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Report of 2017 field activities for the GEM-2 Rae Glacial history activity in the Kivalliq Region, Nunavut

Isabelle McMartin, Tommy Tremblay and Pierre-Marc Godbout

Foreword

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

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

Project Summary

This publication summarizes the 2017 field work completed in the Baker Lake and Arviat areas, mainland Nunavut, as part of the GEM-2 Rae Synthesis of Glacial History and Dynamics Activity in the interior of the Keewatin Sector of the Laurentide Ice Sheet. Field work consisted of targeted mapping of glacial flow indicators to resolve the relative ice-flow chronology at both ends of the Keewatin Ice Divide, sampling material for age dating to help reconstruct the glacial and post-glacial histories at a regional scale, and documenting the nature and composition of the glacial sediments under the ice divide and in selected ice stream terrains. This work will provide new geological knowledge on the chronology of ice flow events and help understand glacial transport characteristics across major glacial landscapes in the Kivalliq Region. The findings will support informed decision making for mineral resource exploration and land use management.

Introduction

Goals and objectives

The 3-year Synthesis of Glacial History and Dynamics GEM-2 Rae Activity, initiated in April 2017, is a collaborative project between the Geological Survey of Canada, the Canada-Nunavut Geoscience Office and the Northwest Territories Geological Survey to compile and better understand the distribution and history of glacial landforms in the interior of the Keewatin Sector of the Laurentide Ice Sheet (LIS) in mainland Nunavut and Northwest Territories (NWT)(Fig. 1). The Rae Province, where there is both proven and suspected high mineral potential, is heavily covered by glacial sediments and has a complex glacial history which impedes both bedrock geological mapping and mineral exploration. Evidence for multiple glaciations and dynamic glacial systems (e.g. fast-flowing ice streams, migrating ice divides, changing basal ice thermal regimes, abrupt changes in deglacial patterns) is inferred from the striation record, intersecting glacial lineations, complex ice-marginal retreat features, relict landscapes, and multiple till stratigraphy. Yet, within this poorly mapped core region of the LIS, the flow direction, sequence, degree of overprinting and duration of glacial and deglacial events have not been systematically identified and/or correlated. A regional compilation of glacial features and reconstruction of the glacial history are required in this area to provide a much needed framework for an improved understanding of glacial dispersal patterns at all scales. The overall goal of this activity is to increase the effectiveness of mineral exploration methods that use compositional data from surface materials directly deposited by glacial ice (till, boulders) or derived from glacial sediments (esker, stream and lake sediments, etc.).

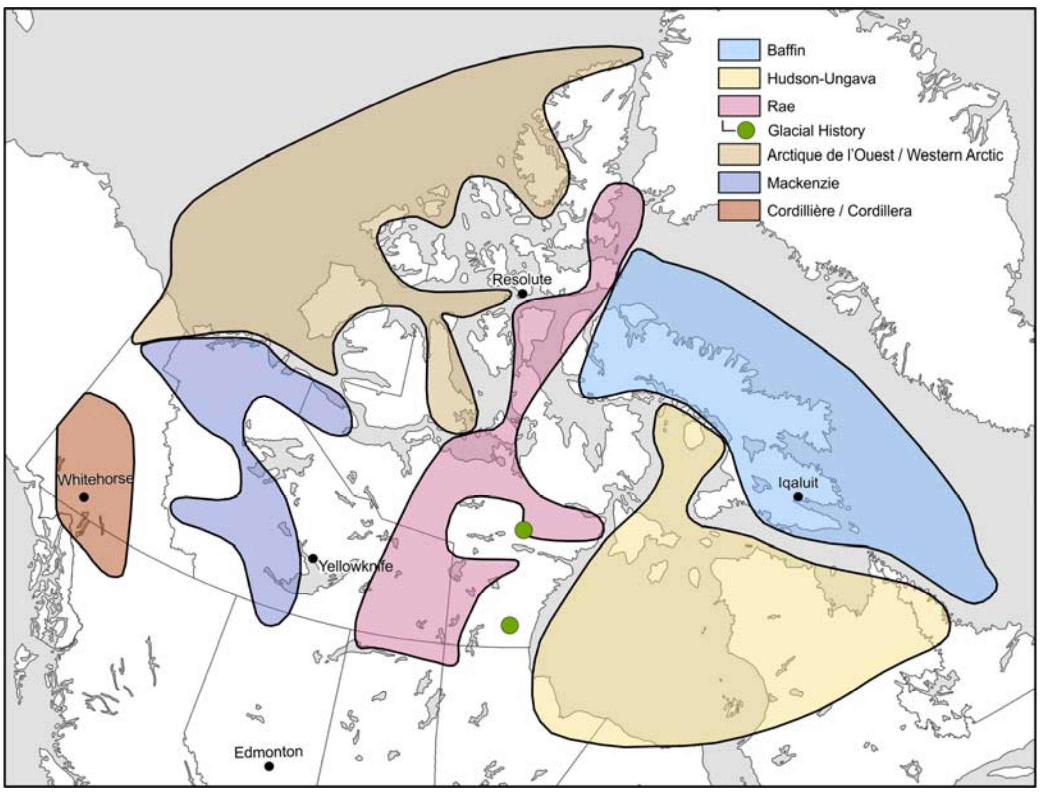

Figure 1. *Overview map of all GEM-2 projects in northern Canada. The location of the centre of the two field areas covered by the Rae Glacial history activity is shown by the green dots. Figure 2 shows the 2017 detailed field areas.*

The work proposed includes a compilation of glacial landforms in a two-step fashion: first in Nunavut, south of latitude 68° and east of longitude 100° (Sector 1), and second in NWT and Nunavut, south of latitude 68° and between longitudes 100° and 108° (Sector 2)(Fig. 2). The compilation will integrate previous mapping based on field work and expert air photo interpretation, new mapping as part of Tri-T surficial compilation project, GEM-1, GEM-2 and CNGO projects, and new interpretation based on targeted field work, satellite imageries and digital elevation models at various scales.

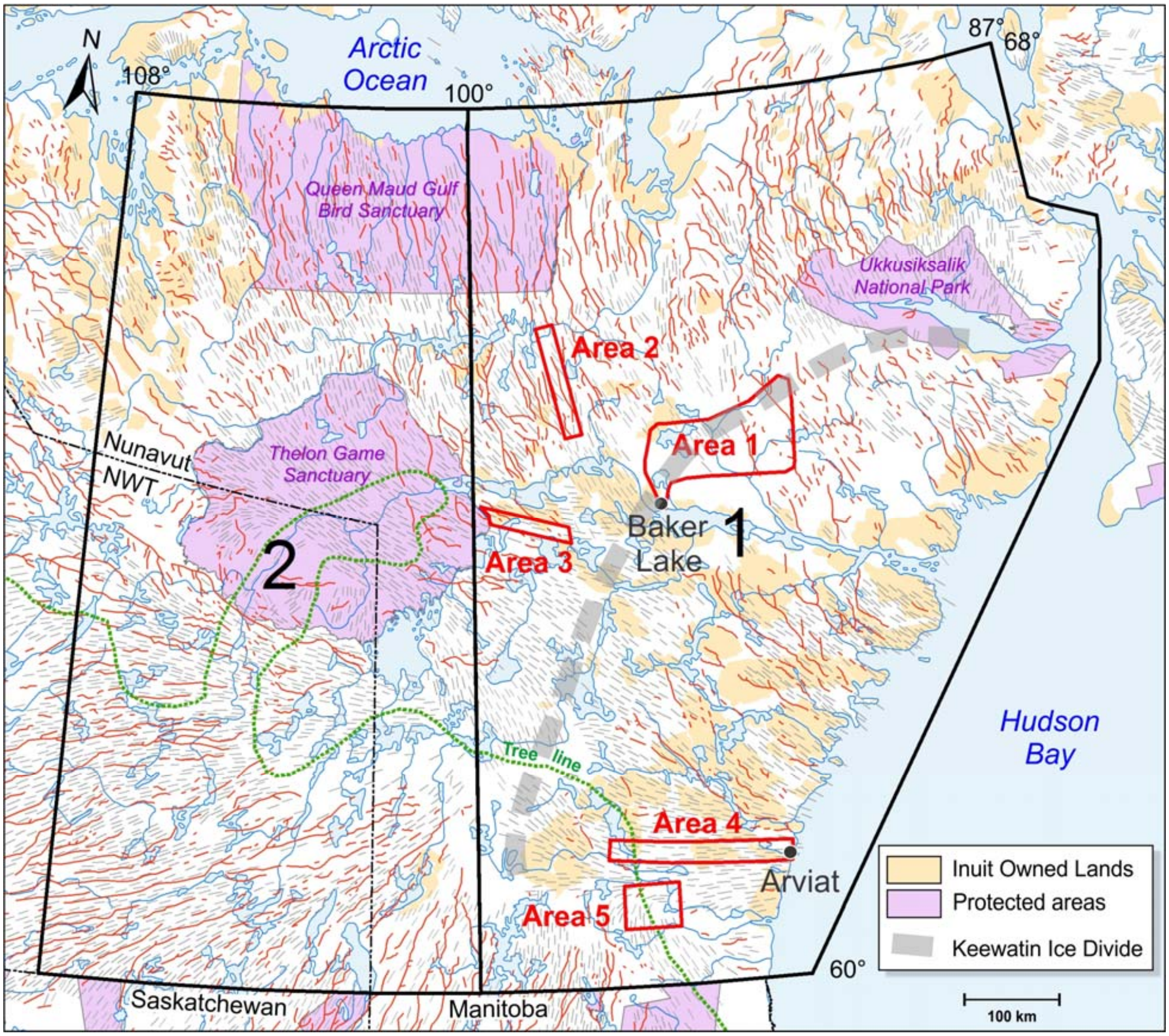

Figure 2. *Region covered by the glacial history compilation in central Nunavut and NWT divided in Sector 1 and Sector 2. The five targeted field areas in 2017 are located in Sector 1 of the project compilation area (red outline). Esker trends (red) and glacial lineations (grey) are from Prest et al. (1968). Last and approximate position of the Keewatin Ice Divide is also shown.*

Scientific question(s) addressed

The key scientific questions addressed in this activity include: 1) what is the flow direction, sequence and degree of overprinting of shifting glacial and deglacial events in a poorly mapped core region of the LIS in Nunavut and NWT; 2) what is the extent and nature of early glacial landscapes that may have escaped younger glaciation(s) under non-erosive ice regimes (ice divides and/or cold-based) and, 3) what is the net effect of the glacial history on the nature of glacial dispersal patterns, i.e. palimpsest, recycled and/or inherited surface sediment composition. This report describes the 2017 field work methodology and provides a summary of the field observations collected in the Baker Lake and Arviat areas.

Methodology

Planning of field areas

Three areas around Baker Lake and two areas west of Arviat were selected using air photos, digital elevation models (DEMs) and satellite imagery (LANDSAT 7 and 8), and integrating previous work (Fig. 2). The high-resolution (5 m) DEM of the Arctic north of 60°N latitude ("ArcticDEM") was particularly useful for planning and initial landscape interpretation (Fig. 3). ArcticDEM data are generated by applying stereo auto-correlation techniques to overlapping pairs of high-resolution optical satellite images (PGC, 2017). After relatively minor processing, including mosaicking and hillshading, ArcticDEM data and derived imagery were directly used in laptop computers and portable field tablets equipped with GIS software and GPS to plan sites accessed by helicopter, visually identify glacial landforms on-screen and verify observations made from the aircraft, and help sort out field relationships measured on the ground.

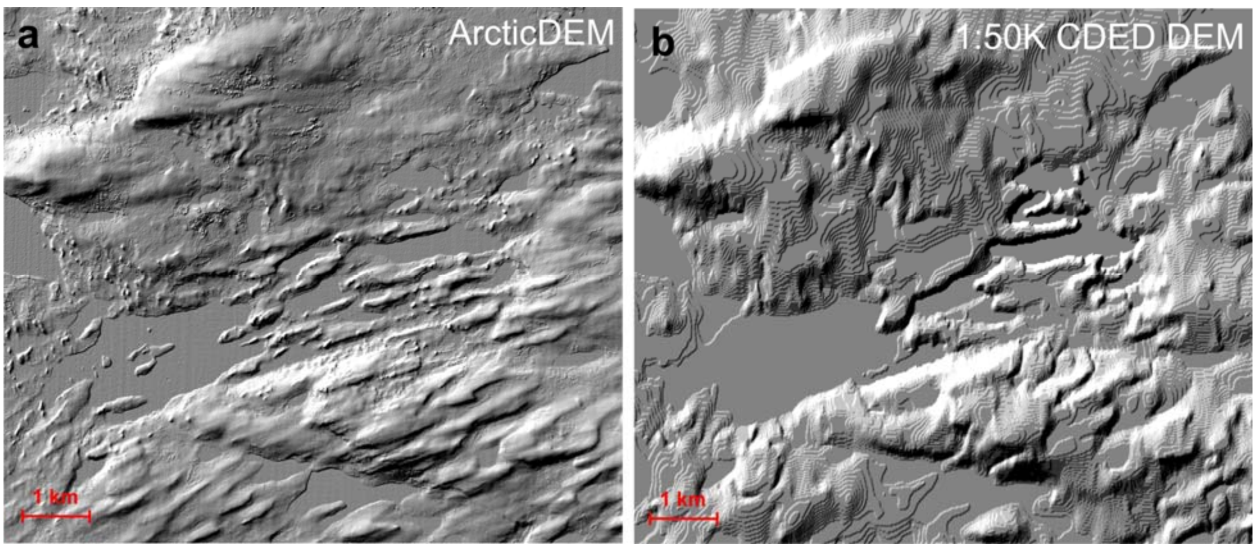

Figure 3. a) *Hill-shaded 5 m resolution ArcticDEM with 315° azimuth (PGC, 2017) in Area 5 showing well-defined streamlined landforms.* ***b)*** *Same area with CDED 1:50 000 scale hill-shaded DEM (15 m resolution). The higher resolution and accuracy of the ArcticDEM represents a breakthrough for areas north of 60° latitude that will allow detailed geomorphological mapping where available DEMs were previously inaccurate and/or imprecise.*

Surficial geology field data recording

Field observations were collected during 2 weeks in July 2017 at 92 stations mainly accessed by helicopter but also by truck along the Meadowbank Mine road between kilometres 0 and 5 (Figs. 2 & 4). Most of the field observations were recorded in the Ganfeld system from a GIS-based tablet. The work at each ground station involved collecting observations on surface sediments (texture, colour, structure, sorting, secondary processes, etc.), landforms, periglacial features, and small-scale glacial erosional features on bedrock. Several photographs of the terrain were taken on the ground at each field station. In addition, close to 1000 GPS-referenced photos were shot from the helicopter and added to the project geodatabase. Altitude measurements of the dating sampling sites and the post-glacial marine limit were collected with GPS and barometer altimeters calibrated to benchmarks using a DataLogger (see method in Randour et al., 2016).

Age dating material sampling

In total, thirteen bedrock outcrop samples in various settings were collected for terrestrial cosmogenic nuclide (TCN) exposure dating in 2017 (Fig. 4). Six of these samples were collected at 3 sites within Area 1 along the post-glacial marine limit to date the timing of marine emergence and provide a minimum deglaciation age in an area with very limited chronological constraints (see Dyke et al., 2003). These sites are characterized by intensely wave-washed bedrock surfaces immediately below coarse bouldery beaches or wave-cut notches in till that form distinct trimlines around small hills with unmodified till-covered surfaces above (Fig. 5). At two of these sites, marine littoral sands were collected for Infrared Stimulated Luminescence (IRSL) dating (Bateman, 2015; Lamothe, 2016) to compare with the TCN ages (Fig. 6). To our knowledge, such a comparison has never been attempted before and represents an alternative and promising method in areas with scarce material for radiocarbon dating at the marine limit. An additional sand sample from an ice-contact delta within a small glacial lake in a meltwater drainage network was also collected for IRSL (see Tremblay et al., 2017). The new ages will be compared with ^{10}Be ages determined at the marine limit south of Wager Bay and contribute to the reconstruction of the deglacial history of the region (see Randour et al., 2016).

Two bedrock outcrop samples were collected in weathered upland terrain north of Lunan Lake under the Keewatin Ice Divide (KID) for TCN exposure dating to evaluate relative erosion rates in potentially preserved (older) surfaces under a cold-based dome (see McMartin et al., 2015a, 2016). Finally, five samples of fresh and/or slightly weathered glacially striated outcrops were collected to provide minimum deglaciation ages in the various streamlined terrains or under the warm-based and last position of the KID west of Arviat (See Fig. 4 for location). Sampling methods with a rock saw for TCN dating are described in McMartin et al. (2015a, 2016), Randour et al. (2016) and Godbout et al. (2017).

Till and bedrock sampling

Till samples were collected at 38 sites to characterize the regional glacial transport under various settings: 10 samples NE of Baker Lake in Area 1 over the KID, 6 samples along a 80 km-long NNW transect north of the Thelon Basin in Area 2, 7 samples along 80 km of the Dubawnt Lake ice stream (DLIS) in Area 3, and 15 samples along 160 km of the Maguse Lake ice stream (MLIS) in Area 4. Samples were carefully collected on flat till surfaces on high ground (top of streamlined landforms, near head of crag-and-tail, middle of plains) in Cy-horizon material from hand dug pits in frost boils, at an average depth of 38 cm. At each site, one small sample (~3 kg) and one large sample (~10-12 kg) were collected. A field duplicate sample was collected 5 m away from the original at one site. All samples will be processed for geochemistry, heavy minerals, clast lithology and texture. At eight of the regional till sample sites over the various field areas, separate till samples were collected to estimate the amount of glacial erosion and link with basal thermal regime by TCN exposure dating (e.g. Staiger et al., 2006). Finally, four bedrock samples from the Dubawnt SuperGroup lithologies (e.g. Rainbird et al., 2003) were collected SW of Baker Lake for whole-rock geochemical analysis in order to better understand the geochemical signature of these distinctive lithologies in till: 1) quartz-sandstone from the Thelon Fm (Barrensland Group), 2) red sandstone from the Amarook Fm (Wharton Group), 3) rhyolite from the Pitz Fm (Wharton Group) and 4) ultrapotassic lava flows from the Christopher Island Fm (Baker Lake Group).

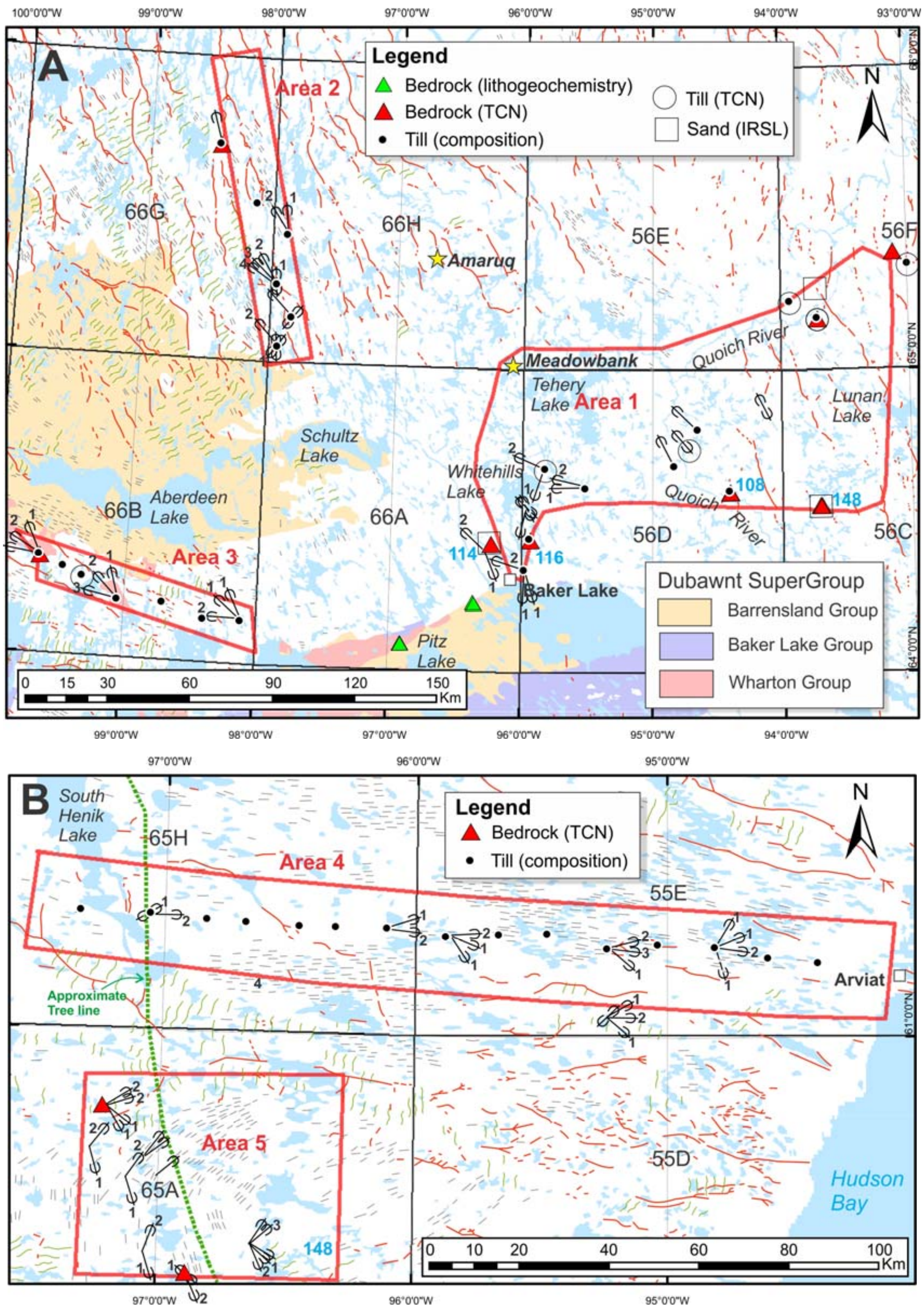

Figure 4. *Location of samples and striations collected in 2017.* ***a)*** *Areas 1, 2 and 3.* ***b)*** *Areas 4 and 5. Relative ages are shown where determined for the striations; marine limit elevations are indicated (in blue). Eskers (red), glacial lineations (grey) and transverse landforms (green) are from Aylsworth and Shilts (1989). Generalized extent of Dubawnt SuperGroup lithologies are from Paul et al. (2002). Yellow stars indicate Agnico Eagle Mines projects north of Baker Lake.*

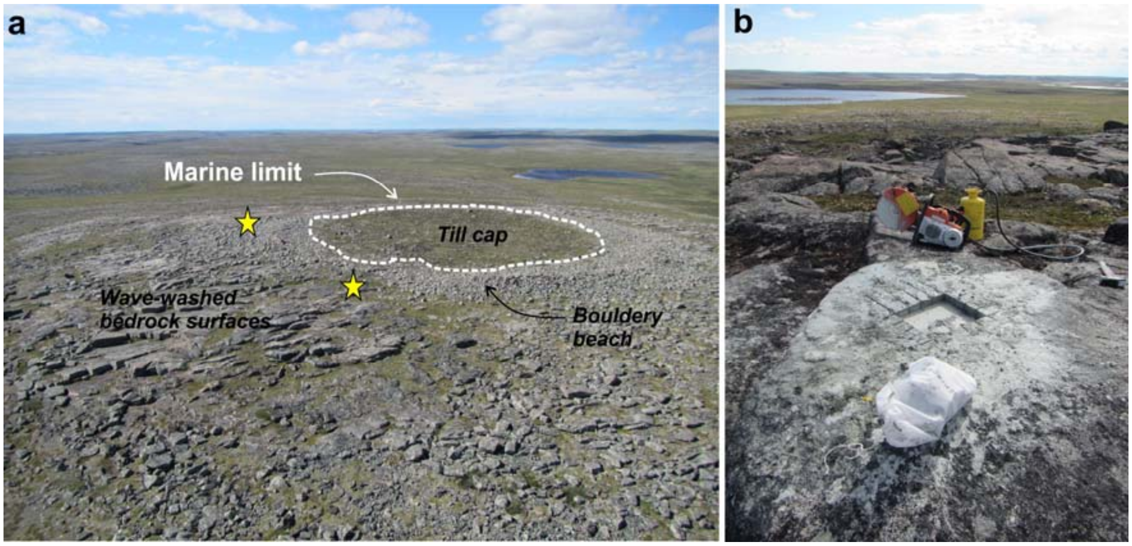

Figure 5. a) *Site of TCN samples (yellow stars) below the marine limit at 108 m asl in NTS 56D near Quoich River (stations 17MOB005&006).* ***b)*** *Flat bedrock surface sampled for TCN exposure dating with rock saw (17MOB005).*

Figure 6. a) *Wave-washed bedrock surface sampled for TCN exposure dating near the post-glacial marine limit at 148 m asl in NTS 56C southwest of Lunan Lake (station 17MOB009).* ***b)*** *Medium-grain littoral sands collected at 138 m asl for IRSL dating and textural analysis by inserting a large tube in a vertical pit (station 17MOB010). Two smaller tubes of material were also collected for the average water content (natural or in situ/at saturation).*

Results

Marine limit

Prominent strandlines marking the highest level of marine inundation are commonly observed far inland from the shores of Hudson Bay. They mainly form boulder beaches with wave-washed bedrock surfaces immediately below (see Fig. 5a) and/or clearly defined wave-cut notches in till (Fig. 7a). The elevation measurements of the marine limit show significant variation locally within Area 1 and regionally between Baker Lake and Arviat. Along the poorly mapped marine limit within Area 1 (i.e. Prest et al., 1968), maximum marine stands vary from 114-116 m asl north of the town of Baker Lake, decrease as low as 108 m in the lowlands up the Quoich River valley, and rapidly increase up to 148 m asl towards Lunan Lake (Fig. 4a). Randour et al. (2016) observed 135-150 m high strandlines 55 km further east in NTS 56C. The marine limit in the Quoich River valley is one of the lowest marine limit recorded for the Tyrrell Sea on the western side of Hudson Bay. Similar to the Pitz Lake basin to the west (McDonald and Skinner, 1969) and the Brown Lake basin to the NE (Dredge and McMartin, 2005), remnant ice blocks over the very last position of the KID probably occupied the lowlands along the Quoich River valley, blocking incursion of the sea. Such a low marine limit indicates a relatively younger deglacial age, rather than a magnitude of glacio-isostatic depression, and the new age dating will constrain the timing of maximum inundation.

In Area 5, the marine limit lies at ~148 m asl 132 km southwest of Arviat forming high gravel beaches circling the tops of till plateaus. This elevation differs from the marine limit at ~170 m asl about 200 km to the north near Kaminak Lake (Lee, 1969) and at ~180 m 200 km south of Caribou River in Manitoba (Dredge and Nixon, 1992). The marine limit in the Arviat region is thought to have formed just after 8000 cal yr (Simon et al., 2014) although very few direct age measurements of the marine limit exist for the area. Most likely the lower marine limit measured inland from Arviat formed after the last remnants of the KID had disappeared in the uplands to the west. The TCN bedrock samples collected on glacially striated surfaces in this area will help determine a minimum age for deglaciation.

Keewatin Ice Divide

The nature of the terrain under the KID was examined in Areas 1 and 5 to document the degree of weathering, age and composition of the surficial materials. In Area 1, the terrain changes progressively towards the northeast from a warm-based landscape in the Baker Lake area to an intermediate cold-based terrain in the upper reaches of the Quoich River. Near Baker Lake and as far as the west side of the Quoich River, the glacial landscape under the ice divide is dominated by thick till with solifluction lobes and surface runoff features, commonly streamlined, interspersed by glacially polished bedrock outcrops, reflecting a warm-based, erosive regime (Fig. 7b). West of Quoich River, the uplands above ~200 m asl are dominated by an extensive and variably weathered, boulder diamicton cover (Fig. 7c, 7d), irregularly weathered bedrock outcrops and a network of ice-marginal and southward flowing subglacial meltwater channels with discontinuous esker ridges. The number of lakes, glacial lineations and glacially carved outcrops decreases towards the NE. This indicates a transition into an intermediate cold-based terrain where at least one indicator of glacial erosion is visible, as opposed to a full cold-based terrain where almost no glacial scouring evidence is observed (lake, glacially-carved bedrock, striae, 2D macroforms, etc.; see Tremblay et al., 2016). This concord with the observations further to the NE where a well-developed but patchy cold-based, weathered landscape was reported in the highlands south (McMartin and Dredge, 2005; McMartin et al., 2015a, 2016) and north (Dredge et al., 2015; McMartin et al., 2015b) of Wager Bay.

The Area 1 striation record indicates that the area as far north as Whitehills Lake was covered by a migrating ice divide with successive southward, northwestward and westward flows (Fig. 4a). The ice-flow reversal, and late westward flow at the onset of the DLIS, is similar to what McMartin and Dredge (2005) and Robinson et al. (2014) reported south of Schultz Lake. Areas to the north of Whitehills Lake and around Tehery Lake experienced N to NW flows (see also Utting and McMartin, 2004).

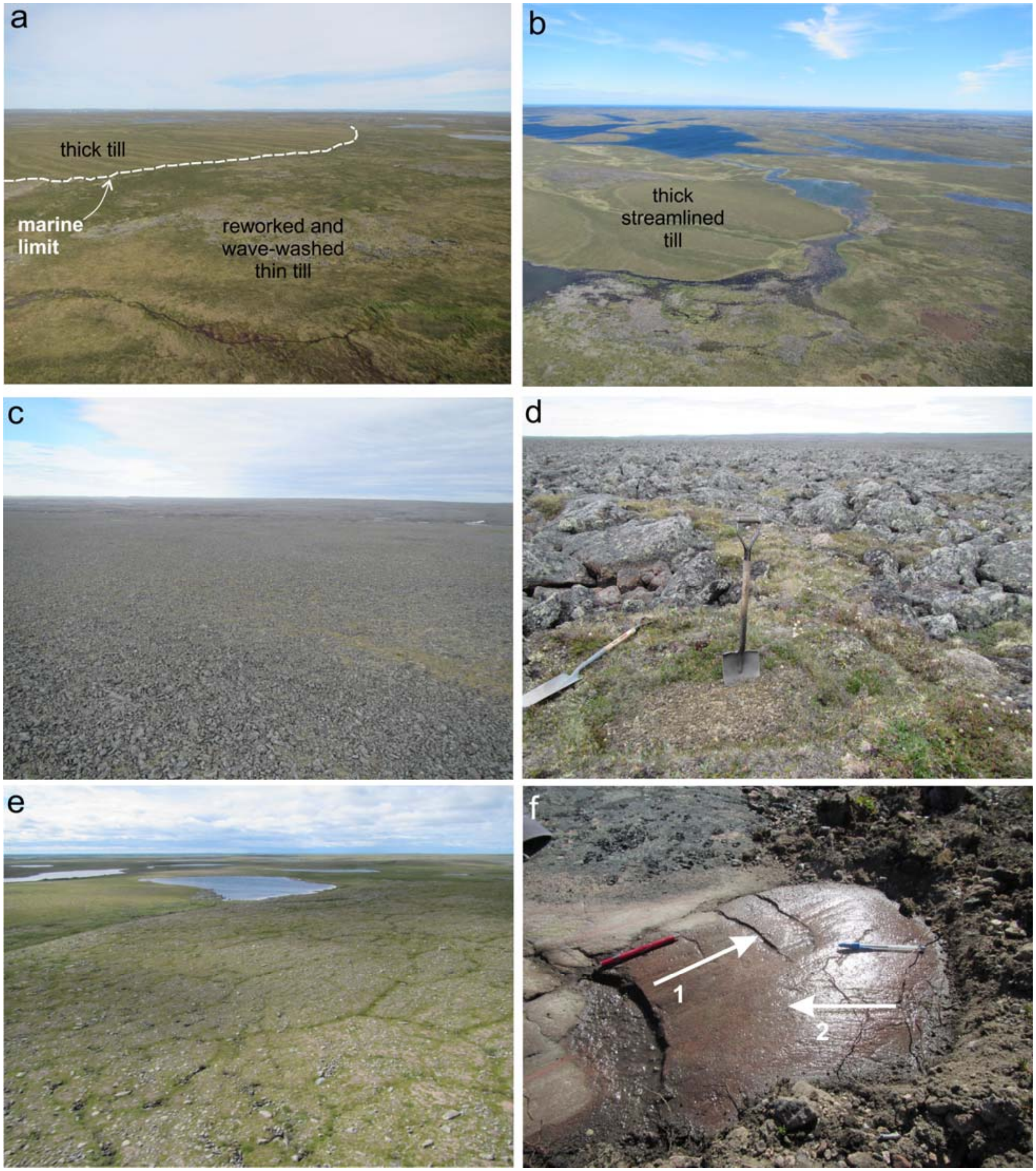

Figure 7. a) *Marine limit at 114 m asl NW of Baker Lake.* ***b)*** *Thick streamlined till north of Baker Lake.* ***c)*** *Featureless plain with boulder diamicton under the Keewatin Ice Divide at the NE extremity of Area 1.* ***d)*** *Weathered boulders and sorted nets in bouldery diamicton under the KID east of Quoich River (station 17MOB022).* ***e)*** *Ice-wedge polygons developed in coarse-grained till on subdued hills under the KID in Area 5.* ***f)*** *Preserved SSE striations (1) on the lee-side of NE striated surface (2) in Area 5.*

In Area 5 southwest of Arviat, the relative chronology of diverging and cross-cutting ice-flow indicators under the southern end of the KID was examined (Fig. 4b). The terrain in parts of this area is dominated by thick bouldery till forming subdued hills and till plateaus interspersed by lakes (Fig. 7e), with glacially polished and striated bedrock outcrops protruding on some of the highest hills, indicating some bedrock control. Well-preserved faceted and striated outcrops indicate a SSE flow cross-cut by a NE flow (Fig. 7f), and therefore documents a clear relative chronology for two dominant sets of superimposed streamlined landforms found in the area, as well as a significant migration and change in the orientation of the central axis of the ice divide prior to deglaciation. The confirmed relative age for the two sets of glacial lineations was previously unknown over the map area (i.e. Aylsworth et al., 1990) and opposite to that found further west in the Nueltin Lake area (Lee, 1969).

Ice stream landscapes

Glacial transport characteristics and relative ice-flow trends were examined in Area 2 over cross-cutting glacial lineations down-ice (north) of distinct Thelon Fm quartz-sandstones of the Dubawnt SuperGroup (Fig. 4a). This streamlined terrain converges along a general N-S axis and is thought to have fed the Boothia ice stream further to the NE (see Hodder et al., 2016; Storrar and Livingstone, 2017). Striation measurements indicate a N flow preceded a NW flow, in agreement with a similar age relationship found north of the Thelon Basin to the west (McMartin et al., 2013) and in the Amaruq deposit area to the east (i.e. Boulianne-Verschelden et al., 2017). Northward glacial transport of Thelon Fm clasts were found at least as far as 30 km down-ice of the Thelon basin indicating long-range glacial dispersal associated with the northward flow.

A transect south of Aberdeen Lake was targeted in Area 3 to characterize glacial transport close to the trunk of the Dubawnt Lake ice stream (i.e. Stokes and Clark, 2003), and to complement similar work at its onset (McMartin et al., 2006) and terminal zones (McMartin, 2017). Similar to what was found near Baker Lake, an anti-clockwise shift in ice flow trend is observed here, from NNW to NW, and finally to WNW, parallel to the glacial lineations associated with the ice stream (Fig. 4a). Lithological analysis of the pebble fraction within the pink-colored till found at the surface will help to evaluate glacial transport from the various Dubawnt SuperGroup rocks that outcrop in the area (Fig. 8a).

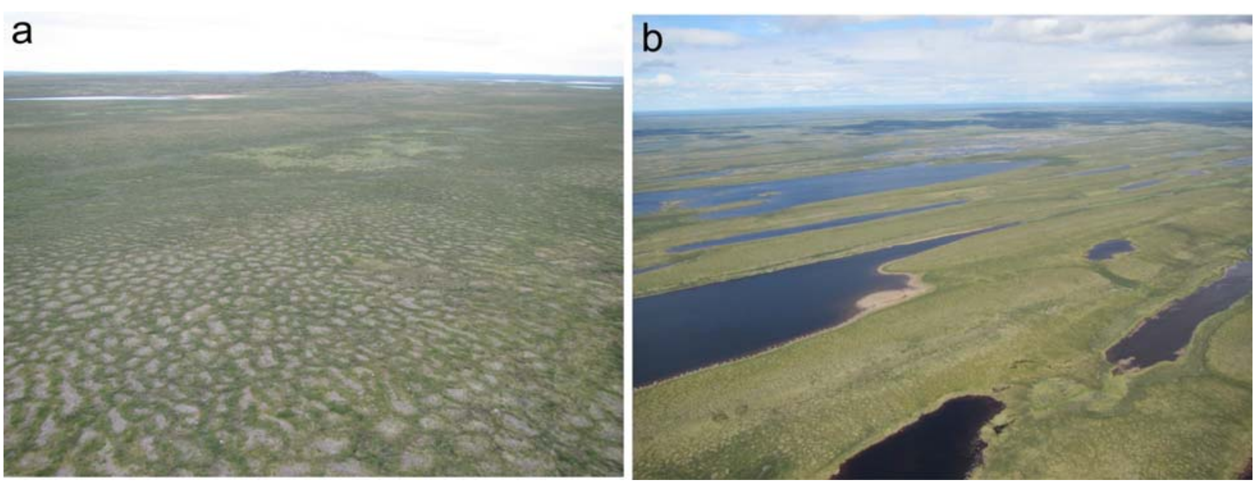

Figure 8. a) *Dubawnt-rich pink-colored till within the Dubawnt Lake ice stream in Area 3.* ***b)*** *Mega-scale glacial lineations within the Maguse Lake ice stream west of Arviat in Area 4.*

Lastly, glacial transport characteristics along the Maguse Lake ice stream (e.g. Margold et al., 2015) west of Arviat were examined in Area 4 (Fig. 8b). Ice-flow measurements indicate early flows to the SE and NE prior to the eastward ice stream flow (Fig. 4b). Distinct orthoquartzite and stromatolitic dolomite boulders were found at the till surface in this area and will help to evaluate transport distances.

Conclusions

Targeted field work was completed in 2017 in five key areas within Sector 1 of the GEM-2 Rae Synthesis of Glacial History and Dynamics Activity to answer questions related to the nature of the landscape under a major ice divide, chronology of glacial and deglacial events, and glacial dispersal characteristics along ice stream flows in the interior of the Keewatin Sector of the Laurentide Ice Sheet. The post-glacial marine limit was examined, measured and sampled for age dating material. Significant variations in the elevation of the marine limit across the area are associated with late ice front positions in contact with the Tyrrell Sea close to the last remnants of the Keewatin Ice Divide. The divide itself varies in nature, degree of weathering and surface materials composition. A warm-base, erosive regime is suggested west of Arviat and near Baker Lake, and grades into an intermediate cold-based, protective (non-erosive) terrain NE of Baker Lake towards the upper reaches of the Quoich River. The determination of relative erosion rates in till and bedrock under the KID will help to evaluate how glacial sediments can be used for mineral exploration in areas potentially complicated by inherited signatures. Surface till composition examined in three ice stream terrains suggests long-range transport of distinctive lithologies. Compositional analysis of the surface till samples, and integration with results of previous regional samples as well as glacial history, will allow a better evaluation of glacial transport characteristics in streamlined terrain across the eastern sector of the compilation area. Targeted field work is planned in 2018 across the western sector in the NWT.

Acknowledgments

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