell will be inferred as part of Hagedorn's M.Sc. research at the University of Waterloo.

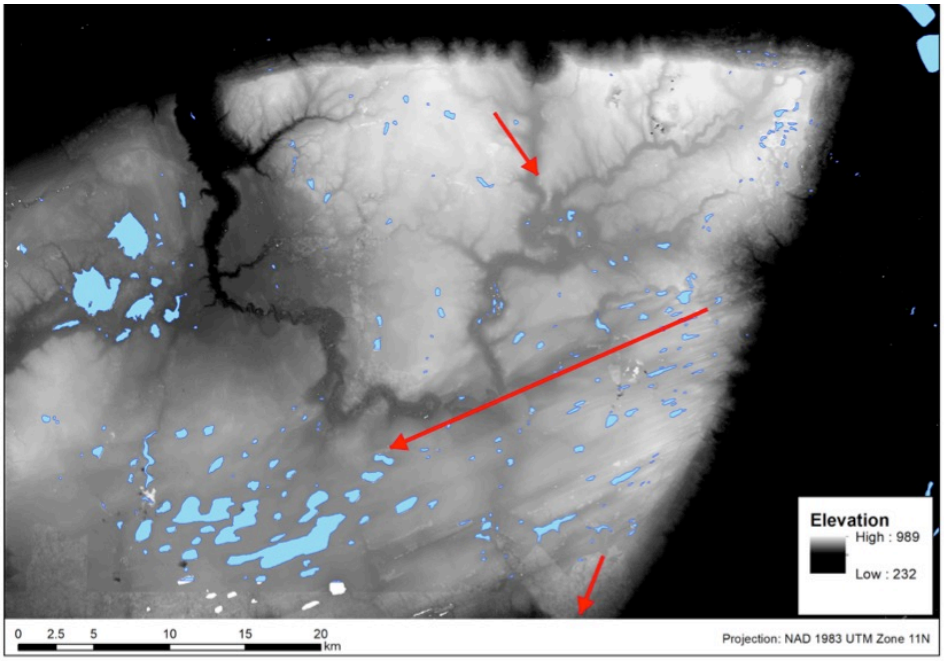

Figure 3.3. Digital Elevation Model (ArcticDEM) of the Cameron Hills in the southwestern portion of the study area. Arrows represent ice flow directions represented by the landforms.

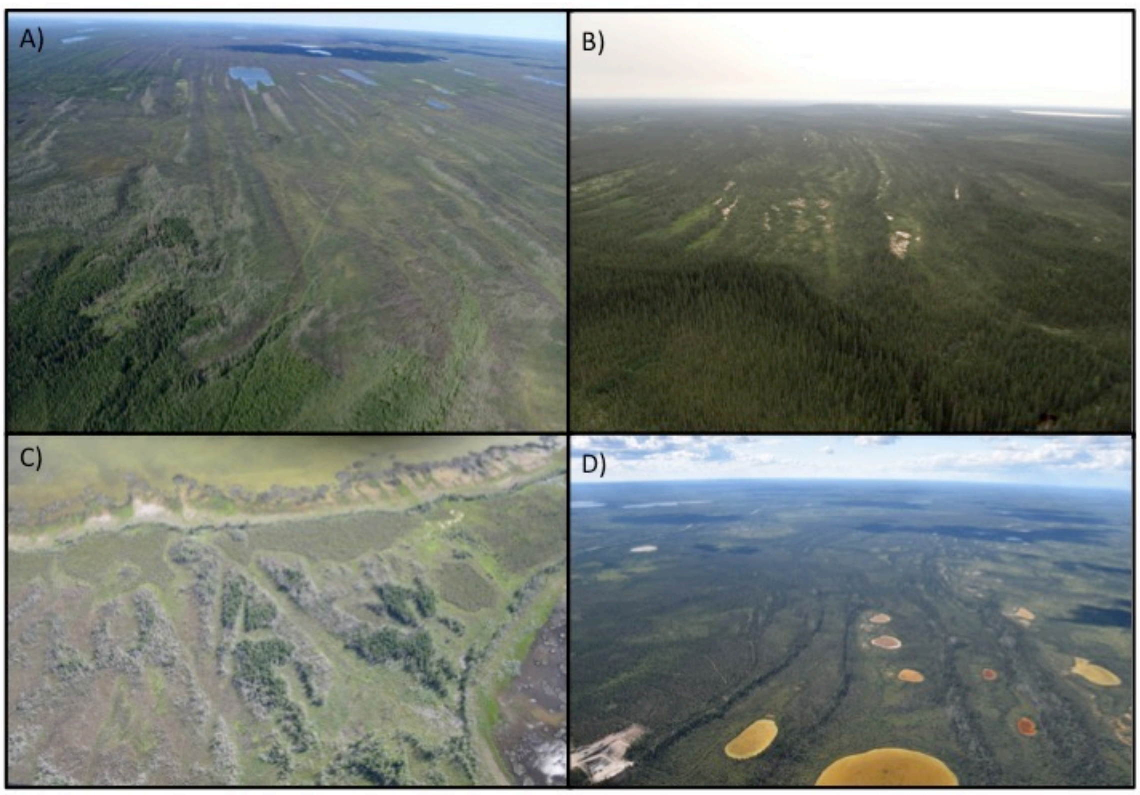

Figure 3.4. Different landforms observed throughout the study area: A) mega-scale glacial lineations on top of the Cameron Hills; B) shorelines below escarpment in northern NTS 85C; C) iceberg scours along the western margin of Great Slave Lake; and, D) sequence of recessional moraines in NTS 85C, north of Enterprise.

References

Benn, D., 2004. Chapter 5: Macrofabric; *in* A Practical Guide to the Study of Glacial Sediments, (ed.) D. Evans, and D. Benn, D. Hodder Education, London.

Craig, B.G., 1965. Glacial Lake McConnell, and Surficial Geology of Parts of Slave River and Redstone River Map-areas, District of Mackenzie; Geological Survey of Canada, Bulletin 112, 32 p. doi:10.4095/100639

Dyke, A.S. 2004. An Outline of North American Deglaciation with Emphasis on Central and Northern Canada; Developments in Quaternary Science, v. 2, p. 373–424. doi:10.1016/s1571-0866(04)80209-4

Dyke, A.S., and Prest, V.K., 1987. Late Wisconsinan and Holocene History of the Laurentide Ice Sheet; Géographie physique and Quaternaire, v. 41, p. 237-263. doi:10.4095/122842

Ely, J.C., Clark, C.D., Spagnolo, M., Stokes, C.R., Greenwood, S.L., Hughes, A.L., Dunlop, P. and Hess, D., 2016. Do subglacial bedforms comprise a size and shape continuum?; Geomorphology, v. 257, p. 108-119. doi:10.1016/j.geomorph.2016.01.001

Evans, D.J., Lemmen, D.S., and Rea, B.R., 1999. Glacial landsystems of the southwest Laurentide Ice Sheet: modern Icelandic analogies; Journal of Quaternary Science, v. 14, p. 673-691. doi:10.1002/(sici)1099-1417(199912)14

Fisher, T.G., and Smith, D.G., 1994. Glacial Lake Agassiz: its northwest maximum extent and outlet in Saskatchewan (Emerson phase); Quaternary Science Reviews, v. 13, n. 9-10, p. 845-858. doi:10.1016/0277-3791(94)90005-1

Hannigan, P.K., 2006. Introduction; *in* Potential for Carbonate-hosted Lead-zinc Mississippi Valley-type Mineralization in Northern Alberta and Southern Northwest Territories: Geoscience Contributions, Targeted Geoscience Initiative, (ed.) P.K. Hannigan; Geological Survey of Canada, Bulletin 591, p. 9–39. doi:10.4095/222883

Hart, J.K., 2017. Subglacial till formation: microscale processes within the subglacial shear zone; Quaternary Science Reviews, v. 170, p. 26-44. doi:10.1016/j.quascirev.2017.06.021

Hickin, A.S., Lian, O.V., Levson, V.M., and Cui, Y., 2015. Pattern and chronology of glacial Lake Peace Shorelines and implications for isostacy and ice-sheet configuration in northeastern British Columbia, Canada; Boreas, v. 44, p. 228-304. doi:10.1111/bor.12110

Lemmen, D.S., Duk-Rodkin, A., and Bednarski. J.M., 1994. Late Glacial Drainage Systems along the Northwest Margin of the Laurentide Ice Sheet; Quaternary Science Reviews, v. 13, n. 9-10, p. 805–828. doi:10.1016/0277-3791(94)90003-5

Margold, M., Stokes, C.R., and Clark, C.D., 2018. Reconciling records of ice streaming and ice margin retreat to produce a palaeogeographic reconstruction of the deglaciation of the Laurentide Ice Sheet; Quaternary science reviews, v. 189, p. 1-30. doi:10.1016/j.quascirev.2018.03.013

McClenaghan, M.B., Paulen, R.C., and Oviatt, N.M., 2018. Geometry of indicator mineral and till geochemistry dispersal fans from the Pine Point Mississippi Valley-type Pb-Zn district, Northwest Territories, Canada; Journal of Geochemical Exploration, v. 190, p. 69-86. doi:10.1016/j.gexplo.2018.02.004

McMartin I., and Paulen R.C., 2009. Ice-flow indicators and the importance of ice-flow mapping for drift prospecting; *in* Application of Till and Stream Sediment Heavy Mineral and Geochemical Methods to Mineral Exploration in Western and Northern Canada; (eds.) R.C. Paulen and I. McMartin; Geological Association of Canada, GAC Short Course Notes, v. 18, p. 15-34.

Menzies, J., van der Meer, J., and Shilts, W., 2017. Subglacial processes and sediments; *in* J. Menzies and J. van der Meer; Past Glacial Environments, Elsevier. p. 105-158. doi:10.1016/C2014-0-04002-6

Munyikwa, K., Feathers, J.K., Rittenour, T.M., and Shrimpton, H.K., 2011. Constraining the Late Wisconsinan retreat of the Laurentide ice sheet from western Canada using luminescence ages from postglacial aeolian dunes; Quaternary Geochronology, v. 6, n. 3-4, p. 407-422. doi:10.1016/j.quageo.2011.03.010

Neudorf, C.M., Lian, O.B., Walker, I.J., Shugar, D.H., Eamer, J.B.R., and Griffin, L.C.M., 2015. Toward a luminescence chronology for coastal dune and beach deposits on Calvert Island, British Columbia central coast, Canada; Quaternary Geochronology, v. 30, p. 275-281. doi:10.1016/j.quageo.2014.12.004

Oviatt, N.M., and Paulen, R.C., 2013. Surficial geology, Breynat Point NTS 85-B/15, Northwest Territories; Geological Survey of Canada, Canadian Geoscience Map 114, 1 sheet. scale 1:50,000. doi:10.4095/292247

Oviatt, N.M., Gleeson, S.A., Paulen, R.C., McClenaghan, M.B., and Paradis, S., 2015. Characterization and Dispersal of Indicator Minerals Associated with the Pine Point Mississippi Valley-Type (MVT) District, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 52, n. 9, p. 776–794. doi:10.1139/cjes-2014-0108

Paulen, R.C., Smith, I.R., Day, S.J.A., Hagedorn, G.W., King, R.D., and Pyne, M.D., 2017. GEM2 Southern Mackenzie Surficial Activity 2017 report: surficial geology and heavy mineral studies in southern Northwest Territories; Geological Survey of Canada, Open File 8322, p. 27. doi:10.4095/306090

Plakholm, J.A., 2018. Glacial dispersal analysis by pebble lithology classification in the southwestern Northwest Territories, Canada; B.Sc. thesis, Department of Environmental Science, Carleton University.

Polar Geospatial Center., 2017. ArcticDEM; DigitalGlobe Incorporated.

Rea, B.R., Evans, D.J.A., Dixon, T.S., Whalley, W.B., 2000. Contemporaneous, localized, basal ice-flow variations: implications for bedrock erosion and the origin of p-forms; Journal of Glaciology, v. 46, p. 470-476. doi:10.3189/172756500781833197

Rice, J.M., Paulen, R.C., Menzies, J.M., McClenaghan, M.B., and Oviatt, N.M., 2013. Glacial stratigraphy of the Pine Point Pb-Zn mine site, Northwest Territories; Geological Survey of Canada, Current Research 2013-5, 14 p. doi:10.4095/292184

Rice, J.M., Paulen, R.C., Menzies, J.M., and McClenaghan, M.B., 2014. Micromorphological descriptions of till from pit K-62, Pine Point mining district, Northwest Territories. Geological Survey of Canada, Open File 7526, 30 p. doi:10.4095/293478

Smith, I.R., and Lesk-Winfield, K., 2010. Seismic shothole drillers' log-derived thematic GIS, Northwest Territories and northern Yukon: bedrock outcrop and subcrop, geohazards, and muskeg thickness; Geological Survey of Canada, Open File 6410, 1 DVD. doi:10.4095/261784

Tarasov, L., and Peltier, W.R., 2004. A geophysically constrained large ensemble analysis of the deglacial history of the North American ice-sheet complex. Quaternary Science Reviews, v. 23, n. 3-4, p. 359-388. doi:10.1016/j.quascirev.2003.08.004

Trommelen, M.S., Ross, M., Campbell, J.E., 2013. Inherited clast dispersal patterns: implications for palaeo-glaciology of the SE Keewatin Sector of the Laurentide Ice Sheet; Boreas, v. 42, p. 693 713. doi:10.1111/j.1502-3885.2012.00308.x

Watson, D.M., 2011. Ka'a'gee Tu area of interest, phase II non- renewable resource assessment – minerals, Northwest Territories, parts of NTS 85C, 85D, 85E and 85F; Northwest Territories Geoscience Office, Open File 2011-001.

Wolfe, S.A., Huntley, D.J., and Ollerhead, J., 2004. Relict late Wisconsinan dune fields of the northern Great Plains, Canada; Géographie physique et Quaternaire, v. 58, n. 2-3, p. 323-336. doi:10.7202/013146ar

Wolfe, S.A., Morse, P.D., Neudorf, C.M., Kokelj, S.V., Lian, O.B., and O'Neill, H.B., 2018. Contemporary sand wedge development in seasonally frozen ground and paleoenvironmental implications; Geomorphology, v. 308, n. 215-229. doi:10.1016/j.geomorph.2018.02.015

Stream Sediment Geochemistry and Heavy Minerals, Southern Mackenzie, Northwest Territories

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Introduction

The stream sediment and water chemistry study initiated in 2017 under the GEM-2 Mackenzie Project, Southern Mackenzie Corridor Surficial activity, in the Hay River – Kakisa Lake area of southern Northwest Territories (Day et al. in Paulen et al. 2017; Day et al., 2018) was continued during the 2018 field season. 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?"*

Previously, non-renewable resource assessments were carried out in the Trout Lake (Watson, 2011a), Kakisa Lake (Watson, 2011b) and Jean Marie River (Watson, 2013) areas by the Northwest Territories Geological Survey (NTGS). Results reported the presence of sphalerite ((Zn,Fe)S) and galena (PbS) grains in the heavy mineral fraction of numerous glacial till samples. Significant sphalerite and galena grain counts were found over a broad area up to nearly 400 km west of the past-producer Pine Point lead-zinc mining district. Expanding the collection area beyond the previously sampled regions has the goal of better understanding any possible link between the known sphalerite and galena grains and the known Pine Point District or other yet to be discovered mineralization.

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) can be found in the heavy mineral concentrate (HMC) fraction of stream sediments. The mineral exploration industry and government geological surveys have successfully employed stream sediment sampling programs in their search for knowledge regarding the mineral prospectivity of areas of interest (cf., Friske and Hornbrook, 1991).

Field activities for 2018 were carried out in July and were based in Fort Providence and Hay River, NT. Sites targeted for sampling in 2018 were selected to augment existing samples, resample a few of the 2017 sites with elevated indicator mineral grain counts, and target a number of coincident till and stream sediment sites in proximity to those with elevated grain counts. A total of eight bulk stream sediment and water samples were collected northeast and southwest of Fort Providence (Fig. 4.1). Planned 2018 stream sediment sampling in the Kakisa and Hay River areas was not feasible because of high water levels. All sites were accessed by helicopter.

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Day, S.J.A., Smith, I.R., Paulen, R.C., and King, R.D., 2019. Stream sediment geochemistry and heavy minerals, southern Mackenzie, Northwest Territories; *in* GEM-2 Southern Mackenzie Surficial Activity 2018 report: Surficial Geology and Heavy Mineral Studies in Southern Northwest Territories, (eds.) R.C. Paulen, I.R. Smith and S.J.A. Day; Geological Survey of Canada, Open File 8477, p. 27-31. http://doi.org/10.4095/313423

Fourteen archived stream sediment HMC samples were selected from the former Horn Plateau study (Fig. 4.1; Day et al., 2007; GSC Open File 5478) and were re-examined to determine the abundance of of Magmatic or Metamorphosed Massive Sulphide Indicator Minerals (MMSIMs®) grain counts (Averill, 2001), which include sphalerite and galena. These data will be published as part of a future GSC Open File report.

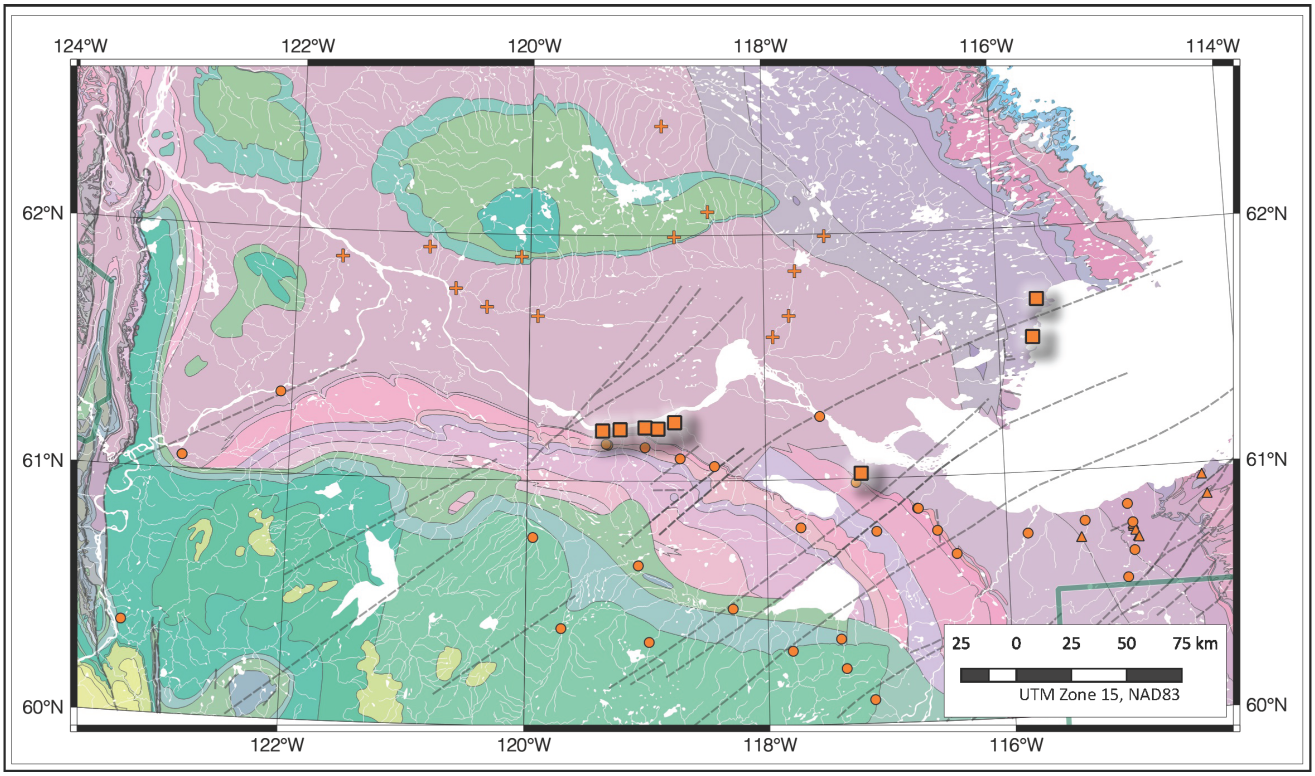

Figure 4.1. Stream sediment sample locations; orange squares represent sites where bulk stream sediment, silt and water samples were collected in 2018; small orange circles show sites sampled in 2017. Orange crosses are archived samples from regional surveys in the Horn Plateau reprocessed for heavy minerals (Day et al., 2007) and small orange triangles show sites sampled in 2010 (McClenaghan et al., 2012). Bedrock geology base modified from Okulitch, 2006.

Methodology

Bulk stream sediment, silt sediment, and water samples were collected from 8 sites, resulting in 8, 6 and 8 field samples, respectively. Sampling efforts were significantly reduced due to exceptionally high water levels in drainage systems in the Hay River area. Figure 4.2 illustrates the field equipment used and samples collected at a typical stream bulk sediment and water site.

Prior to commencing fieldwork, potential stream sediment sample sites were preselected to ensure that a reasonable coverage of samples could be obtained with the available budget. Ideally, at every stream sample site, an on-site (0.45 µm) filtered water sample, a grab sample of silt-sized sediment, and a wet-sieved (<2.0 mm) bulk sediment 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 <177 µm fraction analysed by aqua regia/ICP-MS and 4-acid/ICP-MS. The <2 mm 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 picked from each sample. Indicator mineral grains of interest will be analysed to obtain their chemistry 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.

Figure 4.2. Field gear used and samples collected at a typical bulk stream sediment and water sample site located well upstream of human activity. Numbers indicate: 1) two 60 ml water samples (filtered on site with 0.45 µm filter); 2) stream silt sample (~ 2kg wet); 3) #10 mesh (2mm) sieve; 4) pan for washing gravel during sieving; 5) steel shovel; 6) bulk stream sediment (~12 kg of ≤2mm sediment); and, 7) bucket that will be lined with pre-labeled sample bag.

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 (Friske and Hornbrook, 1991), in order to ensure consistent and reliable results regardless of the area, date of the survey, or the analytical laboratory used.

Results and Conclusions
At the time of publication, all samples collected during 2018 fieldwork have been submitted for sample processing and subsequent mineralogical and geochemical analyses. Preliminary analytical and mineralogical data are not expected until early in 2019, with a complete dataset not expected until mid-2019. Results of the 2017 HMC indicator minerals were published in GSC Open File 8362 (Day et al., 2018). Mineral grain counts for chalcopyrite, galena and sphalerite, in the heavy mineral component, of several stream sediment samples, are elevated at several locations where there are no known mineral occurrences. The past producing Pine Point lead-zinc Mining District lies ~75 km to the east-northeast of the nearest stream sediment site with elevated sphalerite and galena grain counts, and is not likely the source of the grains as samples between these sites have only background-level grain counts. Preliminary examination of mineral grain counts for chalcopyrite, galena and sphalerite in re-picked Horn Plateau samples indicate lower concentrations when compared to samples collected in 2017.

Acknowledgements
The authors wish to thank Grant Hagedorn (University of Waterloo), Jamie Sapera (Brock University) and Matt Pyne (GSC Ottawa) for their field contributions.

References
Averill, S.A., 2001. The application of heavy indicator mineralogy in mineral exploration with emphasis on base metal indicators in glaciated metamorphic and plutonic terrains; *in* Drift Exploration in Glaciated Terrain, (eds.) M.B. McClenaghan, P.T. Bobrowsky, G.E.M. Hall, and S.J. Cook; Geological Society of London, Special Publication 185, p. 69-81.

Day S.J.A., Lariviere J.M., McNeil R.J., Friske P.W.B., Cairns S.R., McCurdy M.W., Wilson, R.S., 2007. Regional Stream Sediment and Water Geochemical Data, Horn Plateau area, Northwest Territories (Parts of NTS 85E, 85F, 85K, 85L, 95H, 95I and 95J) Including Analytical, Mineralogical and Kimberlite Indicator Mineral Data. Geological Survey of Canada, Open File 5478 / NWT Geoscience Office Contribution 0027. doi:10.4095/224262

Day S.J.A, Paulen R.C., Smith I.R., and King R.D., 2018. Heavy-mineral and indicator-mineral data from stream sediments of southwest Northwest Territories: new potential for undiscovered mineralization; Geological Survey of Canada, Open File 8362. doi:10.4095/306587

Friske, P.W.B. and Hornbrook, E.H.W., 1991. Canada's National Geochemical Reconnaissance programme: Transactions of the Institution of Mining and Metallurgy, London Section B; Volume 100, p. 47-56.

McClenaghan, M.B., Oviatt, N.M., Averill, S.A., Paulen, R.C., Gleeson, S.A., McNeil, R.J., McCurdy, M.W., Paradis, S., and Rice, J.M., 2012. Indicator mineral abundance data for bedrock, till and stream sediment samples from the Pine Point Mississippi Valley-Type Zn-Pb deposits, Northwest Territories; Geological Survey of Canada, Open File 7267. doi:10.4095/292121

Okulitch, A.V. (compiler) 2006. Phanerozoic bedrock geology, Slave River, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Open File 5281, scale 1:1 000 000. doi:10.4095/222163

Paulen, R.C., Smith, I.R., Day, S.J.A., Hagedorn, G.W., King, R.D. and Pyne, M. 2017. GEM2 Southern Mackenzie Surficial Activity 2017 report of activities: surficial geology and heavy mineral studies in southern Northwest Territories. Geological Survey of Canada, Open File 8322, 27 p. doi:10.4095/306090

Watson, D.M., 2011a. Sambaa K'e Candidate Protected Area, Phase II Non-renewable Resource Assessment –Minerals, Northwest Territories, Parts of NTS 085D, 095A ,B, H; Northwest Territories Geoscience Office, NWT Open File 2010-08.

Watson, D.M., 2011b., Ka'a'gee Tu Area of Interest, Phase II Non-renewable Resource Assessment – Minerals, Northwest Territories, Parts of NTS 85C, 85D, 85E and 85F; Northwest Territories Geoscience Office, NWT Open File 2011-001.

Watson, D.M., 2013. Non-Renewable Resource Assessment (Minerals): Łue Túé Sųlái Candidate Protected Area, NTS 095H6 & 095H7. NWT Open File 2013-03.

Canadian Database of Geochemical Surveys

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Introduction

The Canadian Database of Geochemical Surveys (CDoGS) stores geochemical data and metadata from GEM and other surveys (Adcock et al., 2013, Spirito et al., 2013). The public interface to the database is found at http://geochem.nrcan.gc.ca. The database is continuing to grow and currently holds results from over 11 million geochemical analyses for sample media of various types collected across Canada.

Metadata for the geochemical stream sediment surveys being carried out around Hay River (Day et al., 2018) have been added to the database, and have been linked to earlier, similar work carried out in the region in 2010-2011 (https://geochem.nrcan.gc.ca/cdogs/content/prj/prj210153_e.htm). Geochemical data for these samples are currently being added to the database.

Figure 1 is a map produced on the CDoGS website showing numerous geochemical surveys that have been carried out in the general area of the Southern Mackenzie Surficial activity in the past, with the current work highlighted. Each blue star indicates the centroid of a geochemical survey area.

Figure 5.1. Geochemical survey coverage and metadata of the general area of the GEM-2 Southern Mackenzie Surficial activity in the CDoGS database.

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Adcock, S.W. and Spirito, W.A., 2019. Canadian database of geochemical surveys; *in* GEM-2 Southern Mackenzie Surficial Activity 2018 report: Surficial Geology and Heavy Mineral Studies in Southern Northwest Territories, (eds.) R.C. Paulen, I.R. Smith and S.J.A. Day; Geological Survey of Canada, Open File 8477, p. 32-33. http://doi.org/10.4095/313424

The database that holds all of the geochemical data is very stable. Its design continues to evolve in response to new sampling and analytical procedures. Populating the database with metadata for new surveys and publications, plus the associated raw analytical data, is an ongoing GEM activity.

Major database development activity is focussed on improving the delivery of data to end-users. This development involves transforming the fully normalized data[a] in the underlying relational database into a format that a typical end-user can work with easily. Automated procedures transform the data into MS Excel spreadsheets, which can be imported easily into specialised software for GIS or statistical analysis. A critical aspect of the system is the inclusion of comprehensive standardised metadata describing the sampling and analytical procedures. The design of the spreadsheets is still being revised as a result of usability testing. Improvements to the online map query tool, to facilitate data discovery, are in the early stages of development.

References

Adcock, S.W., Spirito, W.A., and Garrett, R.G., 2013. Geochemical data management: issues and solutions; Geochemistry: Exploration, Environment, Analysis, v. 13, p. 337-348. doi:10.1144/geochem2011-084

Date, C.J., 2012. Database Design and Relational Theory: Normal Forms and All That Jazz; O'Reilly Media. 276 p.

Day, S.J.A., Paulen, R.C., Smith, I.R., and King, R.D., 2018. Heavy-mineral and indicator-mineral data for stream sediments in southwest Northwest Territories: new potential for undiscovered mineralization; Geological Survey of Canada, Open File 8362, 20 p. doi:10.4095/306587

Spirito, W.A., Adcock, S.W., and Paulen, R.C., 2013. Managing geochemical data: challenges and best practices; *in* New Frontiers for Exploration in Glaciated Terrain, (eds.) R.C. Paulen, M.B. McClenaghan (eds); Geological Survey of Canada, Open File 7374, p. 21-26. doi:10.4095/300288

[a] Normalization is the process of restructuring a relational database in accordance with a series of well-defined "normal forms" in order to reduce data redundancy and improve data integrity (Date, 2012).

Geochemical Studies of Base Metal Indicator Minerals

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Introduction

Surficial sampling surveys conducted in 2008, 2009 and 2012 as part of the Northwest Territories protected area strategy (PAS) recovered anomalous concentrations of base metal indicator minerals in till. In the Sambaa K'e (Trout Lake), Ka'a'gee Tu (Kakisa Lake), and Lue Túé Sųlái (Jean Marie River) regions, results reported potential for undocumented bedrock mineralization (Fig. 6.1; Watson, 2011 a, b, 2013). These findings warranted further exploration in the region and thus an expanded regional till and stream sediment sampling program was undertaken as part of the GEM-2 Southern Mackenzie Surficial activity in an effort to identify anomalous concentrations of indicator minerals and highlight prospective regions (Paulen et al., 2017).

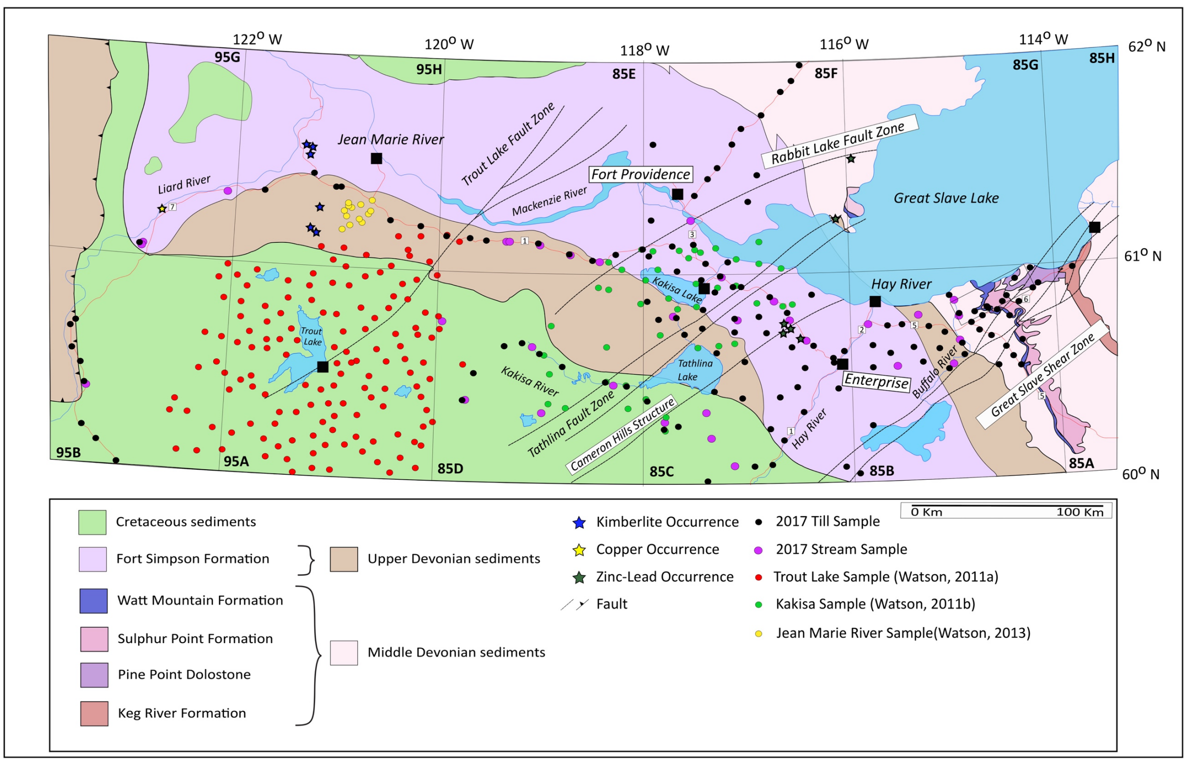

Figure 6.1. Simplified bedrock geology (after Okulitch, 2006; Bednarski, 2008) showing the location of samples from which mineral grains were provided by the Northwest Territories Geological Survey (red, yellow, and green circles; Watson, 2011 a, b, 2013). Till samples collected in 2017 are denoted by black circles, while 2017 stream sediment samples are indicated by purple circles. Blue stars indicate kimberlite showings (Pitman, 2014). Yellow stars indicate copper occurrences (Dudek, 1993) while dark green stars mark the location of zinc-lead occurrences (Paradis et al., 2006).

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King, R.D., Piercey, S.J., and Paulen, R.C., 2019. Geochemical studies of base metal indicator minerals; *in* GEM-2 Southern Mackenzie Surficial Activity 2018 report: Surficial Geology and Heavy Mineral Studies in Southern Northwest Territories, (eds.) R.C. Paulen, I.R. Smith and S.J.A. Day; Geological Survey of Canada, Open File 8477, p. 34-42. http://doi.org/10.4095/313425

In total, 142 till samples and 31 stream sediment samples were collected across the region (Fig. 6.1, see also Figs. 1.2 and 4.1). Indicator minerals recovered from these samples will be analyzed as part of an on-going study being conducted at Memorial University of Newfoundland (cf., King et al., 2018). This project is examining the mineralogy, major- and trace-element chemistry, and S- and Pb- isotope geochemistry to determine potential deposit types and discriminate sources for indicator minerals, in aid of regional mineral exploration.

Methodology

Initial analytical work was conducted on selected heavy mineral grains recovered from previous PAS surveys (Fig 6.1- red, green, and yellow circles; Watson, 2011 a, b, 2013) that were provided by the Northwest Territories Geological Survey. Picked grains of chalcopyrite, sphalerite, galena, and arsenopyrite were mounted in 25 mm epoxy pucks and carbon coated before imaging each grain using a JEOL JSM 7100F emission gun (FEG) scanning electron microscope (SEM) with a 15.0 kV beam in backscatter (BED-C) and secondary electron (LED) mode (Fig. 6.2 and Fig. 6.3). In addition to SEM imaging, semi-quantitative mineral compositions of each grain were determined using a Thermo^{TM} energy dispersive spectrometer (EDS) coupled with a high-resolution silicon drift detector. This semi-quantitative analysis ensured minerals selected by optical methods were correctly identified.

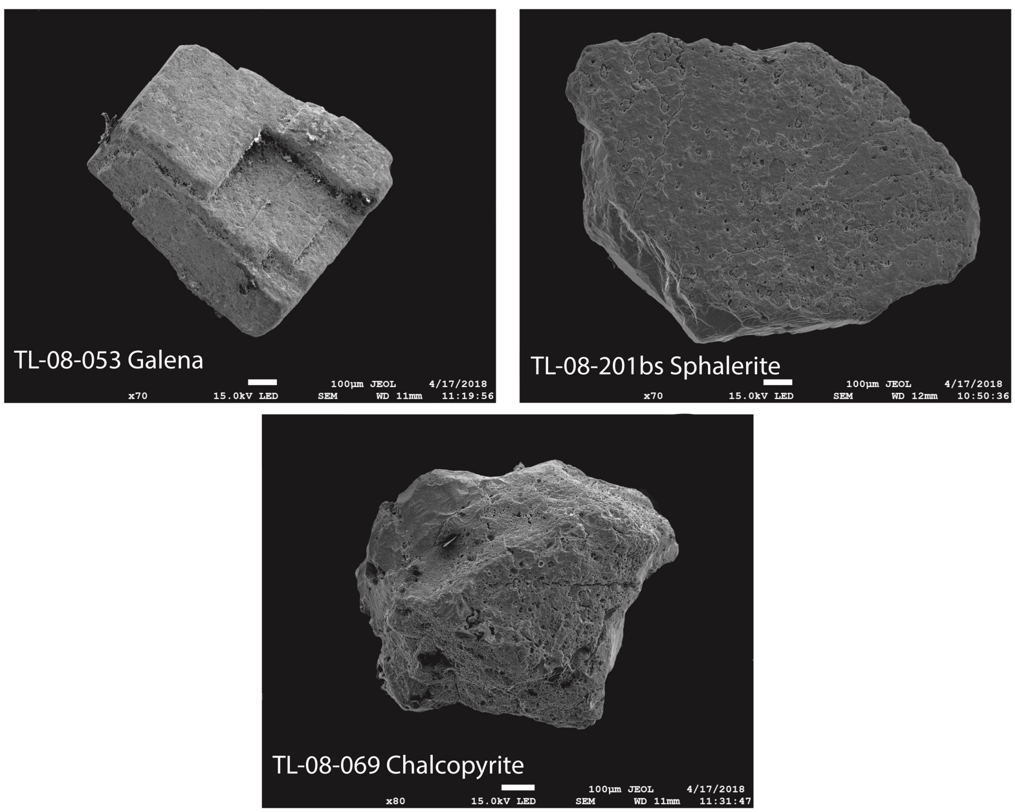

Figure 6.2. Secondary electron images of whole galena, sphalerite, and chalcopyrite grains recovered from PAS survey till samples. These grains, in addition to others, were used for conventional sulphur isotopes determinations at the University of Ottawa.

Detailed methods for *in situ* Pb and $\delta^{34}S$ isotopic determinations are outlined in King et al. (2018). In addition to *in situ* methods, $\delta^{34}S$ isotopes of sphalerite, chalcopyrite and galena were measured at the University of Ottawa G.G. Hatch Stable Isotope Laboratory. For analysis, samples were weighed into tin capsules with at least twice the sample weight of tungstic oxide for inorganic or organic S. Capsules are then loaded into an isotope cube (Elementar, Germany) elemental analyser and flash combusted at 1800° C. Gases released during combustion were carried by helium through the elemental analyser and were cleaned and then separated. The SO_2 gas was then carried into the Delta Plus XP isotope ratio mass spectrometer (ThermoFinnigan, Germany) via a conflo VI interface for ^{34}S determination.

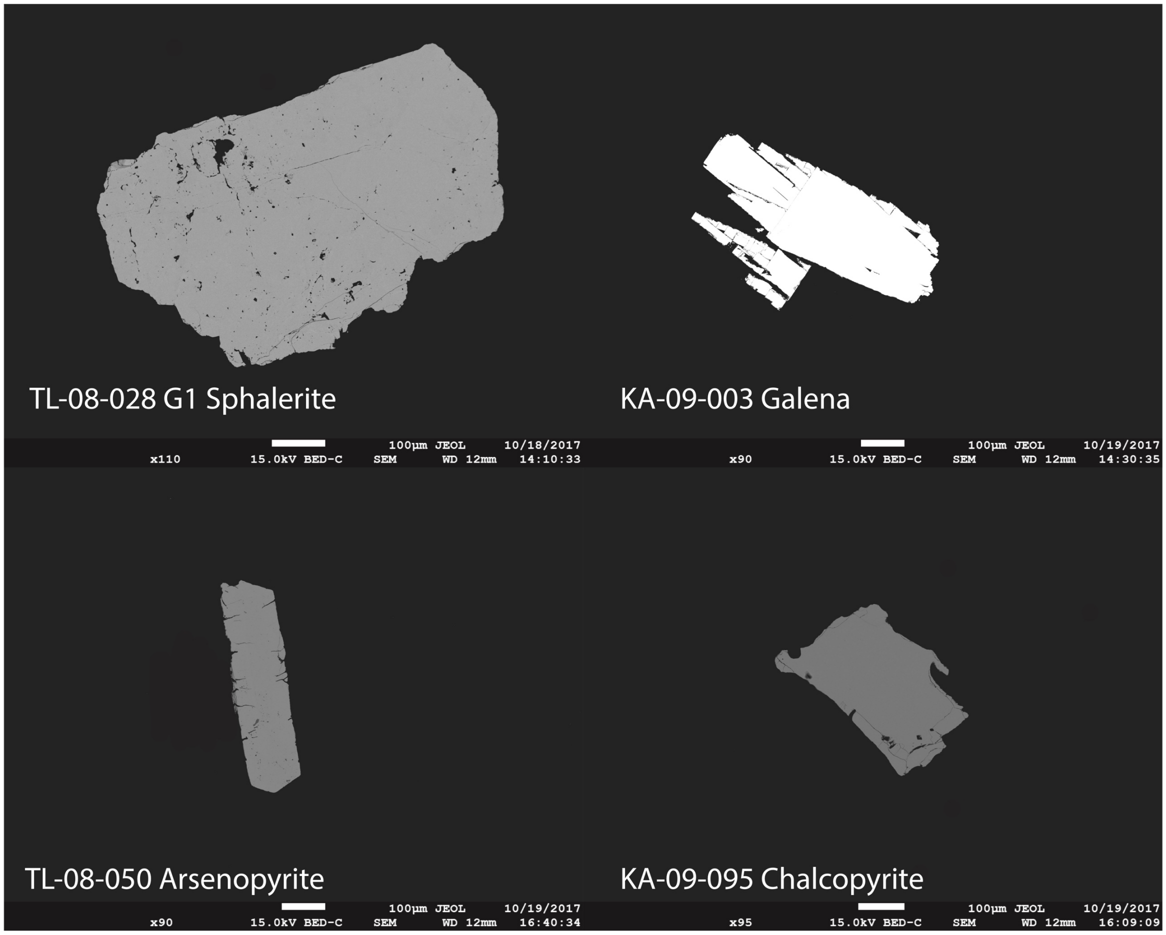

Figure 6.3. Backscatter images of polished sphalerite, galena, arsenopyrite, and chalcopyrite grains from PAS survey till samples. These grains, in addition to others, were used for SIMS at Memorial University of Newfoundland and LA-ICP-MS at Laurentian University.

Till and stream sediment samples collected in the 2017 field season were processed by Overburden Drilling Management Limited (ODM) to recover the 0.25 to 2.0 mm portion of the heavy mineral concentrate (HMC). All the base metal indicator minerals (sphalerite, galena, chalcopyrite, arsenopyrite) recovered from the HMC were sent to Memorial University of Newfoundland. The 2017 samples will undergo similar analyses to previous PAS survey samples, the data from which will be released in future GSC Open File reports.

Results

Sulphur and Pb isotope data, and interpretations for PAS survey samples are reported in King et al. (2018). In summary, PAS survey samples have $^{206}Pb/^{204}Pb$ ratios ranging from 18.00 to 18.20 and $^{207}Pb/^{204}Pb$ ratios ranging from 15.58 to 15.71, clustering proximal to the shale curve (Fig. 6.4;

Godwin and Sinclair, 1982; Cumming et al., 1990; King et al., 2018). Such Pb ratios are indicative of an evolved upper crustal source; however, they have a more radiogenic Pb sources than Pine Point district samples, suggesting that they are older than the source for Pine Point galena grains, or that the fluids responsible for the formation of PAS galena grains tapped separate, older, more radiogenic Pb sources (e.g. Zartman and Doe, 1979; Zartman and Haines, 1988; Cumming et al., 1990; Kramers and Tolstikhin, 1997; Oviatt, 2013).

Secondary ion mass spectrometry (SIMS) $\delta^{34}S$ values for galena range from +0.63 to +26.87‰, similar to values reported in previous studies at Pine Point and indicating that galena grains have a similar S source to those at Pine Point (Fig. 6.5; Kyle, 1981; Oviatt et al., 2015). Chalcopyrite has $\delta^{34}S$ values ranging from -20.64 to +28.33‰ and arsenopyrite has $\delta^{34}S$ values ranging from -2 to +2‰ (Figs. 6.6 and 6.7; King et al., 2018). The $\delta^{34}S$ values of chalcopyrite grains are similar to that of sediment-hosted Cu deposits and chalcopyrite from magmatic hydrothermal Manto-type deposits, suggesting potential for either deposit type in the region (e.g., Ripley and Ohmoto, 1977; El Desouky et al., 2010). Arsenopyrite $\delta^{34}S$ values are similar to that of igneous rocks (e.g. $\delta^{34}S = 0 \pm 3$‰; Fig. 6.7; Ohmoto and Rye, 1979; Ohmoto and Goldhaber, 1997), which could indicate that sulphur in arsenopyrite grains was derived from igneous basement rocks. Additionally, orogenic gold deposits near Yellowknife contain arsenopyrite that have $\delta^{34}S$ values similar to the arsenopyrite grains in the PAS samples, suggesting that the arsenopyrite grains from the study area may be sourced from orogenic Au systems up-ice of the region (Wanless et al., 1960; Marini et al., 2011).

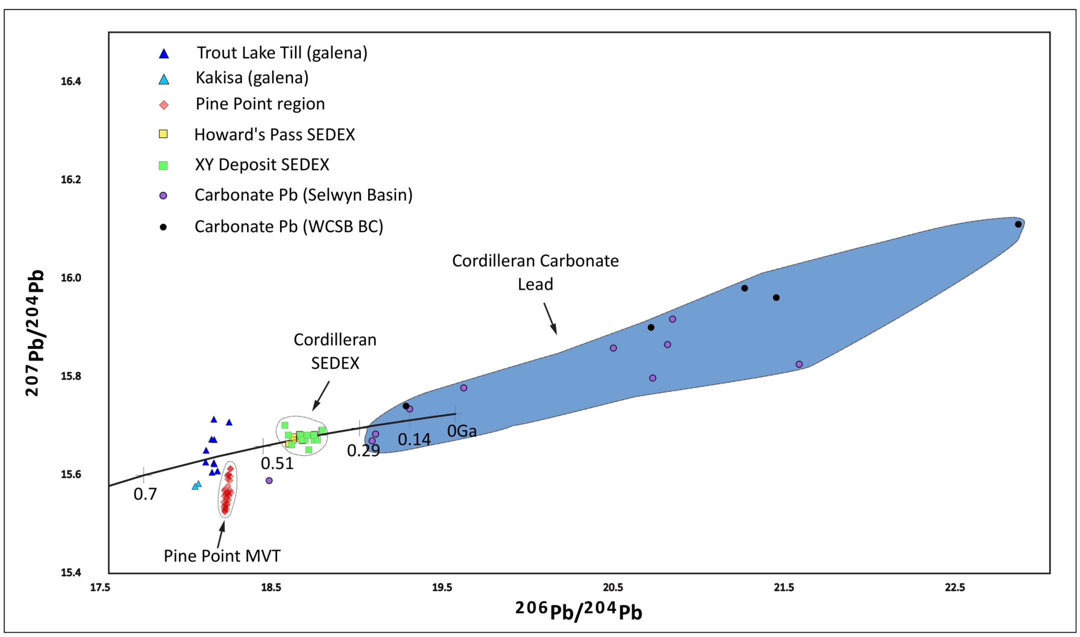

Figure 6.4. Lead isotopic bivariate plot of $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$ for galena grains from the Trout Lake (dark blue triangles) and Kakisa (light blue triangles) regions (from King et al., 2018). Shown for comparison are bedrock samples from Pine Point (pink diamonds; Cumming et al., 1990; Paradis et al., 2006; Oviatt et al., 2015). Data are plotted about the shale curve of Godwin and Sinclair (1982). Additionally, data from other Mississippi Valley-type (MVT) deposits in northern British Columbia as well as sedimentary exhalative (SEDEX) Pb-Zn deposits in Yukon and values from the Western Canada Sedimentary Basin (Godwin et al., 1988; Paradis et al., 2006).

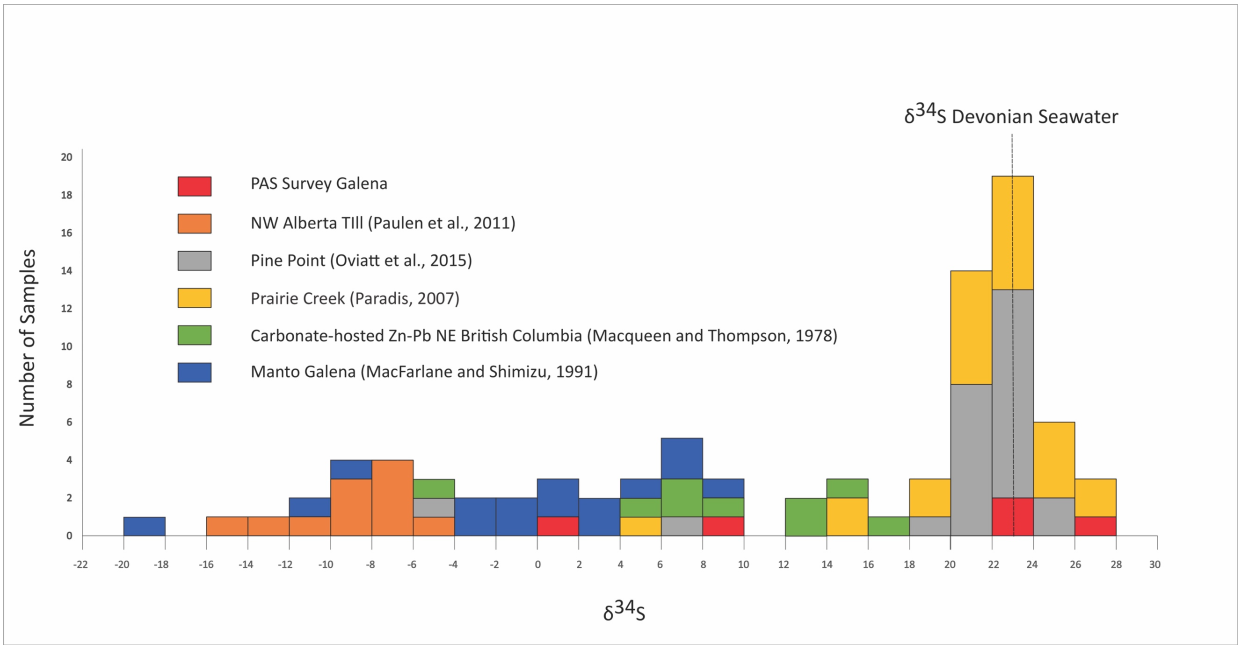

Figure 6.5. Histogram of $\delta^{34}S$ values of PAS Survey galena (red; King et al., 2018) compared to values from carbonate-hosted Pb-Zn mineralization in northeastern British Columbia (green; Macqueen and Thompson, 1978), Manto-style mineralization in Peru (blue; MacFarlane and Shimizu, 1991), Prairie Creek deposit (yellow; Paradis, 2007), till samples from northwestern Alberta (orange; Paulen et al., 2011), and Pine Point Pb-Zn mining district (grey; Oviatt et al., 2015).

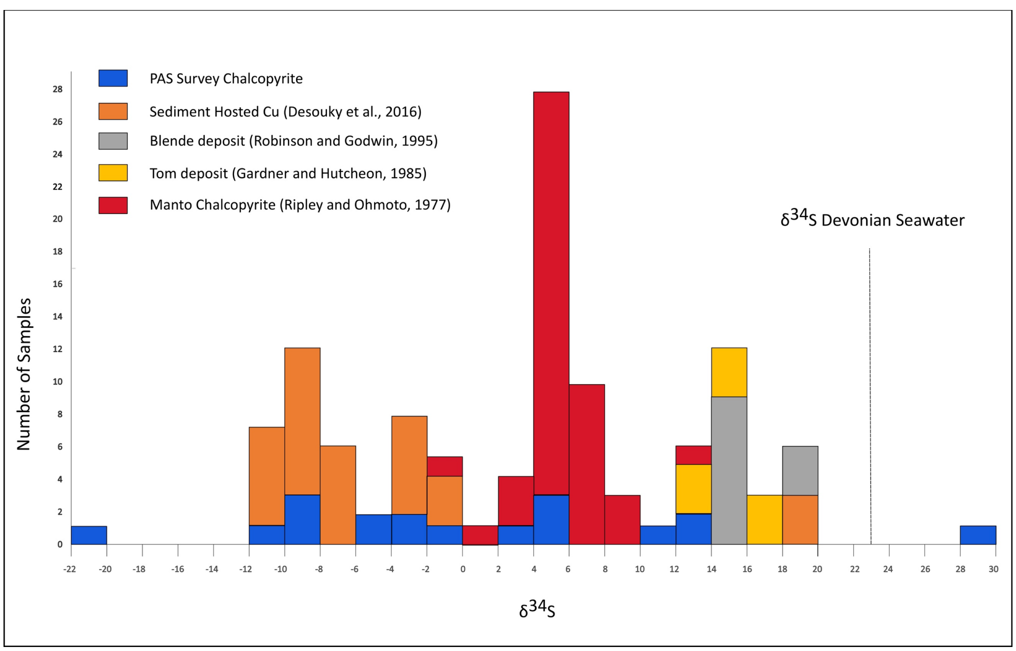

Figure 6.6. Histogram of $\delta^{34}S$ values of PAS Survey chalcopyrite (blue; King et al., 2018) compared with values from Manto-style mineralization in Peru (red; Ripley and Ohmoto, 1977), the Tom sedimentary exhalative (SEDEX) Pb-Zn-Ag deposit, Yukon Territory (yellow; Gardner and Hutcheon, 1985), the Blende carbonate-hosted Pb-Zn deposit, Yukon Territory (grey; Robinson and Godwin, 1995), and sediment-hosted Cu deposits, Africa (orange; El Desouky et al., 2010).

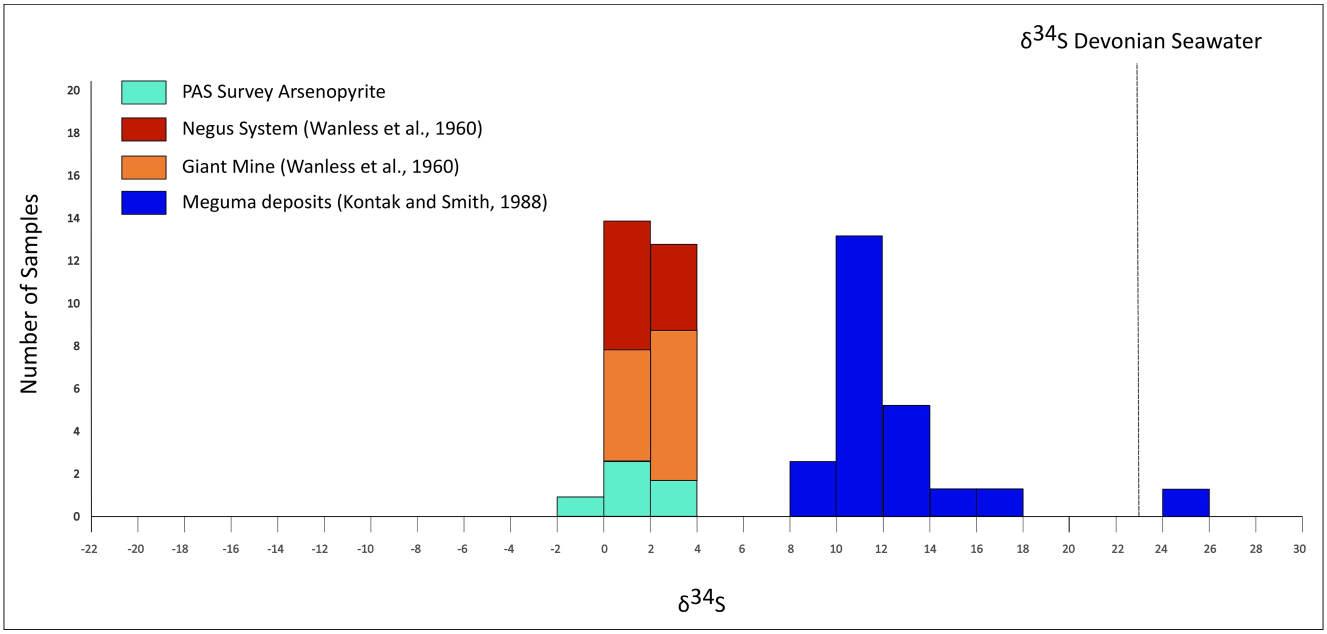

Figure 6.7. Histogram of $\delta^{34}S$ values of PAS Survey arsenopyrite (teal; King et al., 2018) compared with values from the Negus Au Mine, Northwest Territories (red; Wanless et al., 1960), the Giant Au Mine, Northwest Territories (orange; Wanless et al., 1960), and Meguma gold deposits, Nova Scotia (Kontak and Smith, 1989).

Conclusions and Future Work

Full interpretations of $\delta^{34}S$ and Pb-isotopic data from PAS survey samples will be available in future publications. Full data sets and preliminary interpretations of geochemical data acquired by EPMA and LA-ICP-MS on sulphides from PAS survey samples will be presented in future publications. On-going research at Memorial University will provide additional data including $\delta^{34}S$, Pb and geochemical data from 2017 till and stream sediment samples (Paulen et al., 2017; Day et al., 2018) which will be presented and discussed in subsequent publications.

Preliminary S and Pb isotope data from galena grains in regions around Trout and Kakisa Lakes indicate that grains are from proximal bedrock sources and not dispersed from the Pine Point mining district (King et al., 2018). Additionally, chalcopyrite grains possess $\delta^{34}S$ values similar to that of Manto-style mineralization or sediment-hosted Cu (Ripley and Ohmoto, 1977; El Desouky, 2010; King et al., 2018). Arsenopyrite grains have $\delta^{34}S$ values similar to orogenic Au deposits near Yellowknife, indicating grains found in the study region may have been sourced from similar deposits found up-ice of this region (Wheeler et al., 1996).

Future work will include SEM-EDS, EPMA, LA-ICP-MS, SIMS and conventional sulphur isotope work on sulphide phases including sphalerite, galena, chalcopyrite and arsenopyrite grains recovered from 2017 till and stream sediment samples. Several bedrock samples collected from the Pine Point district will also be used in conjunction with data from previous studies (Oviatt, 2013; Oviatt et al., 2015), as well as bedrock and drill core samples from other mineral occurrences in the region, to compare potential source regions for sulphide species recovered from surface till samples.

References

Bednarski, J.M., 2008. Quaternary geology of Fort Liard map area, Northwest Territories; Geological Survey of Canada, Bulletin 596, 59 p. doi:10.4095/225608

Cumming, G.L., Kyle, J.R., and Sangster, D.F., 1990. Pine Point: A case History of Lead Isotope Homogeneity in a Mississippi Valley-Type District; Economic Geology, v. 85, p. 133-144.

Day, S.J.A, Paulen, R.C., Smith, I.R., and King, R.D., 2018. Heavy-mineral and indicator-mineral data from stream sediments of southwest Northwest Territories: new potential for undiscovered mineralization; Geological Survey of Canada, Open File 8362. doi:10.4095/306587

Dudek, D., 1993. Report of Geological work and drilling carried out on the Moisey Property, Mackenzie District, Northwest Territories; Noranda Exploration Company Ltd., Northwest Territories Geoscience Office, Assessment Report 083110.

El Desouky, H.A., Muchez, P., Boyce, A.J., Schneider, J., Cailteux, J.L.H., Dewaele, S., and von Qualdt, A., 2010. Genesis of sediment-hosted stratiform copper-cobalt mineralization at eh Luiswishi and Kamoto, Katanga Copperbelt (Democratic Republic of Congo); Mineralium Deposita, v. 45, p. 735–763. doi:10.1007/s00126-010-0298-3

Gardner, H.D. and Hutcheon, I., 1985. Geochemistry, mineralogy, and geology of the Jason Pb-Zn Deposits, Macmillan Pass, Yukon, Canada; Economic Geology, v. 80, p. 1257–1276.

Godwin, C.J. and Sinclair, A.J., 1982. Average lead isotope growth curves for shale-hosted zinc-lead deposits, Canadian Cordillera; Economic Geology, v. 77, p. 675–690.

Godwin, C.I., Gabites, J.E., and Andrew, A., 1988. Leadtable: A galena lead isotope database for the Canadian Cordillera, with a guide to its use by explorationists; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1988-4.

King, R.D., Piercey, S.J., and Paulen, R., 2018. In situ, microanalytical sulphur and lead isotopic compositions of sulphide indicator minerals from surficial sediments in southwestern Northwest Territories; Geological Survey of Canada, Open File 8449. doi: 10.4095/311247

Kontak, D.J. and Smith, P.K., 1989. Sulphur isotopic composition of sulphides from the Beaver Dam and other Meguma-Group-hosted gold deposits: Nova Scotia: implications for genetic models; Canadian Journal of Earth Sciences, v. 26, p. 1617–1629.

Kramers, J.D. and Tolstikhin, I.N., 1997. Two terrestrial lead isotope paradoxes, forward transport modelling, core formation and the history of the continental crust; Chemical Geology, v. 139, p. 75–110.

Kyle, J.R., 1981. Geology of the Pine Point lead–zinc district; *in* Regional and Specific Deposits, Volume 9 (Handbook of Strata-Bound and Stratiform Ore Deposits); (ed.) K.H. Wolf; Elsevier, p. 643-741.

MacFarlane, A.W. and Shimizu, N., 1991. SIMS measurements of δ34S in sulfide minerals from adjacent vein and stratabound ores; Geochimica et Cosmochimica Acta, v. 55, p. 525–541.

Macqueen, R.W. and Thompson, R.I., 1978. Carbonate-hosted-lead-zinc occurrences in northeastern British Columbia with emphasis on the Robb Lake deposit; Canadian Journal of Earth Sciences, v. 15, p. 1737–1762.

Marini, L., Moretti, R., and Accornero, M., 2011. Sulfur isotopes in magmatic-hydrothermal systems, melts, and magmas; Mineralogy and Geochemistry, v. 73, p. 423–492. doi:10.2138/rmg.2011.73.14

Ohmoto, H. and Goldhaber, M., 1997. Sulfur and carbon isotopes; *in* Geochemistry of Hydrothermal Ore Deposits, V. III, (ed.) H.L. Barnes; John Wiley & Sons, New York, p. 517–611.

Ohmoto, H. and Rye, R.O., 1979. Isotopes of sulfur and carbon, in: Geochemistry of Hydrothermal Ore Deposits, Second Edition, (ed.) H.L. Barnes; John Wiley & Sons, p. 509–567.

Okulitch, A.V. (compiler), 2006. Phanerozoic bedrock geology, Slave River, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Open File 5281, scale 1:1,000,000. doi:10.4095/222163

Oviatt, N.M., 2013. Characterization of indicator minerals and till geochemical dispersal patterns associated with the Pine Point Pb-Zn Mississippi Valley-type Deposits, Northwest Territories, Canada; MSc thesis, University of Alberta, 208 p.

Oviatt, N.M., Gleeson, S.A., Paulen, R.C., McClenaghan, M.B., and Paradis, S., 2015. Characterization and glacial dispersal of indicator minerals associated with the Pine Point Mississippi Valley-type (MVT) district, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 52, p. 776–794. doi:10.1139/cjes-2014-0108

Paradis, S., Turner, W.A., Coniglio, M., Wilson, N., and Nelson, J.L., 2006. Stable and radiogenic isotopic signatures of mineralized Devonian carbonates of the Northern Rocky Mountains and the Western Canada Sedimentary Basin; *in* Potential for Carbonate-Hosted Lead-zinc Mississippi Valley-type Mineralization in Northern Alberta and Southern Northwest Territories: Geoscience Contributions, Targeted Geoscience Initiative, (ed.) P.K. Hannigan; Geological Survey of Canada, Bulletin 591, p. 75–104. doi:10.4095/222922

Paulen, R.C., Paradis, S., Plouffe, A., and Smith, I.R., 2011. Pb and S isotopic composition of indicator minerals in glacial sediments from NW Alberta, Canada: implications for Zn-Pb base metal exploration; Geochemistry: Exploration, Environment, Analysis, v. 11, p. 309–320. doi:10.1144/1467-7873/10-IM-032

Paulen, R.C., Smith, I.R., Day, S.J.A., Hagedorn, G.W., King, R.D., and Pyne, M.D., 2017. GEM2 Southern Mackenzie Surficial Activity 2017 report: surficial geology and heavy mineral studies in southern Northwest Territories; Geological Survey of Canada, Open File 8322, 27 p. doi:10.4095/306090

Pitman, P., 2014. Technical report on the HOAM Project, Northwest Territories Canada, NTS map sheets 85L, 85M, 95A, 95G, 95H, 95I, 95O, 95P, 96A and 96B; Olivut Resources, National Instrument 43-101 Technical Report (www.sedar.com).

Ripley, E.M. and Ohmoto, H., 1977. Mineralogic, sulfur isotope, and fluid inclusion studies of the stratabound copper deposits at the Raul Mine, Peru; Economic Geology, v. 72, p. 1017–1041.

Robinson, M. and Godwin, C.I., 1995. Genesis of the Blende carbonate-hosted Zn-Pb-Ag deposit, north-central Yukon Territory: Geologic, fluid inclusion and isotopic constraints; Economic Geology, v. 90, p. 369–384.

Wanless, R.K., Boyle, R.W., and Lowdon, J.A., 1960. Sulfur isotope investigation of the gold-quartz deposits of the Yellowknife district; Economic Geology, v. 55, p. 1591–1621.

Watson, D.M., 2013. Non-Renewable resource assessment (minerals): Łue Túé Sųlái candidate protected area, NTS 095H6 and 095H7; Northwest Territories Geoscience Office, Open File 2013-03.

Watson, D.M., 2011a. Sambaa K'e candidate protected area phase II non-renewable resource assessment – minerals, Northwest Territories, parts of NTS 085D, 095A, B, H; Northwest Territories Geoscience Office, Open File 2010-08.

Watson, D.M., 2011b. Ka'a'gee Tu area of interest, phase II non-renewable resource assessment – minerals, Northwest Territories, parts of NTS 85C, 85D, 85E and 85F; Northwest Territories Geoscience Office, Open File 2011-001.

Wheeler, J.O., Hoffman, P.F., Card, K.D., Davidson, A., Sanford, B.V., Okulitch, A.V., and Roest, W.R., 1996. Geological map of Canada; Geological Survey of Canada, Map 1860A, scale 1:5,000,000. doi:10.4095/208175

Zartman, R.E. and Doe, B.R., 1979. Plumbotectonics—the model; Tectonophysics, v. 75, p. 135–162.

Zartman, R.E. and Haines, S.M., 1988. The plumbotectonics model for Pb isotopic systematics among major terrestrial reservoirs—A case for bi-directional transport; Geochimica et Cosmochimica Acta, v. 52, p. 1327–1339.

Pebble Lithology Counts from Till Samples Collected in the Southern Northwest Territories (2010-2017)

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Introduction

Lithology classification conducted on the pebble-sized fraction of till samples can provide petrological indicators to asisst in the understanding of regional ice-flow movements and dispersal patterns (Shetsen, 1984; Prest and Nielsen, 1987). Clast lithologies, or till composition, is an alternative but often-overlooked proxy for the evolution of glacial erosional vigour and sediment production (cf., Thorleifson and Kristjansson, 1993; Trommelen et al., 2013). When a distinctive bedrock source is known, indicator clasts within till can delimit transport distances (Dreimanis & Vagners 1971; Dredge 1988; Charbonneau & David 1993; Kjær et al. 2003).

Two different sets of till samples were used for pebble counts in this study. One set of samples was donated by the Northwest Territories Geological Survey (NTGS) from their Protected Area Strategy (PAS) surveys in the Sambaa K'e (Trout Lake), Ka'a'gee Tu (Kakisa Lake) and Lue Túé Sųlái (Jean Marie River) regions (Watson, 2011a, 2011b, 2013). The second set of samples was from the samples collected in 2017 by the Geological Survey of Canada (GSC) GEM-2 Southern Mackenzie Surficial activity (Paulen et al., 2017). The reader is referred to Figure 1.2 of this report for a description of the PAS and GSC survey areas.

The till samples are largely divided between areas underlain by Paleozoic and Cretaceous bedrock and the Canadian Shield outcrops 100 km east of Pine Point, and the Cordillera (deformed belt) which is situated <25 km west of samples collected east of the Liard River (Fig. 7.1). This study examined the regional variations in till pebble lithology with respect to Late Wisconsin Laurentide Ice Sheet (LIS) ice flow patterns in the southern Northwest Territories. Till samples examined were collected near the surface (generally <1 m depth). This pebble dispersal study augments a much larger research activity (e.g., see other chapters in this report) to better understand the glacial history and depositional record of the LIS overlying an area that is down ice from the Canadian Shield in the east, and directly overlies Paleozoic carbonate platform and soft Cretaceous rocks of the Western Canada Sedimentary Basin (cf., Okulitch, 2006).

Methods

The donated pebbles from till samples collected by the NTGS were examined in combination with pebbles GSC till samples collected in 2017 along several east-west (EW) and north-south (NS) transects. A subset of 30 PAS samples and 44 GSC samples were evaluated based on lithology classifications, lithology counts, relative frequency percentages, and proportional dot maps (Fig. 7.2). EW-1 is the northernmost transect and EW-2 is the southernmost one. Four NS transects that included abundant sample locations were examined; NS-1 is the westernmost of these and NS-4 is the easternmost, with NS-2 and NS-3 being contained between them.

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Plakholm, J.A., Paulen, R.C., Sapera, J.R., and Hagedorn, G.W., 2019. Pebble lithology counts from till samples collected in the southern Northwest Territories (2010-2017); *in* GEM-2 Southern Mackenzie Surficial Activity 2018 report: Surficial Geology and Heavy Mineral Studies in Southern Northwest Territories, (eds.) R.C. Paulen, I.R. Smith and S.J.A. Day; Geological Survey of Canada, Open File 8477, p. 43-51. http://doi.org/10.4095/313426

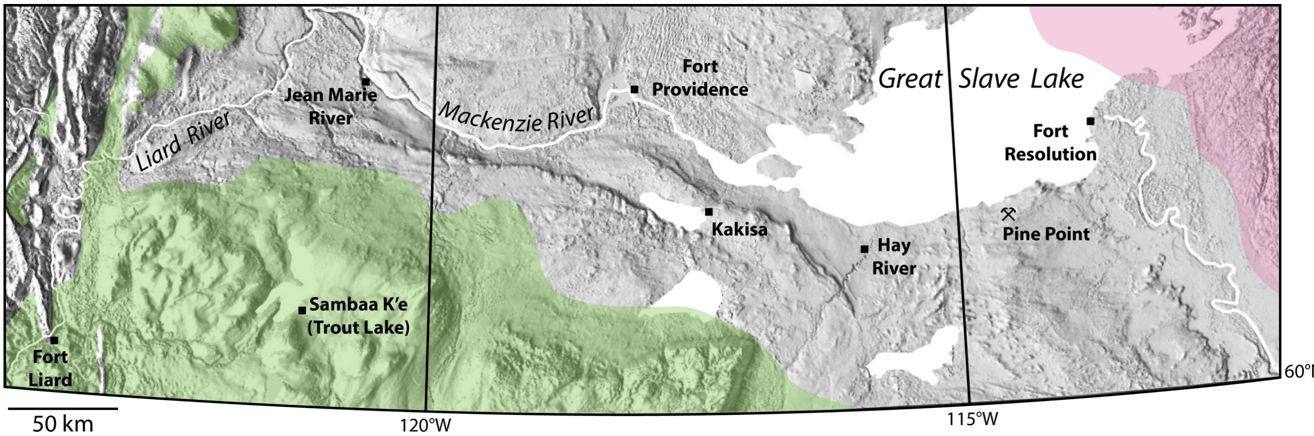

Figure 7.1. Map (ArcticDEM (Polar Geospatial Center, 2017)) of the pebble lithology study area in the southwest Northwest Territories with the Paleozoic carbonate sediments (no colour) occurring between the Canadian Shield to the east (pink overlay) and the Cretaceous sandstones and shales to the southwest (green overlay). Bedrock geology modified from Douglas (1974); Douglas and Norris (1976, 1977), and Okulitch (2006).

The PAS till samples were sorted and counted in 2011 by Consorminex Incorporated, Gatineau. into the following size fractions: >2.0 mm, 8-16 mm, and >16mm fractions. First, the >16mm oxalic-washed pebbles were sorted and counted, and when necessary to reach a minimum of 300 pebbles, the smaller 8-16 mm fraction was counted. The 300 pebbles examined were selected at random by using the cone and quarter method to partition the sample and then select the opposite diagonal two quarters of the sample to count. The selected pebbles were classified into separate lithological categories and unusual lithologies or features such as easily disaggregated clasts, abundant striations, heavily rounded and other out of the normal features were noted. The derivative pebble lithology data were used to determine the frequency percentages of each lithologic group, summing to 100%. Similar sorting and counting techniques were also applied to the pebbles from the 2017 GSC till samples.

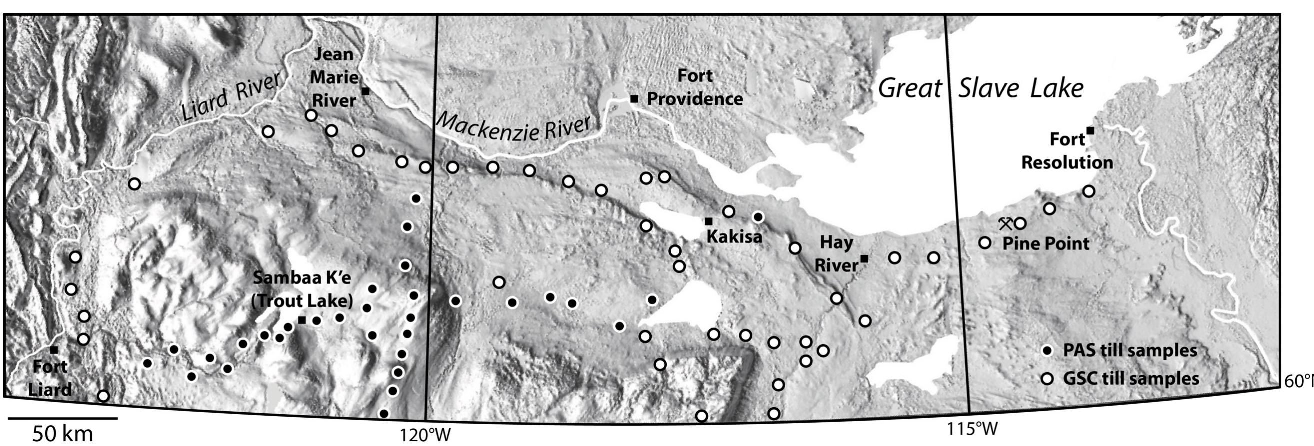

Figure 7.2. Study area (ArcticDEM) with the PAS and GSC till samples used for this pebble lithology study. The sample distribution was designed to create two east-west fences (longitudinal to regional ice-flow) and four north-south cross-fences.

Pebble lithology categories included four regional sources (from east to west): i) Canadian Shield rocks (Felsic Intrusive, Mafic Intrusive, Metavolcanic, Metasediment, Iron-rich Arkosic Quartzite, Undifferentiated Arkosic Quartzite, and Quartz Vein); ii) Paleozoic carbonates (Limestone, Green Shale, Dolomitized Limestone, Shale, Sandstone); iii) Cretaceous rocks (Sandstone, Shale, Chert Conglomerate, Ironstone, and Coal); iv) Cordilleran (Quartzite, Chert) rocks; and, v) 'Other' (e.g., Vein Quartz). Pebble locations for the PAS and GSC samples were plotted in ArcMap®.

Results

Relative abundance trends of Canadian Shield, Paleozoic, Cordillera and Cretaceous lithologies most frequently encountered in samples are summarized as fences in Tables 7.1 and 7.2 and shown on Figure 7.3. Frequency histograms (as total percentages) were created for both east to west transects (Figs. 7.4 and 7.5).

Table 7.1. Summary of east to west (Shield to Cordillera) frequency percentages.

Regional Lithology	Transect EW-1	Transect EW-2
Canadian Shield	Decreasing	Homogenous
Paleozoic carbonate	Homogenous	Homogenous
Cretaceous sediment	Slightly increasing	Increasing
Cordilleran	Slightly increasing	Homogenous
Other	Homogenous	Homogenous

Table 7.2. Summary of north to south fences frequency percentages.

Regional Lithology	Transect NS-1	Transect NS-2	Transect NS-3	Transect NS-4
Canadian Shield	Decreasing	Increasing	Decreasing	Homogenous
Paleozoic carbonate	Homogenous	Homogenous	Increasing	Homogenous
Cretaceous sediment	Homogenous	Homogenous	Homogenous	Homogenous
Cordilleran	Increasing	Homogenous	Homogenous	Homogenous
Other	Homogenous	Homogenous	Homogenous	Homogenous

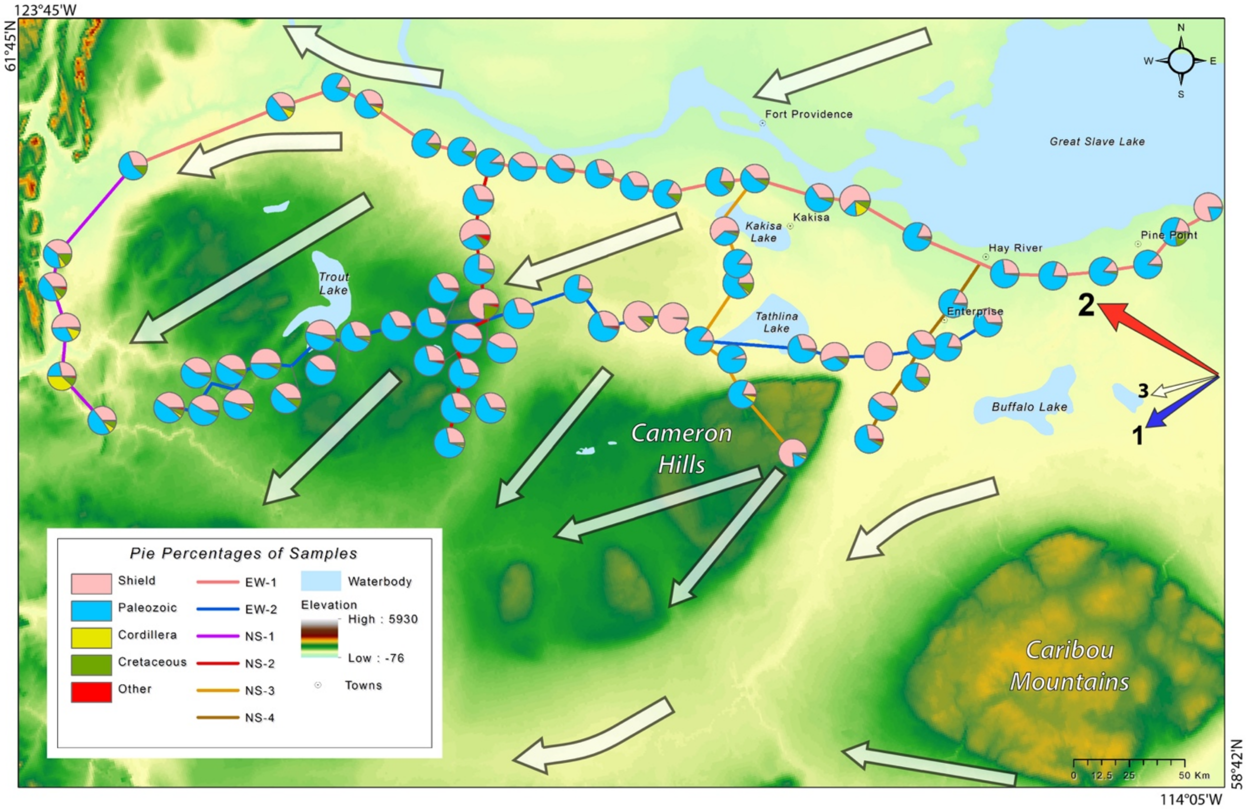

Figure 7.3. Proportional pie diagrams of frequency percentage of Canadian Shield, Paleozoic, Cordillera, Cretaceous, and Other pebble lithologies present at each sample location plotted on a regional DEM (GTOPO30, United States Geological Survey (2007)). Late Wisconsin ice-flow arrows are summarized from Prest et al. (1968); Paulen et al. (2007), Bednarski (2008), Huntley et al. (2008), and ice-flow history at Pine Point from Oviatt et al. (2015).

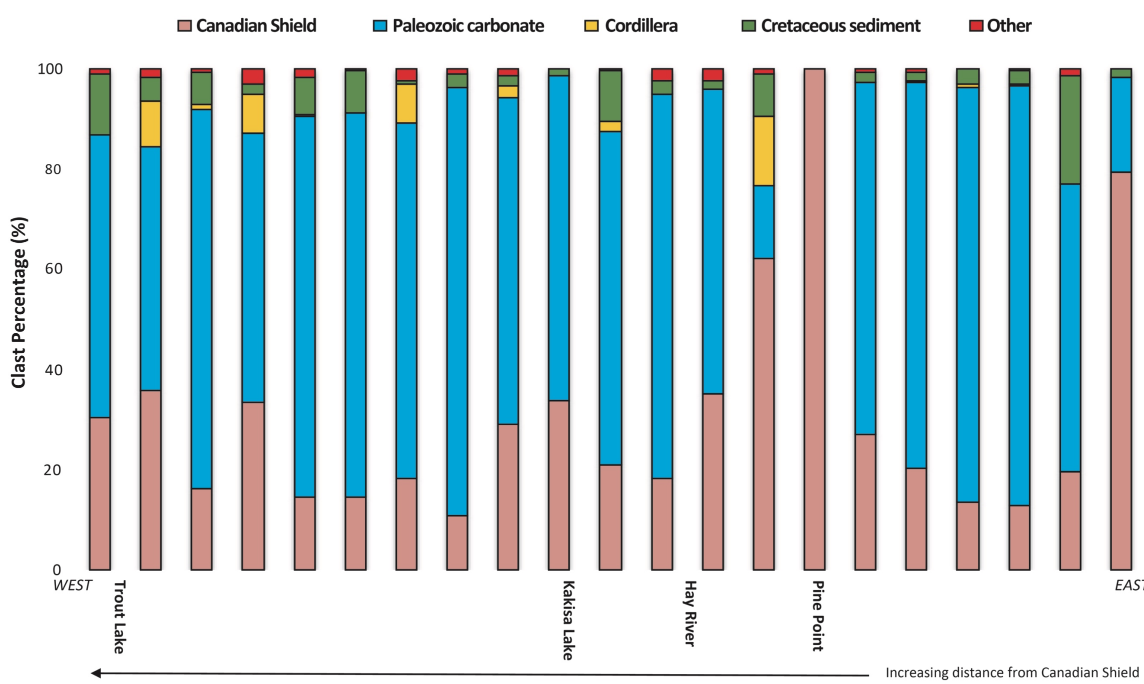

Figure 7.4. Weighted percentage variation of Canadian Shield, Paleozoic carbonate, Cordillera, Cretaceous sediment, and Other lithologies on the northern East-West fence (EW-1).

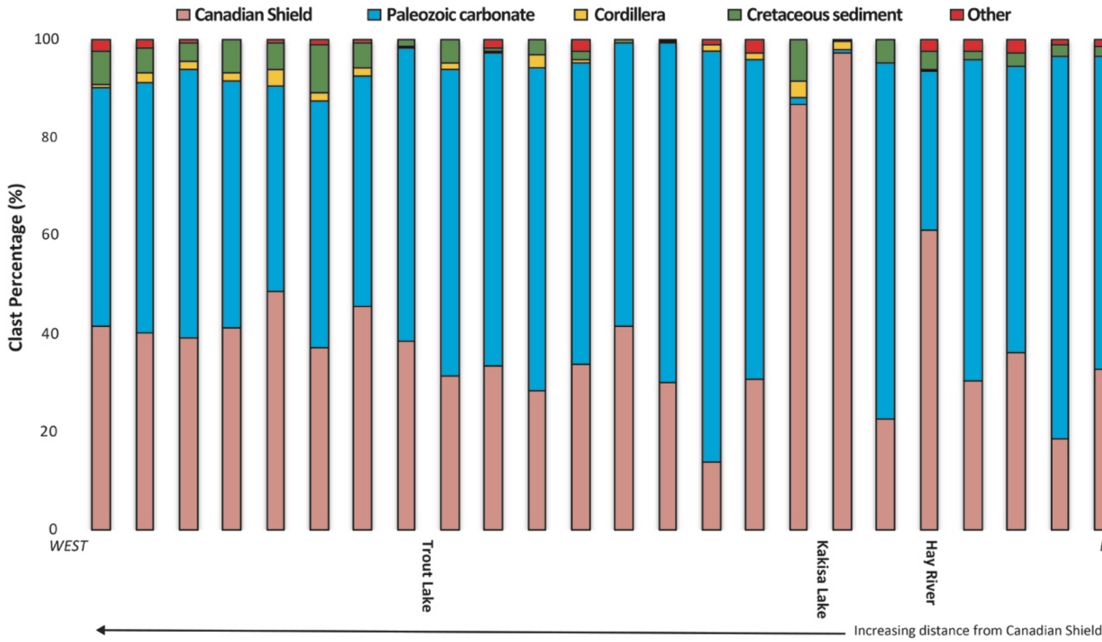

Figure 7.5. Weighted percentage variation of Canadian Shield, Paleozoic carbonate, Cordillera, Cretaceous sediment, and Other lithologies on the southern East-West fence (EW-2).

Canadian Shield

The northern east-west fence (EW-1) shows a decreasing frequency percentage travelling from east to west whereas the southern east-west fence (EW-2) shows a mostly homogenous distribution along the transect. However, EW-2 shows a higher frequency percentages of Canadian Shield pebbles punctuated by low frequency percentages on the eastern portion of the fence whereas the western portion of the fence shows a more homogenous frequency percentage. Overall, the general trend of the north-south fences for Canadian Shield pebbles is homogenous. Anomalous samples amongst all the fences are found along the southern EW-2 fence falling between 80 to 90 percent frequency range whereas the majority of the samples generally contain between the 20 to 30 percent Canadian Shield pebbles.

Paleozoic Carbonate

The east-west fences, EW-1 and EW-2, show a homogenous frequency distribution of Paleozoic pebble lithologies. Similarly, the north-south fences all show a homogenous frequency distribution of Paleozoic pebble lithologies. The anomalous samples discovered in the EW-1 and EW-2 fences showed very low frequencies that coincide with the same samples showing very high frequencies of Canadian Shield pebbles. The anomalous samples discovered in the NS-1 and NS-3 showed considerably low frequencies between 10 to 20 percent whereas the majority of the samples in the study area are generally contain between 30 to 60 percent Paleozoic carbonate pebbles.

Cretaceous Sediment

The east-west fences, EW-1 and EW-2, show an increase in frequency distribution at Hay River, but then homogenous frequency of Cretaceous pebbles west and southwest. Similarly, all the north-south fences show a homogenous frequency distribution of Cretaceous pebbles. There is one anomalous sample, TL-08-042, on the NS-2 fence falling within the 20 to 30 percent frequency range whereas the majority of till samples contain <10 percent clasts derived from the Cretaceous bedrock.

Cordillera
The east-west fences, EW-1 and EW-2, show a homogenous, but very low frequency distribution of Cordillera pebbles in till. There is one anomalous sample, 17-PTA-049, on the NS-1 fence falling within the 30 to 40 percent frequency range, whereas the majority of the samples generally contain <10 percent.

Discussion and Future Work
Anomalous high or low percentages in the till samples may be due to a variety of circumstances including sampling error (misidentification, broken local bedrock, differential weathering of erratics), blockages or deflection of sediment debris from higher elevations, and concentrated areas of glacial erosion of specific source areas or a shift in resistive stresses in basal drags (Shilts, 1973).

In general, the dispersal pebble lithologies is dependent on source outcrop area and glacial dynamics such as ice-flow history of the former LIS. Englacial transport may elucidate the higher frequencies within the western portion of the study area following the natural dipping Phanerozoic bedrock. An alternative approach may be lodgement and plucking of high relative hardness Canadian Shield pebbles, which would survive long distance transport over softer bedrock without being heavily eroded or disaggregated. The anomalously high frequency distribution in samples contained within the EW-2 fence may be influenced by local topography differences such as the Cameron Hills south of Tathlina Lake, where the LIS may have locally undergone compression and till advection of Shield-rich englacial debris. The prominent eastern ridge of the Cameron Hills may also have deflected portions of the LIS, leading to the displacement or truncation of Canadian Shield debris (Shilts, 1991).

The Paleozoic pebble lithologies dispersal is broad and homogenous; the results we see are due to deposition of locally derived source components along the ice flow trajectories (cf., Shilts, 1991). The Paleozoic source material is located immediately beneath half of the till samples collected and slightly up-ice of the remaining samples. The lithologies present within the Paleozoic region are composed of soft rocks that are easily fractured and eroded and therefore plucked without difficulty by ice sheets. This elucidates the higher frequency percentages of Paleozoic pebble lithologies seen throughout the study area due to the proximity of the till sampling locations.

The Cretaceous source material is located immediately beneath half of the till samples collected. This proximity of the Cretaceous bedrock is similar to the proximity of the Paleozoic bedrock, however, the Cretaceous frequency distribution is contrastingly very low. The Cretaceous sediments are easily eroded and disaggregated by basal ice traction and subsequent advection of till. In northwest Alberta, Paulen (2009) demonstrated using till micromorphology that while the tills derived from the lower Fort St. John Group Cretaceous shales had almost no recovery with bulk sample processing, the tills are, in fact, rich in Cretaceous bedrock fragments. This discordant relationship is also reflected with the samples processed in the PAS and GSC sample surveys. Therefore, the soft Cretaceous sediments did not likely survive sample processing methods. Other studies of pebble lithology distribution in western Canada (Shetsen, 1984) noted that local Cretaceous lithologies were either scarce or absent in the surface tills and were thus eliminated from statistical studies of clasts in southern and central Alberta.

The Cordilleran pebble frequency distributions were generally very low over the entire study area. The original source area for these pebbles is located amongst the front ranges on the eastern portion of the Cordillera. The Cordilleran-sourced pebbles recovered from ice sheets is likely derived from reworking and incorporation of ancient, preglacial eastward flowing river sediments into the sediments of the advancing continental ice sheets (Leckie, 2006). Higher percentages of Cordillera pebbles were seen on the westernmost portion of the map due to accumulation and proximity to the foreland basin of the Rocky Mountains.

Previously, it was determined by Rice et al. (2013) and Oviatt et al. (2015) that three glacial trajectories impacted the study area during the LIS glaciation (see Fig. 7.3). Long distance westward transport of Canadian Shield pebbles occurred over a relatively softer, younger bedrock resulting in a relatively ubiquitous distribution and high frequency percentages of Canadian Shield pebbles within surface till samples collected throughout the study area. Rice et al. (2013) showed a general upward decreasing content of Canadian Shield clasts with till thickness at Pine Point. The tills sampled at the surface for this study, and their Canadian Shield clast contents, have to be considered that they are not necessarily single vector products of the last glacial movement of the Laurentide Ice Sheet, diluted by distance, but rather are most likely reworked from tills previously deposited by either older glacial events or from different phases of ice flow that occurred during the last glacial event.

Pebble counts from only 44 GSC till samples, out of 137 till samples collected from the 2017 GEM-2 field season (Paulen et al., 2017) were included with the PAS pebble counts for this study. Additional pebbly lithology counts will be conducted on the remaining 2017 till samples and samples collected during 2018 fieldwork (see Smith et al., this report), which should help further delineate dispersal trends in the western sector of the Laurentide Ice Sheet. The pebble counts from the PAS samples will be published in GSC Open File 8437 (Plakholm et al., in press). Pebble counts from the 2017 and 2018 GSC field seasons will be released at a future date.

References

Bednarski J.M., 2008. Landform assemblages produced by the Laurentide Ice Sheet in northeastern British Columbia and adjacent Northwest Territories – constraints on glacial lakes and patterns of ice retreat; Canadian Journal of Earth Sciences, v. 45, p. 593-610. doi:10.1139/E07-053

Charbonneau, R. and David, P.P., 1993. Glacial dispersal of rock debris in central Gaspesie, Quebec, Canada; Canadian Journal of Earth Sciences, v. 30, p. 1697–1707.

Douglas, R.J.W. 1974. Geology, Trout River, District of Mackenzie; Geological Survey of Canada, Map 1371A, scale 1:250 000. doi:10.4095/109150

Douglas, R.J.W. and Norris, D.K., 1976. Geology, Fort Liard, District of Mackenzie; Geological Survey of Canada, Map 1379A, scale 1:250 000. doi:10.4095/109154

Douglas, R.J.W. and Norris, D.K., 1977. Geology, Sibbeston Lake, District of Mackenzie; Geological Survey of Canada, Map 1377A, scale 1:250 000. doi:10.4095/109051

Dredge, L.A., 1988. Drift carbonate on the Canadian Shield. II: Carbonate dispersal and ice-flow patterns in northern Manitoba; Canadian Journal of Earth Sciences v. 25, p. 783–787.

Dreimanis, A. and Vagners, U.J., 1971. Bimodal distribution of rock and mineral fragments in basal tills; *in* Till, a Symposium; (ed.) R. Goldthwait; Ohio State University Press, Columbus, OH, p. 237-250.

Huntley, D., Mills, A., and Paulen, R., 2008. Surficial deposits, landforms, glacial history, and reconnaissance drift sampling in the Trout Lake map area, Northwest Territories; Geological Survey of Canada, Current Research 2008-14, 14 p. doi:10.4095/225636

Kjær, K.H., Houmark-Nielsen, M., and Richardt, N., 2003. Ice-flow patterns and dispersal of erratics at the southwestern margin of the late Scandinavian Ice Sheet: signature of palaeo-ice streams; Boreas, v. 32, p. 130–148.

Leckie, D.A., 2006. Tertiary fluvial gravels and evolution of the Western Canadian Prairie Landscape; Sedimentary Geology, v. 190, p. 139–158. doi:10.1016/j.sedgeo.2006.05.019

Okulitch, A.V. (compiler) 2006. Phanerozoic bedrock geology, Slave River, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Open File 5281, scale 1:1 000 000. doi:10.4095/222163

Oviatt, N.M., Gleeson, S.A., Paulen, R.C., McClenaghan, M.B., and Paradis, S., 2015. Characterization and glacial dispersal of indicator minerals associated with the Pine Point Mississippi Valley-type (MVT) district, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 52, p. 776–794. doi:10.1139/cjes-2014-0108

Paulen R.C., 2009. Sampling techniques in the Western Canada Sedimentary Basin and the Cordillera; *in* Application of Till and Stream Sediment Heavy Mineral and Geochemical Methods to Mineral Exploration in Western and Northern Canada; (eds.) R.C. Paulen and I. McMartin; Geological Association of Canada, GAC Short Course Notes, v. 18, p. 49–73.

Paulen, R.C., Prior, G.J., Plouffe, A., Smith, I.R., McCurdy, M.W., and Friske, P.W.B. 2007. Cretaceous shale of northern Alberta: a new frontier for base metal exploration; *in* Exporation in the New Millenium; (ed.) B. Milkereit; Proceedings of the Fifth Decennial International Conference on Mineral Exploration, p. 1207−1213.

Paulen, R.C., Smith, I.R., Day, S.J.A., Hagedorn, G.W., King, R.D., and Pyne, M.D., 2017. GEM2 Southern Mackenzie Surficial Activity 2017 report: surficial geology and heavy mineral studies in southern Northwest Territories; Geological Survey of Canada, Open File 8322. doi.org:10.4095/306090

Plakholm, J.A., Paulen, R.C. and Paré, D., in press. Clast lithology counts from selected surficial samples, Trout Lake and Kakisa Protected Areas Strategy Surveys, southwest Northwest Territories; Geological Survey of Canada, Open File 8437.

Polar Geospatial Center., 2017. ArcticDEM; DigitalGlobe Incorporated.

Prest, V.K. and Nielsen, E., 1987. The Laurentide Ice Sheet and long distance transport; Geological Survey of Finland, Special Paper 3, p. 91–101.

Prest, V.K., Grant, D.R., and Rampton, V.N., 1968. Glacial map of Canada; Geological Survey of Canada, Map 1253A, scale 1:5 000 000. doi:10.4095/108979.

Rice, J.M., Paulen, R.C., Menzies, J.M., McClenaghan, M.B., and Oviatt, N.M., 2013. Glacial stratigraphy of the Pine Point Pb-Zn mine site, Northwest Territories; Geological Survey of Canada, Current Research 2013-5, 14 p. doi:10.4095/292184

Shetsen, I., 1984. Application of till pebble lithology to the differentiation of glacial lobes in southern Alberta; Canadian Journal of Earth Sciences, v. 21, p. 920-933.

Shilts, W.W., 1973. Glacial Dispersal of Rocks, Minerals and Trace Elements in Wisconsinan Till, Southeastern Quebec, Canada; Geological Society of America, Memoir 136, p. 189-217.

Shilts, W.W., 1991. Principles of Glacial Dispersal and Sedimentation; in Exploration Geochemistry Workshop; (eds.) J.M. Franklin, J.M. Duke, W.W. Shilts, W.B. Coker, P.W.B. Friske, Y.T. Maurice, S.B. Ballantyne, C.E. Dunn, G.E.M. Hall, and R.G. Garrett; Geological Survey of Canada, Open File 2390, p. 2.1-2.42. doi:10.4095/132390

Thorleifson, L.H. and Kristjansson, F.J., 1993. Quaternary geology and drift prospecting, Beardmore-Geraldton area, Ontario; Geological Survey of Canada, Memoir 435, 146 p. doi:10.4095/183987

Trommelen, M.S., Ross, M., and Campbell, J.E., 2013. Inherited clast dispersal patterns: Implications for palaeoglaciology of the SE Keewatin Sector of the Laurentide Ice Sheet; Boreas, v. 42, p. 693-713. doi: 10.1111/ j.1502-3885.2012.00308.x

United States Geological Survey, 2007. GTOPO30: North America elevation 1-kilometer resolution dataset; United States Department of the Interior. http://eros.usgs.gov/products/elevation/gtopo30.html (accessed October 2018).

Watson, D.M., 2011a. Sambaa K'e Candidate Protected Area Phase II Non-renewable Resource Assessment – Minerals, Northwest Territories, Parts of NTS 085D, 095A, B, H; Northwest Territories Geoscience Office, NWT Open File 2010-08.

Watson, D.M., 2011b. Ka'a'gee Tu Area of Interest, Phase II Non-renewable Resource Assessment – Minerals, Northwest Territories, Parts of NTS 85C, 85D, 85E and 85F; Northwest Territories Geoscience Office, NWT Open File 2011-001.

Watson, D.M., 2013. Non-Renewable Resource Assessment (Minerals): Łue Túé Sųlái Candidate Protected Area, NTS 095H6 & 095H7; Northwest Territories Geoscience Office, NWT Open File 2013-03.

Glacial Dynamics and Stratigraphic Research at the Past-Producing Pine Point Mine, Northwest Territories

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Introduction

A detailed Quaternary glacial stratigraphic study is being undertaken at the past-producing Mississippi Valley-type (MVT) Pb-Zn Pine Point district. Research from the GEM-1 Tri-Territorial Indicator Minerals project identified several well-preserved Quaternary exposures in former open-pit mines at Pine Point. In some instances, the glacial drift cover is greater than 20 m, providing a unique opportunity for detailed glacial stratigraphic analyses. For the present GEM-2 Southern Mackenzie Surficial activity, open pit deposit M-52 was selected for a detailed Quaternary stratigraphic study at Pine Point (elevation ~192 m above sea level), building on earlier glacial sediment studies at Pine Point (Rice et al., 2013a; Oviatt et al., 2015; McClenaghan et al., 2018).

Detailed stratigraphic investigations undertaken at pit M-52 include glacial stratigraphy, micromorphology, geochemistry, sedimentology, and geomorphology. The goal of this research is to augment our understanding of glacial dynamics in the western sector of the Laurentide Ice Sheet (LIS) and to link till advection processes to modern glacial dispersal models. Additionally, interpretation of the glacial sequence at pit M-52 will be correlated with the previous GEM-1 stratigraphic research at Pine Point (Rice, 2014; Rice et al., in press; Menzies et al., submitted), with sections exposed along the Mackenzie River (see Hagedorn et al., Chapter 3 of this report), and extensionally with seismic shothole and diamond drill hole stratigraphy (Smith and Lesk-Winfield, 2010; also see Smith et al., Chapter 2 of this report).

Glacial stratigraphy and surficial geochemistry will improve our understanding of the glacial history of the region and help decipher sediment provenance and mineral dispersal histories. This study will improve our understanding of which glacial flow trajectory was responsible for the main erosional and depositional mechanisms that created the mineral dispersal trains documented at Pine Point in GEM-1 (Oviatt, 2013; McClenaghan et al., 2018). Thus, this study will contribute knowledge towards improved exploration methods and encourage further utilization of drift prospecting methodologies by the exploration industry.

Location

The past-producing Pine Point mining district extends 50 km along an east-west trend south of Great Slave Lake, Northwest Territories (Fig. 8.1). The mining district was a world class carbonate-hosted Mississippi Valley-type Pb-Zn deposit, operated by Cominco from 1963 to 1988 (Hannigan, 2006a). While the town of Pine Point and most of the mining infrastructure were completely removed after the mine's closure, the former open pits used to mine the deposits were not reclaimed, and extensive exposures of Quaternary sediments and bedrock are available for study. The former mining district is accessible by all-season highway and is approximately 90 km east of the town of Hay River, NT, and is located on the Buffalo Lake National Topographic System (NTS) 1:250 000 map sheet 85-B.

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Sapera, J.R., Paulen, R.C., and Menzies, J. 2019. Glacial dynamics and stratigraphic research at the past-producing Pine Point Mine, Northwest Territories; *in* GEM-2 Southern Mackenzie Surficial Activity 2018 report: Surficial Geology and Heavy Mineral Studies in Southern Northwest Territories, (eds.) R.C. Paulen, I.R. Smith and S.J.A. Day; Geological Survey of Canada, Open File 8477, p. 52-61.
http://doi.org/10.4095/313427

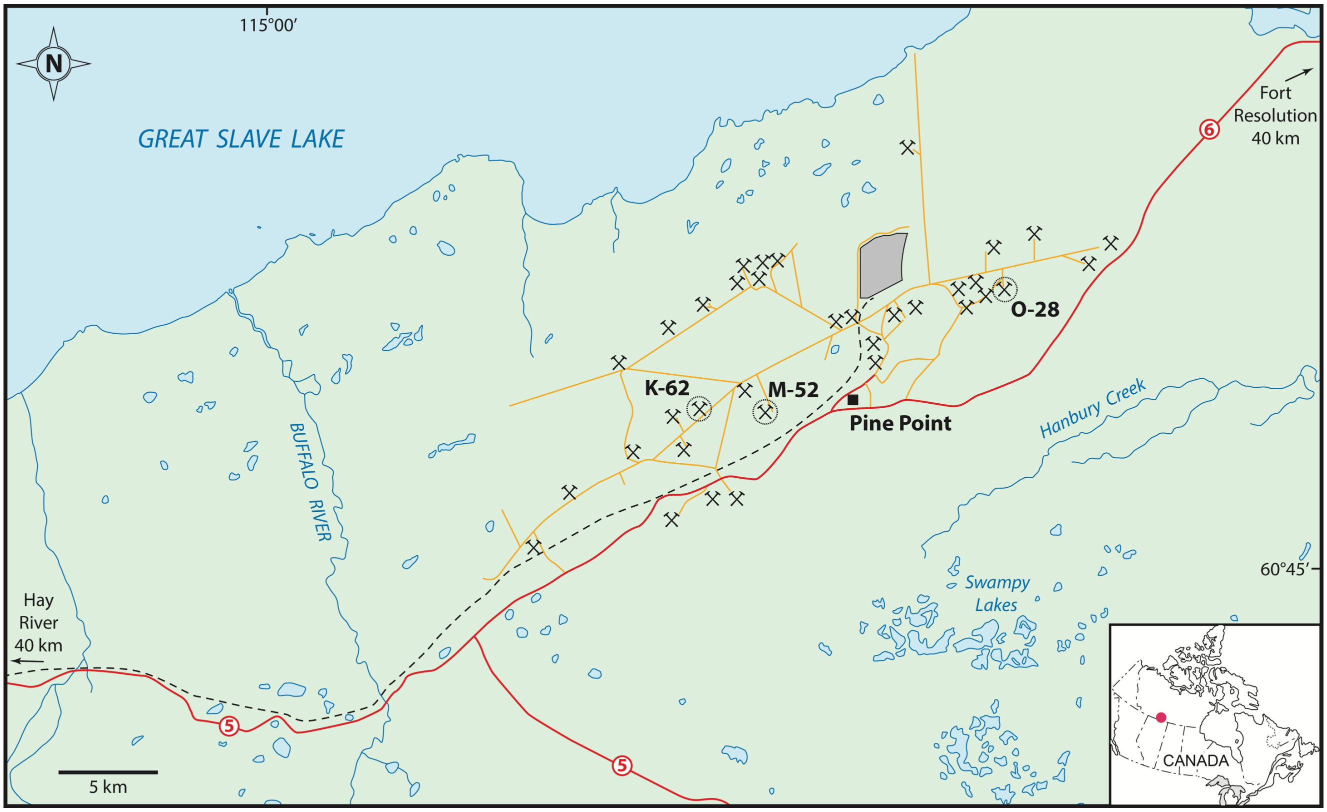

Figure 8.1. Location of study area within the former Pine Point mining district. The grey shaded area is the large region of mine tailings and the dashed line indicates the former rail bed of the Great Slave Railway (Canadian National) that once serviced the mine. Former open pits are indicated by the crossed hammers, and pits with previous work (O28 and K62) are indicated along with pit M-52, the focus of this study.

Regional Geology

The Pine Point mining district is located in the Great Slave Plain of the Interior Plains physiographic region, in the Western Canadian Sedimentary Basin (Bostock, 1970). The bedrock in the area is composed of gently west dipping Paleozoic sedimentary strata that extend between the Precambrian Shield ~100 km to the east and the Cordillera ~500 km to the west (Hannigan, 2006a). Orebodies at the Pine Point are hosted within middle Devonian carbonate rocks, dolostone and limestone, of the Presqu'ile Formation (Rhodes et al., 1984).

The Pine Point mining district is characterized by low relief and thick till overlying bedrock. Till is thickest in the west, reaching over 25 m, and thins to 1 m towards the east (Oviatt et al., 2015). Historic drill hole data (cf., Lemmen, 1990) and modern diamond drill logs (S. Clemmer, Osisko Metals Incorporated, pers. comm. 2018) along with observations in exposed pit walls (e.g., Rice et al., 2013) indicate that till is locally thicker in karst collapse features. The thick till sequences were deposited by the LIS during the Wisconsin glaciation. The bedrock striation record indicates multiple phases of ice flow (Paulen et al., 2011; Oviatt et al., 2015; McClenaghan et al., 2018). At the surface, flutings to the south were shaped by ice streaming and indicate multiple flow phases, observable in overprinted landforms (Oviatt et al. 2015; McClenaghan et al., 2018). Accompanying retreat of the LIS, the area became inundated by glacial Lake McConnell which resulted in winnowing of till and overprinting of landforms by glaciolacustrine sediments and beaches (Lemmen, 1998; Oviatt and Paulen, 2013).

Previous Surficial Geology Research

Understanding of the surficial geology of the Pine Point mining district has evolved over time, beginning with regional observations and then narrowing into studies executed on the property. Observations made by early Geological Survey of Canada (GSC) reconnaissance surveys were compiled by Prest et al. (1968) in the Glacial Map of Canada. This publication indicated one ice flow direction and generalized the region as having been inundated by a glacial lake. More detailed studies of the surficial geology of the Pine Point mining district were conducted by the GSC in Lemmen's (1990, 1998) investigation of glacial Lake McConnell and regional surficial geology. Lemmen (1998) described the deposits and landforms in the area and identified one direction of ice flow.

GSC fieldwork conducted in 2010 documented cross-cutting striations on bedrock surfaces exposed in Pine Point open pits (Oviatt et al., 2011; Oviatt, 2013). As a part of GEM-1, the surficial geology of the western half of the Pine Point mining camp was mapped (NTS 85-B/15) (Oviatt and Paulen, 2013) and described in detail by Oviatt (2013). Documented striations, recorded in the field, coupled with aerial photograph and satellite imagery landform analysis, have determined a minimum of three ice-flow trajectories (Oviatt, 2013). Furthermore, a detailed dispersal study was conducted at pit O-28 to document glacial dispersal down-ice from a known orebody and reported by Oviatt (2013), Oviatt et al. (2015), and McClenaghan et al. (2018).

Stratigraphic (Rice et al., 2013a) and micromorphological studies (Rice 2014; Rice et al. 2014; Rice et al. (in press); Menzies et al. (submitted)) have been conducted at selected open pits at Pine Point: K-62 and O-28. Rice (2014) concluded that the erosional history in the striation records generally correlated with the subglacial depositional sequences and that there is no evidence at Pine Point to support that the tills observed in K-62 were deposited in different glaciations, thus the area was never ice free during the Late Wisconsin (Rice et al., 2013b). Menzies et al. (submitted) evaluated deformation bands within the till in a vertical section at O-28 to reconstruct the paleo-strain records of past glacial processes and related it to till advection and basal ice-bed conditions.

Methods

Field work was conducted at pit M-52 in July 2018. The M-52 pit was selected because: 1) it was one of the last open pits to be mined (Hannigan, 2006b) and has retained the freshest vertical faces, 2) the exposed glacial sediments were in contact with bedrock; and, 3) the Quaternary exposure was in excess of 20 m thick, well preserved, and easily accessed. Due to slumping and safety factors, it was not possible to work on a single vertical section through the complete Quaternary succession. Instead, three sections faces were identified as suitable and the units were correlated stratigraphically and by using an altimeter (Fig. 8.2).

Once the sections were selected, preliminary stratigraphic observations were made and then the sections were cleared off. Talus and slumped till were cleared using hand picks and shovels to at least 0.5 m into the face. From preliminary observations there appeared to be two different till units, a lower, dense grey till and a lighter brown till overlying it (Fig. 8.2). The top 1.5 m (discontinuous) of M-52 is glaciolacustrine sediments, consisting of winnowed till and littoral sediments deposited by glacial Lake McConnell. A horizon of discrete boulders in the upper till was investigated to see if it was a boulder pavement. Striation measurements on the upper surface of boulders pavements have been used to reconstruct glacial flow directions (cf., Paulen and McClenaghan, 2015). Many of the boulders were composed of lithologies that were not easily abraded such as granite. The general trends of the striations were measured using a Brunton compass (Fig. 2) and were plotted in RockWorks14® on a rose diagram (Fig. 8.3).

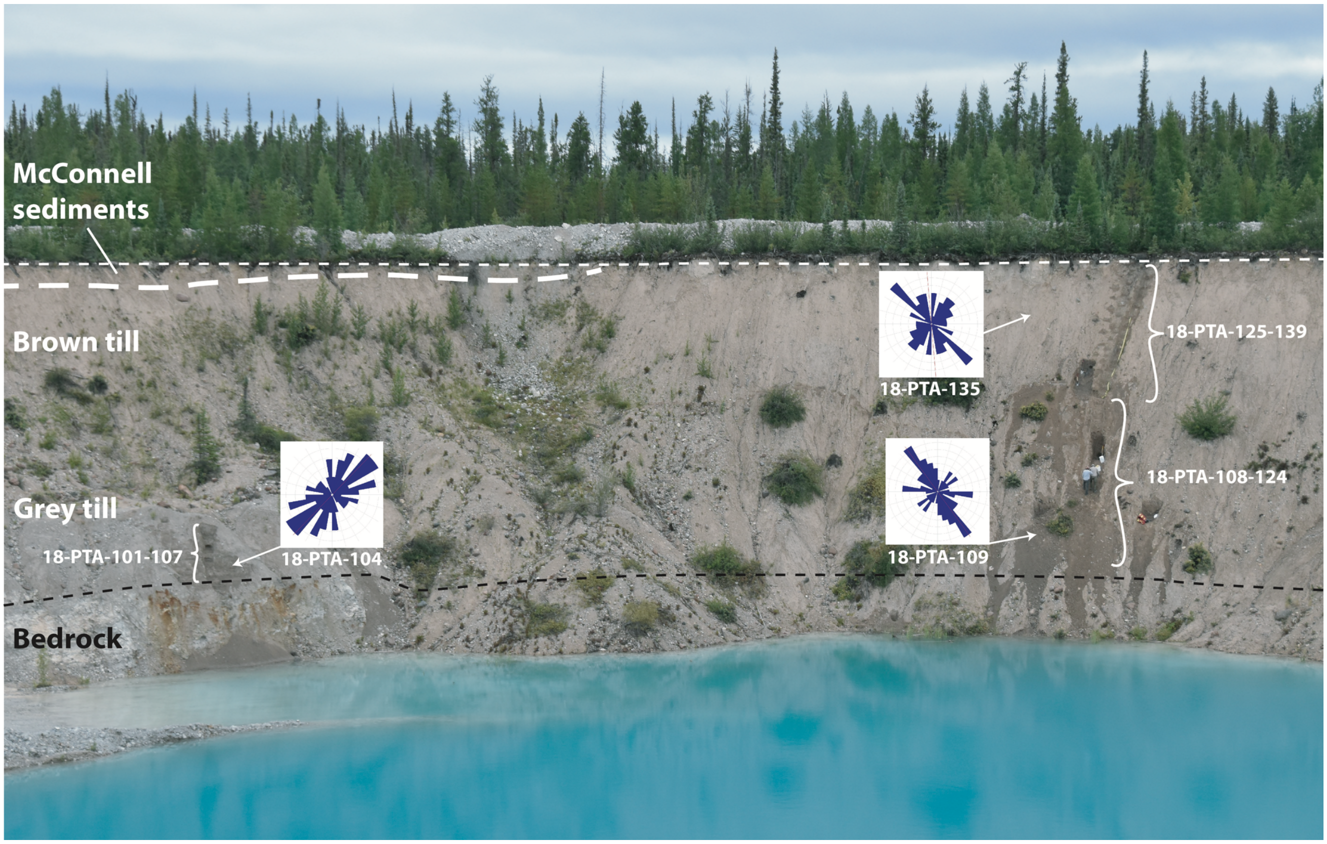

Figure 8.2. Annotated photograph of the north face of the M-52 pit, showing the bedrock surface and almost 20 m of two observed till units. Locations of samples collected and till fabrics are shown. People for scale at right side of the photo.

Figure 8.3. Example of a boulder in the upper portion of the brown till, with a consistent glacial polish on the top (Brunton compass for scale). The inset rose plot shows the directions of all the boulders that had a glacial polish on their upper surface.

Till Samples
Three types of till samples were collected throughout the section (Table 8.1). Samples for matrix (<0.063 mm) geochemistry, grain size, carbonate content, clay mineralogy, and Munsell colour were collected using an uncoated steel sampling shovel and placed in 3 kg sample plastic bags. Bulk samples, approximately 20 kg, were collected in 13 litre (3.5 gallon) pails for heavy mineral processing, to provide mineral grain counts and pebble fractions for lithology counts. Two till samples were also collected from pit M-52 in 2017 for matrix geochemistry and recovery of heavy minerals. (Table 8.1).

To study the micromorphology of the section, Kubiëna tins were utilized to capture a bulk sample of undisturbed sediment. Kubiëna tin sample locations and intervals were determined in order to further refine the previous work by Rice et al. (in press) and Menzies (submitted). A sample interval of 25 to 50 cm was established in order to capture a more detailed sedimentological history of the till sequences. Tighter sample spacing was utilized closer to areas of interest, such as immediately overlying the bedrock surface, contacts/transitions between till units, and rip-up clasts. At each sample site, the specific reason to collect the sample, and the following sedimentological data was recorded: colour, texture, moisture, clast content, clast characteristics, joint surfaces, and when present, iron staining. Sampling began above the contact with bedrock and continued upwards so as to reduce contamination from progressively upward section clearing (Fig. 8.2).

Clast Fabrics
Three macro clast fabrics were measured throughout the section; their locations are identified in Figure 8.2. The first fabric was measured close to the bedrock surface in the lower grey till (18-PTA-104), the second fabric was measured at the base of the larger section (18-PTA-109), and the third was measured close to the top of the unit in the light brown till (18-PTA-135). The till fabrics will contribute to the discrimination of till units in addition to the micromorphology. At each of the selected sites, a horizontal bench was excavated adjacent to the Kubiëna tin site and 50 prolate clasts with an a:b axis ≥1.5 were identified (Benn, 2004). Non-magnetic, aluminum knitting needles were inserted into the till parallel to the trend and plunge of each clast to measure the orientation of the long axis with a Brunton compass. The clast fabric data were plotted in RockWorks14® on lower hemisphere equal area stereonets.

Results
Pit M-52 has two visibly distinct tills, a grey till exposed at the base of the section and a brown till at the top. However, when the entire section was cleared and logged in detail, the contact between the two tills was undiscernible, and suspected to be gradational over several metres. This undiscernable contact could have two possible interpretations with respect to the stratigraphy: 1) only a single till is exposed here, with the upper brown colour reflecting greater oxidation near the natural land surface; or, 2) the contact is gradational and a product of extensive glacial inheritance and mixing as the glacial dynamics shifted during till accretion. Given the high matrix carbonate content of the tills in the region (Rice et al., 2013a; Oviatt 2013) and the preservation of abundant sulphide mineral grains in the near-surface till (McClenaghan et al., 2012; Oviatt et al., 2015; McClenaghan et al., 2018), we conclude that the latter interpretation is probably more likely. The drastic difference observed between the lowest clast fabric relative to the upper till fabrics supports this interpretation. Detailed glacial micromorphology will provide further insights.

Boulder Horizon
Located in the upper part of the brown till unit, approximately 2 to 4 metres depth from the surface, a total of 13 boulders were investigated for striations; glacial polish was only identifiable on the top

surface of five boulders (Fig. 8.3). The flow vectors on the boulders range from SW to NW, with no definitive trend.

Table 8.1. Summary of till samples and clast fabric data collected at Pit M-52.

Sample #	Sample Depth (m)	Kubiëna Tin	Matrix Geochemistry	Bulk HMC Sample	Clast Fabric	Notes
18-PTA-101	18.00	X	X	X	-	Overlying bedrock
18-PTA-102	17.75	X	X	-	-	
18-PTA-103	17.50	X	X	-	-	
18-PTA-103-A	17.35	X	-	-	-	Shear structure
18-PTA-104	17.25	X	X	-	X	
18-PTA-105	17.00	X	X	-	-	
17-PTA-016	17.00	-	X	X	-	2017 till sample (grey till)
18-PTA-106	16.50	X	X	-	-	
18-PTA-107	16.00	X	X	X	-	
18-PTA-108	16.00	X	X	X	-	
18-PTA-109	15.75	X	X	-	X	
18-PTA-110	15.50	X	X	-	-	
18-PTA-111	15.20	X	X	-	-	
18-PTA-112	15.00	X	X	-	-	
18-PTA-112-A	14.90	X	-	-	-	Till intraclast or sheared bed
18-PTA-113	14.80	X	-	-	-	Rip-up clast (?)
18-PTA-114	14.70	X	X	-	-	
18-PTA-115	14.40	X	X	-	-	
18-PTA-117	13.90	X	X	-	-	
18-PTA-118	13.40	X	X	-	-	
18-PTA-119	12.90	X	X	X	-	
18-PTA-120	12.40	X	X	-	-	
18-PTA-121	11.90	X	X	-	-	
18-PTA-122	11.40	X	X	-	-	
18-PTA-123	10.90	X	X	-	-	
18-PTA-124	10.30	X	X	-	-	
18-PTA-124-A	10.15	X	-	-	-	
18-PTA-124-B	10.05	X	X	-	-	
18-PTA-124-C	10.00	X	-	-	-	
18-PTA-124-D	9.95	X	-	-	-	
18-PTA-125	9.70	X	X	-	-	
18-PTA-126	9.20	X	X	X	-	
18-PTA-127	8.70	X	X	-	-	
18-PTA-128	8.20	X	X	-	-	
18-PTA-129	7.70	X	X	-	-	
18-PTA-130	7.20	X	X	X	-	Increasing fissility in till
18-PTA-131	6.70	X	X	-	-	
18-PTA-132	6.20	X	X	-	-	
18-PTA-133	5.70	X	X	-	-	Very strong till fissility
18-PTA-134	5.20	X	X	-	-	Three joint planes in till
18-PTA-135	4.70	X	X	X	X	
18-PTA-136	4.20	X	X	-	-	
18-PTA-137	3.70	X	X	-	-	
18-PTA-138	3.20	X	X	-	-	
18-PTA-139	2.7	-	X	X	-	
17-PTA-015	2.0	-	X	X	-	2017 till sample (brown till)

Till Samples
A summary of till samples collected is given in Table 8.1. A total of 44 Kubiëna tin samples were collected, and then shipped to the Petrographic Thin-Sectioning Laboratory at Brock University where they were impregnated with epoxy and made into thin sections (cf., Rice et al., 2014). At 38 sites throughout the three sections, 3 kg samples were collected for matrix geochemical and other physicochemical analyses. A subset of 20 till samples, generally spaced at one metre intervals, were submitted to the Sedimentology Laboratory, Geological Survey of Canada for clay mineralogy determinations by X-ray diffraction. At 8 sites throughout the entire vertical exposure, approximately 2 m apart, 20 kg bulk till samples were collected and shipped to Overburden Drilling Management Limited, Nepean. In addition to the indicator mineral counts and pebble fractions, these samples will also be subjected to representative 100 grain counts of the heavy mineral fraction.

Clast Fabrics
Till fabrics were completed at three locations: 18-PTA-104, 18-PTA-109, and 18-PTA-135 (Fig. 8.2). Sample 18-PTA-104 was taken to reflect the lower till near the bedrock, since the bedrock surface was friable and not striated. 18-PTA-109 was taken at the base of the larger section and 18-PTA-135 was taken to reflect the till close to the top of the section. From a preliminary evaluation of the data (Table 8.2, Fig. 8.2), there are apparent directional trends in the upper two fabrics, while the lowermost fabric displays the strongest s1 eigenvalue and is markedly different from the upper fabrics.

Table 8.2. Summary statistics for clast fabrics and boulder striations measured in pit M-52 at the Pine Point Mining District (s1, s2, and s3 are primary, secondary, and tertiary eigenvector values, respectively; K is the cluster index; r is the correlation coefficient; n is the number of clasts measured).

Site ID	Site depth from land surface (m)	*n*	s1	s2	s3	*K*	R	Mean Vector
18-PTA-104	17.25	52	0.575	0.331	0.094	0.442	0.284	220.9 / 7.7
18-PTA-109	15.75	60	0.454	0.35	0.196	0.499	0.516	155.6 / 12.9
18-PTA-135	4.7	50	0.451	0.401	0.148	0.119	0.39	008.7 / 10.6

Ongoing and Future Research
Thin section analysis and interpretation on the M-52 till samples is set to commence January 2019. Thin sections will be analyzed using the micromorphological techniques of Menzies and van der Meer (2018). These interpretations will be combined with geochemical data, heavy mineral data, field observations, and previous research to establish the glacial history and sediment dynamics at the M-52 pit. This research will contribute to the GEM-2 Southern Mackenzie Surficial activity and to a greater understanding of the subglacial conditions and subglacial glaciodynamics of the western sector of the Laurentide Ice Sheet. Future results will be disseminated in GSC Open File reports.

Acknowledgements
The research is supported at Brock University with a GEM-2-funded Research Associate Program (RAP) bursary from the Geological Survey of Canada. Stratigraphic logging and sample collection benefited from the field assistance of Robert King (Memorial University), Grant Hagedorn (University

of Waterloo), and Matt Pyne (Geological Survey of Canada). Wildlife Monitors for this fieldwork was provided by Tom Unka (Fort Resolution Deninu Kue First Nation) and John Delorma (Fort Resolution Métis Nation).

References

Benn, D., 2004. Chapter 5: Macrofabric; *in* A Practical Guide to the Study of Glacial Sediments, (eds.) D.J.A. Evans, and D.I. Benn; Hodder Education, London, 266 p.

Bostock, H.S., 1970. Physiographic regions of Canada; Geological Survey of Canada, Map 1254A, scale 1:5 000 000. doi: /10.4095/293408

Hannigan, P.K., 2006a. Introduction; *in* Potential for Carbonate-hosted Lead-zinc Mississippi Valley-type Mineralization in Northern Alberta and Southern Northwest Territories: Geoscience Contributions, Targeted Geoscience Initiative, (ed.) P.K. Hannigan; Geological Survey of Canada, Bulletin 591, p. 9-39. doi:10.4095/222883

Hannigan, P.K., 2006b. Synthesis of Mississippi Valley-type lead-zinc deposit potential in northern Alberta and southern Northwest Territories; *in* Potential for Carbonate-hosted Lead-zinc Mississippi Valley-type Mineralization in Northern Alberta and Southern Northwest Territories: Geoscience Contributions, Targeted Geoscience Initiative, (ed.) P.K.. Hannigan; Geological Survey of Canada, Bulletin 591, p. 305-347. doi:10.4095/222945

Lemmen, D.S., 1990. Surficial materials associated with glacial Lake McConnell, southern District of Mackenzie; Geological Survey of Canada, Current Research, Paper 90-1D, p. 79-83. doi:10.4095/131342

Lemmen, D.S., 1998a. Surficial geology, Klewi River, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 1905A, scale 1:250 000. doi:10.4095/209686

Lemmen, D.S., 1998b. Surficial geology, Buffalo Lake, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 1906A, scale 1:250 000. doi:10.4095/209687

Mark, D.M., 1973. Analysis of axial orientation data, including till fabrics; Geological Society of America Bulletin, v. 84, p. 1369-1374.

McClenaghan, M.B., Oviatt, N.M., Averill, S.A., Paulen, R.C., Gleeson, S.A., McNeil, R.J., McCurdy, M.W., Paradis, S., and Rice, J.M., 2012. Indicator mineral abundance data for bedrock, till and stream sediment samples from the Pine Point Mississippi Valley-Type Zn-Pb deposits, Northwest Territories; Geological Survey of Canada, Open File 7267. doi:10.4095/292121

McClenaghan, M.B., Paulen, R.C., and Oviatt, N.M., 2018. Geometry of indicator mineral and till geochemistry dispersal fans from the Pine Point Mississippi Valley-type Pb-Zn district, Northwest Territories, Canada; Journal of Geochemical Exploration, v. 190, p. 69-86.

Menzies, J.M. and van der Meer, J.J.M., 2018. Micromorphology and microsedimentology of glacial sediments; *in* Past Glacial Environments, second edition, (ed) J.M. Menzies and J.J.M van der Meer; Elsevier Netherlands, p. 753-806. doi:10.1016/B978-0-08-100524-8.00027-0

Menzies, J., Oviatt, N.M., Dhiullin, N., Paulen, R.C., McClenaghan, M.B., Rice, J.M., submitted. 'Deformation 'front' movements in subglacial tills – a microsedimentological perspective from till near Pine Point, NWT; The Depositional Record (submitted, manuscript ID: DEP2-2018-07-0024)

Oviatt, N.M., 2013. Characterization of indicator minerals and till geochemical dispersal patterns associated with the Pine Point Pb-Zn Mississippi Valley-type deposits Northwest Territories, Canada; M.Sc. thesis, University of Alberta, Edmonton, Alberta, 212 p.

Oviatt, N.M. and Paulen, R.C., 2013. Surficial geology, Breynat Point, Northwest Territories, NTS 85-B/15; Geological Survey of Canada, Canadian Geoscience Map 114 (preliminary), scale 1:50 000. doi:10.4095/292247

Oviatt, N.M., S.A. Gleeson, R.C. Paulen, M.B. McClenaghan, and Paradis, S., 2015, Characterization and dispersal of indicator minerals associated with the Pine Point Mississippi Valley-type (MVT) district, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 52, p. 776-794.

Paulen, R.C., and McClenaghan, M.B., 2015. Late Wisconsin ice-flow history in the Buffalo Head Hills kimberlite field, north-central Alberta; Canadian Journal of Earth Sciences, v. 52: p. 51-67. doi:10.1139/cjes-2014-0109.

Paulen, R.C., Paradis, S., Plouffe, A., and Smith, I.R., 2011. Pb and S isotopic composition of indicator minerals in glacial sediments from NW Alberta, Canada: implications for Zn-Pb base metal exploration; Geochemistry: Exploration, Environment, Analysis, v. 11, p. 309– 320. doi:10.1144/1467-7873/10-IM-032.

Prest, V.K., Grant, D.R., and Rampton, V.N., 1968. Glacial map of Canada; Geological Survey of Canada, Map 1253A, scale 1:5 000 000. doi:10.4095/108979.

Rhodes, D., Lantos, E.A., Lantos, J.A., Webb, R.J., and Owens, D.C., 1984. Pine Point Orebodies and their relationship to the stratigraphy, structure, dolomitization, and karstification of the Middle Devonian Barrier Complex; Economic Geology, v. 79, p. 991-1055.

Rice, J.M., 2014. Glacial stratigraphy and micromorphology of the Pine Point Pb-Zn mining district, Northwest Territories; M.Sc. thesis, Brock University, St. Catharines, Ontario, 146 p.

Rice, J.M., Paulen, R.C., Menzies, J.M., McClenaghan, M.B., and Oviatt, N.M., 2013a. Glacial stratigraphy of the Pine Point Pb-Zn mine site, Northwest Territories; Geological Survey of Canada, Current Research 2013-5, 14 p. doi:10.4095/ 292184

Rice, J.M., Paulen, R.C., Menzies, J., and McClenaghan, M.B., 2013b. Stratigraphic and micromorphologic analysis of the Quaternary sediment cover in the southern Great Slave Lake region, Northwest Territories: Implications for glacial history of the western sector of the Laurentide Ice Sheet; Program and Abstracts, CANQUA, Edmonton, Canada.

Rice, J.M., Paulen, R.C., Menzies, J., and McClenaghan, M.B., 2014. Micromorphological descriptions of till from pit K-62, Pine Point mining district, Northwest Territories; Geological Survey of Canada, Open File 7526, 30 p. doi:10.4095/293478

Rice, J.M., Menzies, J., Paulen, R.C., and McClenaghan, M.B., in press. Microsedimentological evidence of vertical fluctuations in subglacial stress associated with ice-sheet bed decoupling in the northwest sector of the Laurentide Ice Sheet, Northwest Territories, Canada; Canadian Journal of Earth Sciences, accepted. doi:10.1139/cjes-2018-0201

Smith, I.R. and Lesk-Winfield, K., 2010. Drift isopach, till isopach, and till facies reconstructions for Northwest Territories and northern Yukon; Geological Survey of Canada, Open File 6324. doi:10.4095/261783

Middle Wisconsin Radiocarbon Dated Wood in Glacial Sediments Exposed in the Muskeg River (NTS 95B) Region

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Introduction

In 2008, work was undertaken in the southern Northwest Territories that was initiated by the Northwest Territories Geoscience Office (NTGO; now Northwest Territories Geological Survey) in support of the Sambaa K'e (Trout Lake) Protect Area Strategy (PAS) survey (Pronk et al., 2009; Watson, 2011).

The Trout Lake region was also an area of interest to the Geological Survey of Canada, which was compiling an inventory of terrain, landforms, and geomorphic processes for the Mackenzie Valley transportation corridor (Huntley et al., 2008). This inventory built on a number of earlier regional studies (e.g., Rutter et al., 1993; Duk-Rodkin and Lemmen, 2000; Bednarski, 2003; Huntley et al., 2006; Paulen et al., 2006; Plouffe et al., 2006) conducted in the southern Mackenzie Valley, and later also contributed to regional glacial and deglacial reconstructions of the Late Wisconsin Laurentide Ice Sheet (LIS; Bednarski, 2008a, b). More recently, this region has had renewed interest in diamond (Poitras et al., 2018) and base metal exploration (King et al., 2018).

The LIS was the predominant ice mass over North America through the last glacial cycle (110–10 ka). Prior to the Late Wisconsin Last Glacial Maximum (LGM), during Marine Isotope (MIS) Stage 3 (59-27 ka), the LIS covered most of central and eastern Canada, with its margins in western Canada estimated to be coincident with the limits of the Canadian Shield (Dyke et al., 2002) and, more recently, with a reduced area in central and eastern Canada, such as Hudson Bay (Dalton et al., 2018; McMartin et al., in press). The pre-LGM configuration in the southern Northwest Territories has received little attention because there are very few stratigraphic sections that preserve pre-LGM sediments (Dyke et al., 2001).

Several AMS ^{14}C dates on wood redeposited in glaciofluvial sediment along the upper Mackenzie River, north of Wrigley, indicate that ice-free conditions existed there until at least 27.2 ^{14}C ka BP (Smith, 1992). In the Fort Liard area, wood fragments between reworked till and glaciolacustrine sediment radiocarbon dated 32.7 ^{14}C ka BP (I-3187, Millar 1968), which provides a maximum age for the last glaciation of the southern Mackenzie Mountains (Fig. 9.1). In northern British Columbia, east of Fort Nelson, a fragment of wood recovered from gravels stratigraphically underlying till dated 24.4 ^{14}C ka BP (Beta 183598; Levson et al. 2004; Trommelen 2006). Additionally, several older, infinite dates were obtained from sediments underlying Laurentide till south of Fort Nelson on the Prophet River (Trommelen and Levson, 2008). In northwestern Alberta, a date of 22.0 ^{14}C ka BP (AECV-719C) was obtained from a mammoth tusk in glacial sediments near High Level (Burns, 1996). And, interstadial sediments and organic detritus were recovered from between two till units in geotechnical boreholes in the Birch Mountains of northern Alberta (Paulen et al., 2005), and produced an AMS date on pine wood fragments of 32.7 ka BP (TO-10545).

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Paulen, R.C., Smith, I.R., and Hickin, A.S. 2019. Middle Wisconsin radiocarbon dated wood in glacial sediments exposed in the Muskeg River (NTS 95B) region; *in* GEM-2 Southern Mackenzie Surficial Activity 2018 report: Surficial Geology and Heavy Mineral Studies in Southern Northwest Territories, (eds.) R.C. Paulen, I.R. Smith and S.J.A. Day; Geological Survey of Canada, Open File 8477, p. 62-68. http://doi.org/10.4095/313428

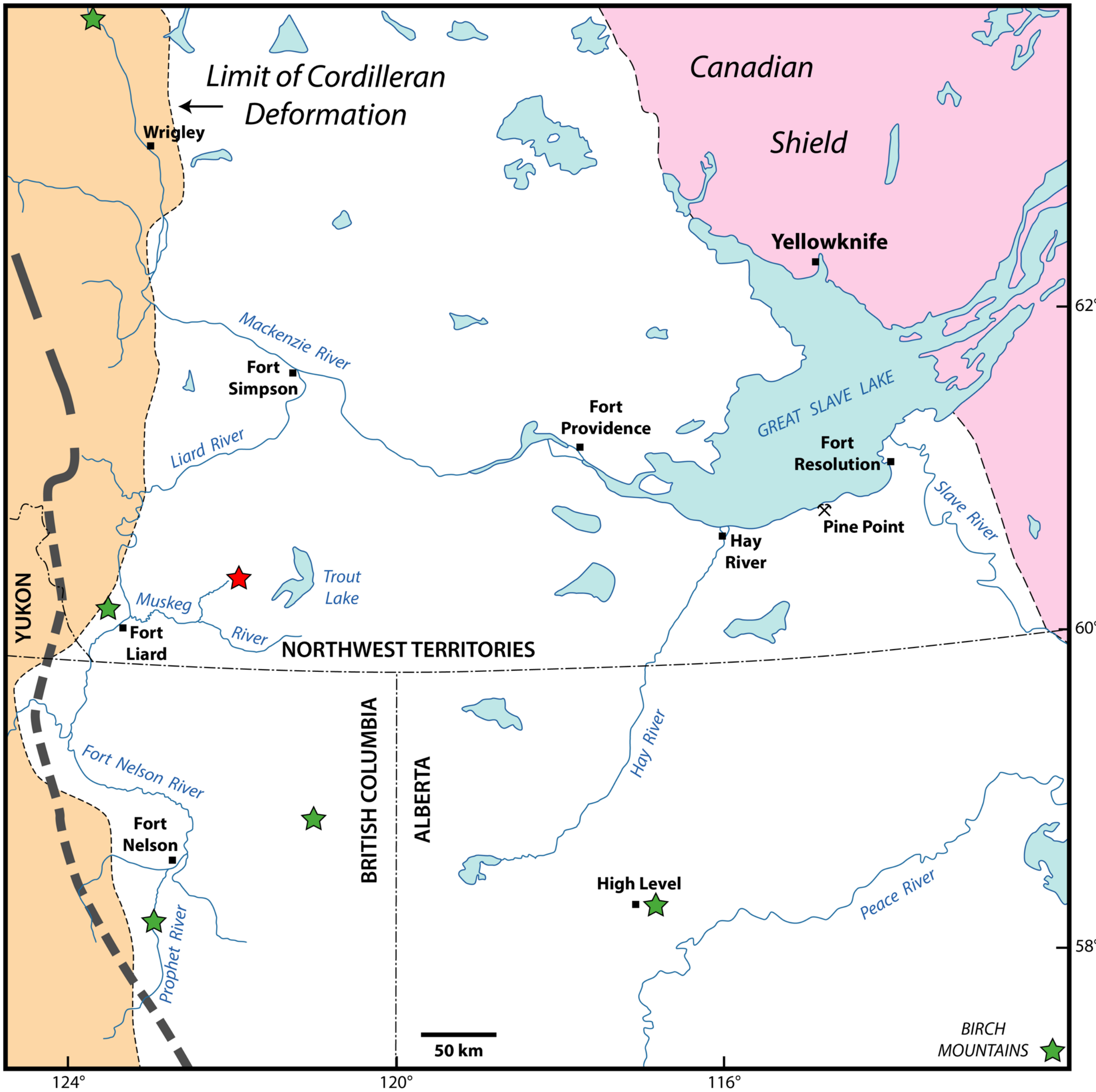

Figure 9.1. Map showing the location of pre-LGM radiocarbon chronologies discussed in the report (green stars) and the new reported radiocarbon date west of Trout Lake (red star). The thick grey line with long dashes marks the limit of LIS at LGM; the thick grey line with short dashes marks the contact between the Laurentide and Cordilleran ice sheet (after Dyke and Prest, 1987).

At the past-producing Pine Point Pb-Zn mining district, there are several former open pits with thick (>20 m) Quaternary exposures available for study. A survey of these open pits determined that there were no exposures with older reworked glacial sediments, oxidized horizons, or inter-till advance or retreat phase glaciofluvial or glaciolacustrine sediments preserved under the thick (>25 m) till sequences (Rice et al., 2013a). Being proximal to the Canadian Shield (~100 km to the east), with a diverse ice-flow record, and neither stratigraphic nor sedimentological evidence of ice-marginal advance or retreat fluctuations preserved in the stratigraphy at Pine Point, Rice et al. (2013b) proposed that the southern Great Slave Lake region was affected by continuous glaciation throughout the

Wisconsin. Micromorphological studies of a thick (>22 m) exposure at Pine Point subsequently concluded that the thickest till unit exposed there (Unit C of Rice et al., 2013a) was the result of a long-term, time-transgressive accretion of a deforming bed, with an abundant sediment, and with the LIS flowing northwestward into the Great Slave Lake basin (Rice et al., in press).

At one of the Sambaa K'e PAS till sample sites, TL-08-097 (see Appendix 2 of Watson, 2011), a fragment of wood 4 cm in length was recovered from the base of a till section in a tributary of the Muskeg River (NTS 95-B; red star, Fig. 9.1; Fig.9.2), which is near the western margin of the present GEM-2 Southern Mackenzie Surficial activity study area. The wood fragment was sent for AMS radiocarbon dating, in an effort to help refine the MIS 3 ice margin in western Canada; results are reported here.

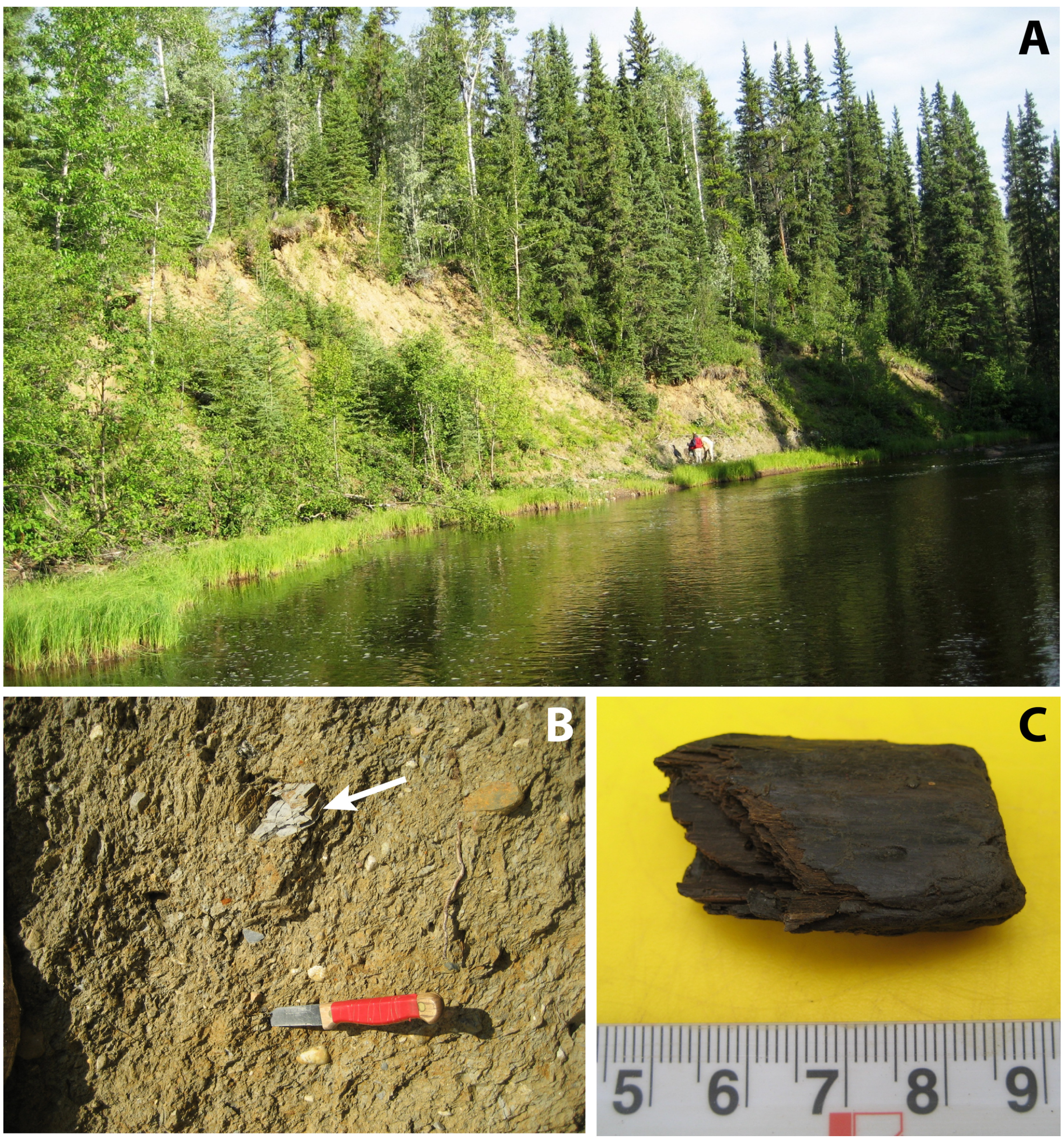

Figure 9.2. The 10 m high till section exposed on a tributary of the Muskeg River, with two people standing at the base of the section collecting till sample TL-08-097. B) Till at the site, with abundant Cretaceous shale fragments in it, a large shale clast is indicated by the white arrow (knife handle is 10 cm long). C) Fragment of wood recovered from the section and submitted for AMS dating, ruler scale in centimetres.

Methods
Wood sample TL-08-097 was collected on 13 August 2008 (NTS 095-B/09 (540357E 6705519N, datum NAD 83, elevation 508 m above sea level) from the base of a 10 m section. The sample depth was approximately 9 m from surface (Fig. 2). The wood fragment was dried and sent to Beta Analytic Incorporated, Florida, from the British Columbia Ministry of Energy, Mines and Petroleum Resources, for an AMS radiocarbon dating analysis.

Results
The wood fragment was obtained from LIS LIS till with a silty-sandy, strongly fissile matrix and 15% clast content (many clasts derived from the Cretaceous shale bedrock; Fig. 9.2). The wood fragment (Beta-249392) yielded a measured radiocarbon age of 35,560 +/- 330 BP (13C/12C Ratio of -24.6 ‰) with a corrected conventional radiocarbon age of 35,570 +/- 330 BP.

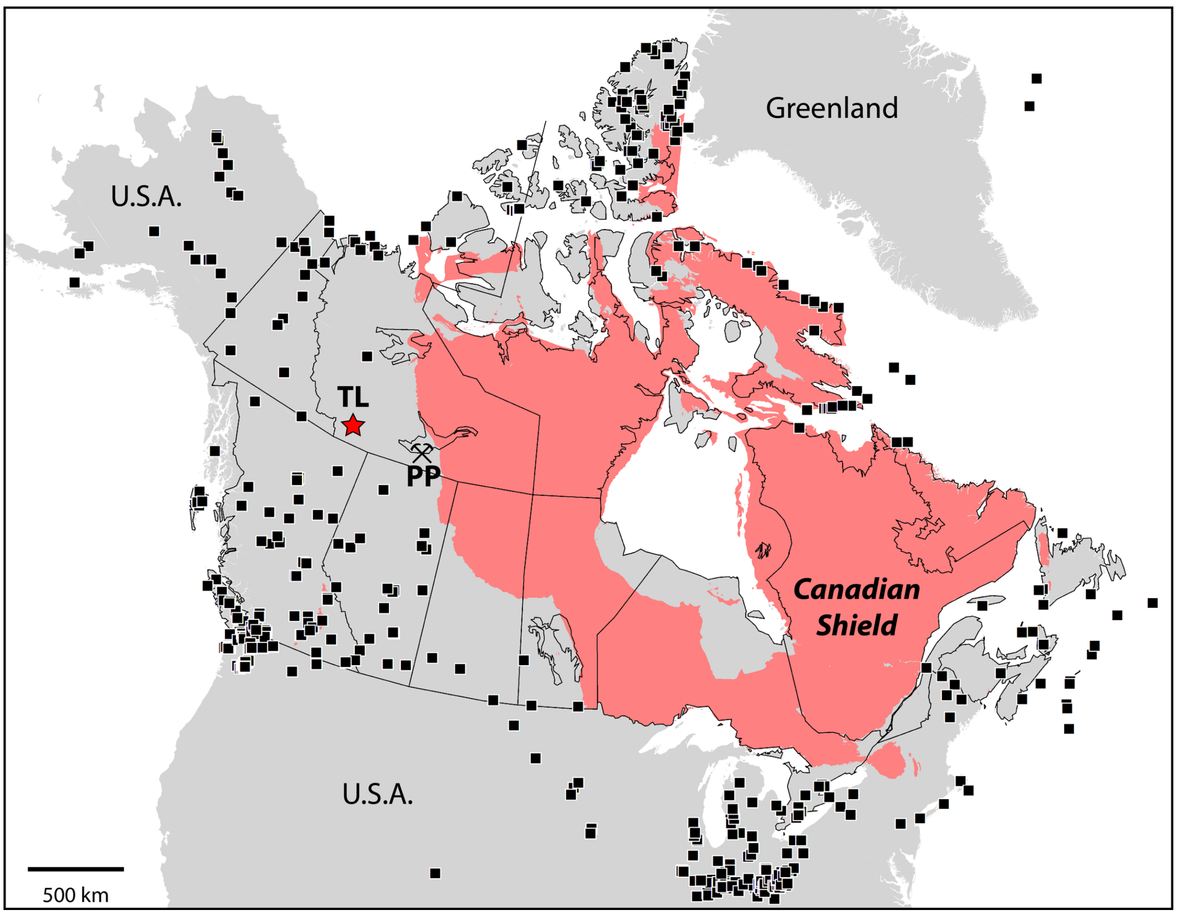

Figure 9.3. Location of pre-LGM radiocarbon ages in North America (modified from McMartin et al., in press). Trout Lake (TL) AMS date is indicated by a red star), the former Pine Point (PP) mining district is indicated by the crossed hammers symbol. Pink shading delineates the Canadian Shield and other Precambrian bedrock extents in Canada.

Discussion
The Birch Mountain MIS 3 radiocarbon date, sandwiched between two tills in northern Alberta (Paulen et al., 2005), along with the known Quaternary stratigraphy elsewhere in northern Alberta (e.g., Andriashek, 2003; Fenton et al., 2006), implies that LIS advanced into western Canada in the early Wisconsin, then retreated with a stable ice margin in the Great Slave Lake basin (Rice et al.,

2013b). Based upon the existing radiocarbon chronology of northeast British Columbia, northwest Alberta and southwest Northwest Territories, the Middle Wisconsin (MIS 3) ice margin was west of the Pine Point mining district and occupied most of the Great Slave Lake basin prior to advance of the LIS into southwestern Canada at the onset of the Late Wisconsin. This wood fragment obtained from the base of a thick section of LIS sediments helps refine the MIS 3 ice margin which is estimated to have been north of High Level, Alberta, east of Trout Lake, Northwest Territories and west of Pine Point, Northwest Territories (Fig. 9.3). This new date refines the constraints on the MIS 3 ice margin depicted by Dyke et al. (2002) and recently, McMartin et al. (in press).

Acknowledgements
Fieldwork to support this research was supported by the NTGO. The British Columbia Ministry of Energy, Mines and Petroleum Resources is gratefully acknowledged for paying for the AMS radiocarbon date. Assistance in the field was also provided by Toon Pronk (as a secondment to NTGO in 2008-2009).

References

Andriashek, L.D., 2003. Quaternary geological setting of the Athabasca Oil Sands (in situ) Area, northeast Alberta; Alberta Geological Survey, Earth Sciences Report 2002-03.

Bednarski, J.M., 2003. Surficial geology, Fort Liard, Northwest Territories - British Columbia; Geological Survey of Canada, Open File 1760, 1 sheet, scale 1:50 000. doi:10.4095/214418

Bednarski, J.M., 2008a. Quaternary geology of Fort Liard map area, Northwest Territories; Geological Survey of Canada, Bulletin 596, 59 p. doi:10.4095/225608.

Bednarski, J.M., 2008b. Landform assemblages produced by the Laurentide Ice Sheet in northeastern British Columbia and adjacent Northwest Territories - constraints on glacial lakes and patterns of ice retreat; Canadian Journal of Earth Sciences, v. 45, p. 593–610. doi:10.1139/E07-053

Burns, J.A. 1996. Vertebrate paleontology and the alleged ice-free corridor: The meat of the mater; Quaternary International, v. 32, p. 107–112.

Dalton, A.S., Finkelstein, S.A., Forman, S.L., Barnett, P., Pico, T., and Mitrovica, J.X., 2018. Did the Laurentide Ice Sheet undergo significant reduction during Marine Isotope Stage 3?; *in* Program with Abstracts, Joint Meeting of the Canadian and American Quaternary Associations (CANQUA-AMQUA), August 7-11, Ottawa, Canada; p. 83, [https://docs.wixstatic.com/ugd/da584a_a59b212318c54d6582a29f0b9acbb8d5.pdf; accessed October 2018]

Duk-Rodkin, A. and Lemmen, D.S., 2000. Glacial history of the Mackenzie region; *in* The Physical Environment of the Mackenzie Valley, Northwest Territories: A Base Line for the Assessment of Environmental Change, (eds.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547, p. 11–20. doi:10.4095/211903.

Dyke, A.S. and Prest, V.K., 1987. Late Wisconsinan and Holocene retreat of the Laurentide Ice Sheet; Geological Survey of Canada, Map 1702A, scale 1:5 000 000. doi:10.4095/122842.

Dyke, A.S., Andrews, J.T., Clark, P.U., England, J.H., Miller, G.H., Shaw, J., and Veillette, J.J., 2001. Radiocarbon Dates pertinent to defining the Last Glacial Maximum for the Laurentide and Innuitian Ice Sheets. Geological Survey of Canada, Open File 4120. doi:10.4095/212843.

Dyke, A.S., Andrews, J.T., Clark, P.U., England, J.H., Miller, G.H., Shaw, J. and Veillette, J.J., 2002. The Laurentide and Innuitian ice sheets during the Last Glacial Maximum; Quaternary Science Reviews, v. 21, p. 9–31.

Fenton, M.M., Pawlowicz, J.G., Paulen, R.C., and Prior, G.J., 2006. Quaternary stratigraphy and till geochemistry of the southern Buffalo Head Hills, Alberta: results of an auger coring program; Alberta Geological Survey, Geo-Note 2005-10.

Huntley, D., Mills, A., and Paulen, R.C., 2008. Surficial deposits, landforms, glacial history, and reconnaissance drift sampling in the Trout Lake map area, Northwest Territories; Geological Survey of Canada, Current Research 2008-14, 14 p. doi: 10.4095/225636.

King, R.D., Piercey, S.J., and Paulen, R.C., 2018. In situ microanalytical sulphur and lead isotopic compositions of sulphide indicator minerals from surficial sediments in southwestern Northwest Territories; Geological Survey of Canada, Open File 8449. doi: 10.4095/311247.

Levson, V., Ferbey, T., Kerr, B., Johnsen, T., Bednarski, J., Black- well, J., and Jonnes, S., 2004. Quaternary geology and aggregate mapping in Northeast British Columbia: Applications for oil and gas exploration and development; *in* Summary of Activities 2004; British Columbia Ministry of Energy and Mines, Paper 2004-1, p. 29–40.

McMartin, I., Campbell, J.E., and Dredge, L.A., in press. Middle Wisconsinan marine shells in Rae Isthmus ice stream till near Repulse Bay, Nunavut: implications for LGM Laurentide Ice Sheet dynamics and MIS 3 ice-free conditions in northwest Hudson Bay; Journal of Quaternary Science, accepted (Manuscript ID: JQS-18-0077).

Millar, J.F.V. 1968. Archeology of Fisherman Lake, western District of Mackenzie, N.W.T.; Unpublished Ph.D. dissertation, University of Calgary, Calgary, AB.

Paulen, R.C., Beaudoin, A.B. and Pawlowicz, J.G., 2005. An interstadial site in the Birch Mountains, north-central Alberta. Program and Abstracts, CANQUA, Winnipeg, Canada, p. A66.

Paulen, R.C., Plouffe, A., and Smith, I.R., 2006. Surficial geology of the Beatty Lake area (NTS 84M/NE); Alberta Energy and Utilities Board, EUB/AGS Map 360, and Geological Survey of Canada, Open File 5183, scale 1:100 000. doi:10.4095/222040.

Plouffe, A., Paulen, R.C., and Smith, I.R., 2006a. Surficial geology, Thinahtea Creek, Alberta (NTS 84 M/NW); Geological Survey of Canada, Open File 5070, and Alberta Energy and Utilities Board, EUB/AGS Map 395, scale 1:100 000. doi:10.4095/224908.

Poitras, S.P., Pearson, D.G., Hardman, M.F., Stachel, T., Nowell, G.M., and Cairns, S., 2018. Evidence for a 200 km thick diamond-bearing root beneath the Central Mackenzie Valley, Northwest Territories, Canada? Diamond indicator mineral chemistry from the Horn Plateau and Trout Lake regions; Mineralogy and Petrology, published online: https://doi.org/10.1007/s00710-018-0641-4

Pronk, T., Paulen, R.C., Mills, A., and Hickin, A.S., 2009. Surficial geochemical studies in support of Non-renewable Mineral Resource Assessments, Northwest Territories, Canada; *in* Proceedings of the 24th International Applied Geochemistry Symposium (IAGS); (eds.) D.R. Lentz, K.G. Thorne and K.L. Bea; volume II; p. 943–946.

Rice, J.M., Paulen, R.C., Menzies, J.M., McClenaghan, M.B., and Oviatt, N.M., 2013a. Glacial stratigraphy of the Pine Point Pb-Zn mine site, Northwest Territories; Geological Survey of Canada, Current Research 2013-5, 14 p. doi:10.4095/ 292184

Rice, J.M., Paulen, R.C., Menzies, J., and McClenaghan, M.B., 2013b. Stratigraphic and micromorphologic analysis of the Quaternary sediment cover in the southern Great Slave Lake region, Northwest Territories: Implications for glacial history of the western sector of the Laurentide Ice Sheet. Program and Abstracts, CANQUA, Edmonton, Canada.

Rice, J.M., Menzies, J., Paulen, R.C., and McClenaghan, M.B. in press. Microsedimentological evidence of vertical fluctuations in subglacial stress from the northwest sector of the Laurentide Ice Sheet, Northwest Territories, Canada; Canadian Journal of Earth Sciences, accepted. doi:10.1139/cjes-2018-0201

Rutter, N.W., Hawes, R.J., and Catto, N.R., 1993. Surficial geology, southern Mackenzie River valley, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 1693A, scale 1:500 000. doi:10.4095/193343.

Smith, D.G., 1992. Glacial Lake Mackenzie, Mackenzie Valley, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 29, p. 1756–1766.

Trommelen, M.S., 2006. Quaternary stratigraphy and glacial history of the Fort Nelson (southeast) and Fontas River (southwest) Map Areas (NTS 094J/SE and 094I/SW), Northeastern British Columbia; unpublished M.Sc. thesis, University of Victoria, Victoria, BC.

Trommelen, M.S. and Levson, V., 2008. Quaternary stratigraphy of the Prophet River, northeastern British Columbia; Canadian Journal of Earth Sciences, v. 45, p. 565–575.

Watson, D.M., 2011. Sambaa K’e candidate protected area phase II non-renewable resource assessment – minerals, Northwest Territories, parts of NTS 085D, 095A, B, H; Northwest Territories Geoscience Office, Open File 2010-08.

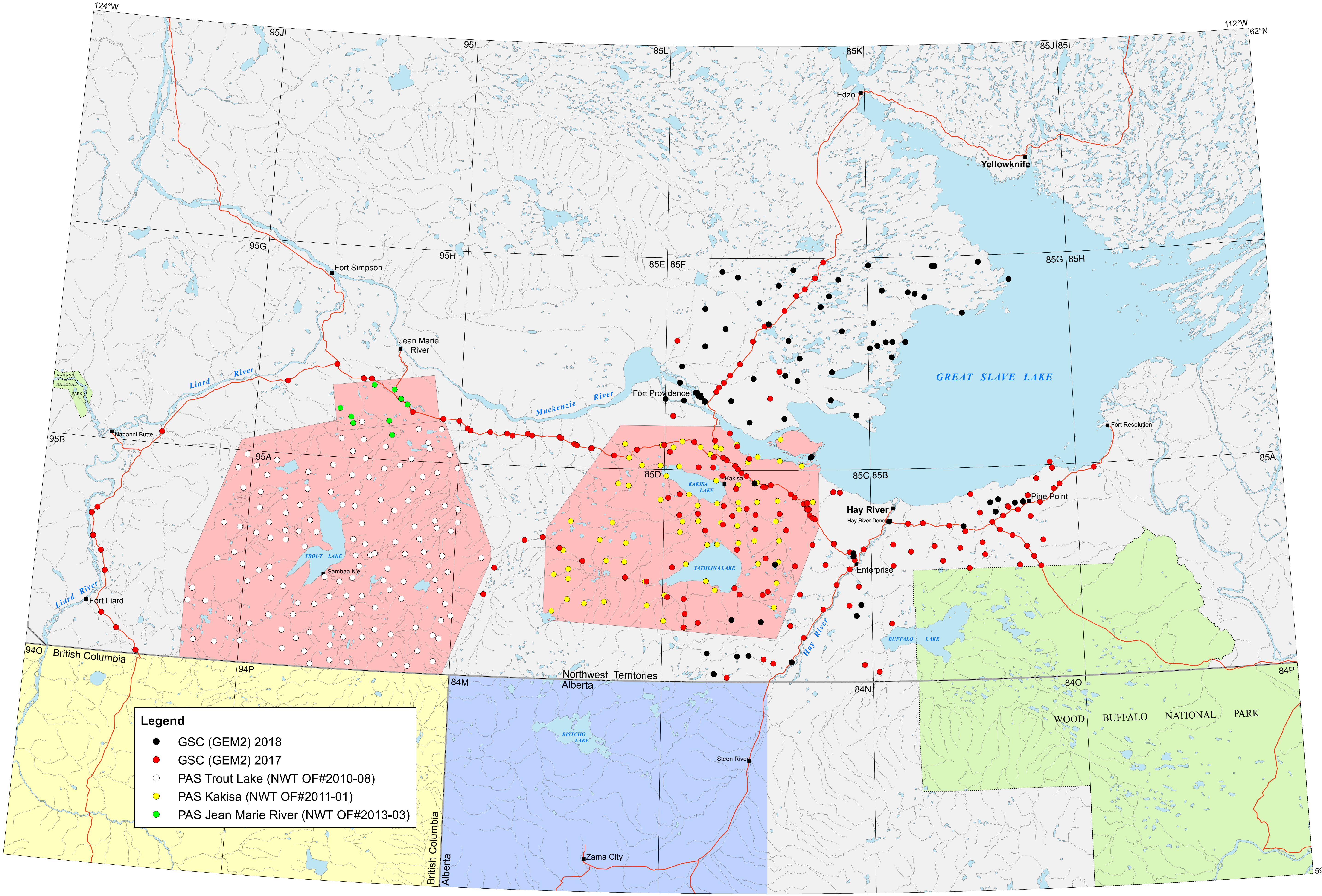

Figure 1.2. Location of till samples collected during surficial mapping and heavy mineral studies by this research activity (2017-2018). Previous related mapping and sampling activities conducted by provincial and federal projects are shown for British Columbia (yellow), Alberta (blue) and Northwest Territories (pink - PAS indicator mineral surveys).

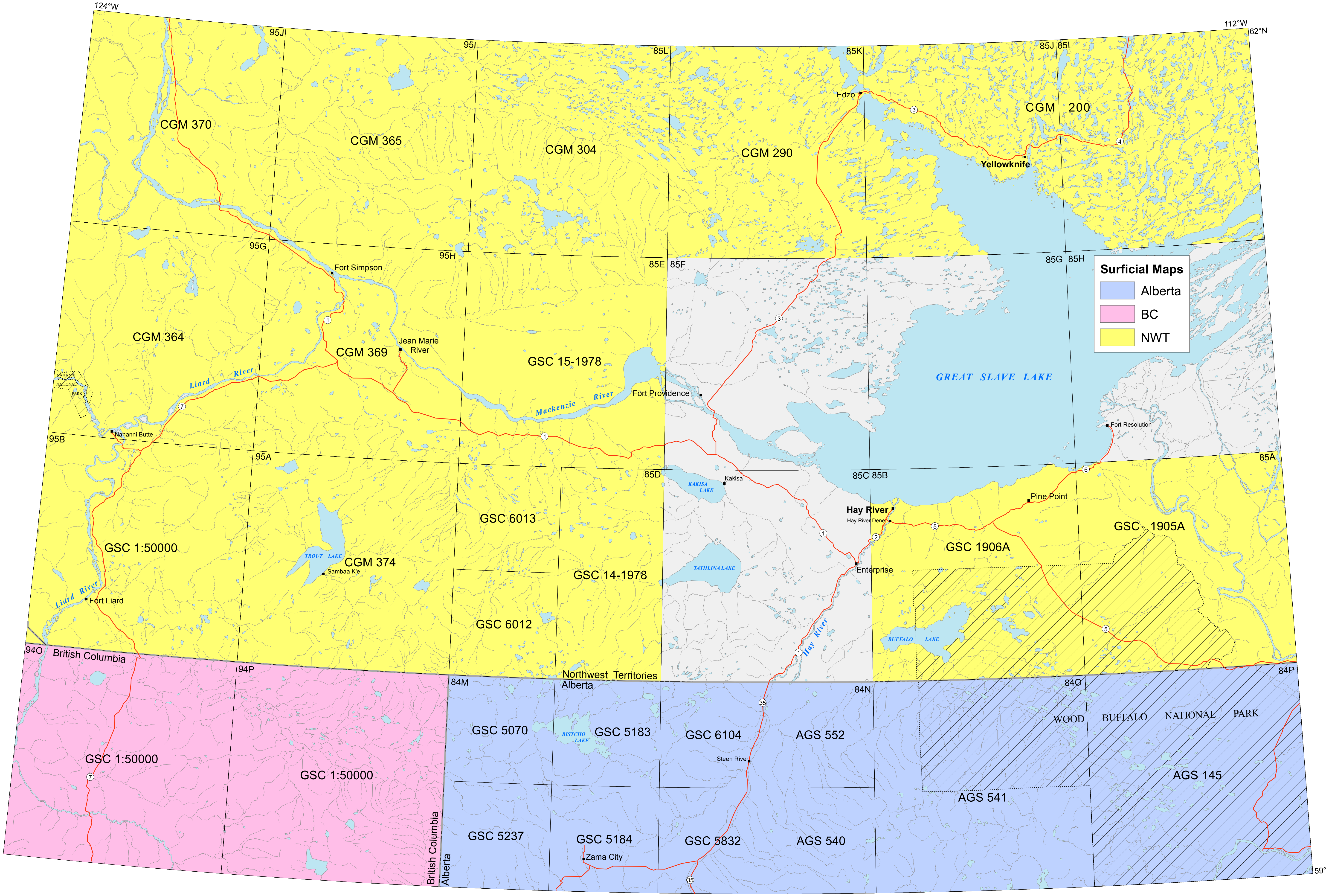

Figure 1.3. Current status of surficial map coverage in the southwest Northwest Territories (yellow), northeast British Columbia (pink) and northwest Alberta (blue). The large gap on the west side of Great Slave Lake comprises the surficial mapping area to be completed by the GEM-2 Southern Mackenzie Surficial activity (CGM = Canadian Geoscience Map).