MANITOBA

INVEST. BUILD. GROW

OPEN FILE OF2018-1

ICE-FLOW HISTORY AND TILL COMPOSITION OF THE SOUTHERN INDIAN LAKE AREA, NORTH-CENTRAL MANITOBA (PARTS OF NTS 64G1, 2, 7–10, 64B15)

Manitoba Geological Survey

Manitoba

Open File OF2018-1

Ice-flow history and till composition of the Southern Indian Lake area, north-central Manitoba (parts of NTS 64G1, 2, 7–10, 64B15)

by T.J. Hodder
Manitoba Geological Survey
Winnipeg, 2018

Hodder, T.J. 2018: Ice-flow history and till composition of the Southern Indian Lake area, north-central Manitoba (parts of NTS 64G1, 2, 7–10, 64B15); Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, Open File OF2018-1, 21 p.

NTS grid: 64G1, 2, 7, 8, 9, 10, 64B15

Keywords: drift exploration; drift prospecting; ice flow; KIM; kimberlite-indicator minerals; north-central Manitoba; Quaternary; radiocarbon; till composition; till geochemistry; Southern Indian Lake

Published by:

Manitoba Growth, Enterprise and Trade
Manitoba Geological Survey
360–1395 Ellice Avenue
Winnipeg, Manitoba
R3G 3P2 Canada

Telephone: 1-800-223-5215 (General Enquiry)
204-945-6569 (Publication Sales)
Fax: 204-945-8427

E-mail: minesinfo@gov.mb.ca

Website: manitoba.ca/minerals

ISBN No.: 978-0-7711-1590-5

This publication is available to download free of charge at manitoba.ca/minerals

Cover illustrations:

Left: Example of Quaternary sections observed in the SIL area (Figure 5).

Right: Striated bedrock indicating two ice-flow events. The black pencil highlights the earlier ice-flow event which is on a protected facet from a later ice-flow event highlighted by the pink pencil on top of the outcrop. The outcrop has been streamlined into a roche moutonnée morphology indicating that the down-ice direction is to the right in the photo.

Abstract

Shoreline geological fieldwork was conducted in 2015 and 2016 in the Southern Indian Lake area to document the ice-flow history and conduct till sampling. Ice-flow observations reveal a complex history with eight ice-flow phases identified. The dominant ice-flow trend in the region is 210–244° and is the inferred dominant dispersal trend, but earlier ice-flow phases cannot be ignored and are demonstrated to have a significant impact on till-composition in the study area. Distally sourced carbonate, 180–230 km to the east, comprises 4.2–48.0 ct. % of the till composition in the Southern Indian Lake area. Distinctive erratics of eastern Hudson Bay provenance are recognized throughout the study area, indicating a significant influence of west-trending ice-flow on the till composition. Kimberlite-indicator mineral results have hinted at the diamond potential of the region and further follow-up till sampling is recommended.

TABLE OF CONTENTS

Page

TABLES

FIGURES

APPENDICES

Introduction

Shoreline Quaternary geology fieldwork was undertaken in the north and central areas of the Southern Indian Lake (SIL) basin (parts of NTS 64G1, 2, 7–10, 64B15) using boat access during the 2015 and 2016 field seasons. The purpose of this study is to 1) interpret the ice-flow history from observations of bedrock ice-flow indicator mapping; 2) document the composition of glacial sediment (till) using till-matrix geochemistry and clast-lithology counts; and 3) assess the diamond potential of the SIL area at a reconnaissance-scale (1–2 samples per 100 km^2) from a till indicator-mineral perspective. This work builds on previous regional-scale surficial mapping and till composition datasets from 1983–1989 (Kaszycki, 1989; Lenton and Kaszycki, 2005; Kaszycki et al., 2008; McMartin et al., 2016) and recent detailed 1:50 000 surficial mapping and till composition data from the Gauer Lake to Wishart Lake area (Trommelen, 2015). This report contains field station, ice-flow indicator and till composition datasets to assist with the application of drift prospecting in the SIL area and complements recently released kimberlite-indicator mineral (KIM) data (Hodder, 2017).

Regional setting

The SIL study area is located in north-central Manitoba (Figure 1). Elevation varies from 243 to 349 m asl and relief is low (≤30 m) within the study area. The lake surface elevation during the 2015 and 2016 field seasons was approximately 260 m asl. North-central Manitoba lies within a region of discontinuous permafrost (Sladen, 2011); variable permafrost conditions were encountered during fieldwork. Natural exposures of sediment along the SIL shoreline are relatively rare, typically exposing only 1–2 m of sediment; however, exposures in excess of 10 m in thickness are present. Bedrock exposed along the shorelines of SIL provided excellent, fresh surfaces to document the paleo–ice-flow history of the region. This is due to the Missi Falls control structure, which began operations in 1977 and raised water levels in SIL by ~3 m. Wave washing along this higher level of the lake surface has exposed fresh, unweathered bedrock surfaces with exceptionally well-preserved ice-flow indicators and age relationships.

Bedrock geology

The study area is largely underlain by granitoid bedrock of the Chipewyan and Southern Indian domains (Figure 2). The south half of the study area includes supracrustal rocks of the Pukatawakan Bay and Partridge Breast Lake assemblages, which are composed of metagreywacke, metabasalt, amphibolite, sandstone and conglomerate rock types (Kremer, 2008b; Kremer et al., 2009a; Kremer et al., 2009b). Detailed 1:25 000 to 1:50 000 scale bedrock geological mapping has recently taken place within the study area (Kremer, 2008a; Kremer et al., 2009a; Kremer and Martins, 2014; Martins, 2015a, 2016a) and these maps should be consulted for detailed information on bedrock geology of the SIL area. The closest source of carbonate (limestone and dolostone) rocks is the Hudson Bay Basin, located 180–230 km east of the study area.

Distinctive far-travelled erratic sources

Several distinctive erratics were observed in the study area, interpreted to be derived from different sources located north and east of Manitoba (Figure 3a). Oolitic jasper clasts (Figure 3b) are relatively rare in the SIL area and are interpreted to be derived from the Kipalu Formation (Kipalu), located in the south and southeastern regions of the Hudson Bay Lowland (Stott et al., 2010; Jackson, 2013). Erratics derived from the Dubawnt Supergroup (Dubawnt) of central mainland Nunavut (Figure 3a), are also found throughout northern Manitoba (e.g., Dredge and McMartin, 2011). These include reddish to pinkish sandstone and conglomerate of the Thelon Formation, purple to mauve rhyolite with glassy quartz and chalky sanidine phenocrysts of the Pitz Formation (Figure 3c), and volcaniclastic rocks with phlogopite phenocrysts of the Christopher Island Formation (Rainbird et al., 2003). These erratics were transported southwards over 700 km by the Laurentide ice sheet into the SIL area. The Omarolluk Formation of the Belcher Group in southeastern Hudson Bay (Figure 3a) is a distinctive greywacke with hemispherical calcareous concretions (Figure 3d, e; Prest et al., 2000). These distinctive erratics are the most abundant in the study area, are commonly referred to as Omars (Prest et al., 2000), and were transported westward ~1 100 km by the Laurentide Ice Sheet. Omar erratics are commonly found throughout most of Manitoba (Prest et al., 2000).

Quaternary geology

Surficial geology

The surficial geology in the SIL area is predominantly glaciolacustrine sediments (Figure 4; Kaszycki and Way Nee, 1990a, b). Till veneer mantling bedrock exposures have been mapped in the south and west-central regions of the study area (Figure 4). Glaciofluvial landforms are present across the study area and trend east-northeast to west-southwest. While the purpose of this study was not to update the surficial geology mapping in the SIL area, shoreline sections logged during this study are plotted on Figure 4 according to the surficial geology mapping unit present. One important observation from this fieldwork is the presence of till in areas mapped pervasively as glaciolacustrine sediments, e.g., along the west-shore of SIL. Glaciolacustrine sediments also exhibit variable thickness, with glaciolacustrine veneer (<1 m thick) over till present at many sections investigated.

Ice-flow history

North-central Manitoba has a complex ice-flow history. During the last glacial cycle, the region experienced ice-flow from the Laurentide Ice Sheet (LIS) trending southward from an ice dome in central Nunavut to the north and ice-flow trending west from a dome in Quebec–Labrador to the east (e.g., Kaszycki et al., 2008; Trommelen, 2015). Previous regional-scale ice-flow mapping in the SIL area recognized ice-flow indicators ranging from 180–245° (Kaszycki and Way Nee, 1990a, b; McMartin et al., 2010), but lacked detailed age relationships. Trommelen (2015) conducted ice-flow indicator mapping in a small area on the eastern shoreline of SIL, near the Missi Falls

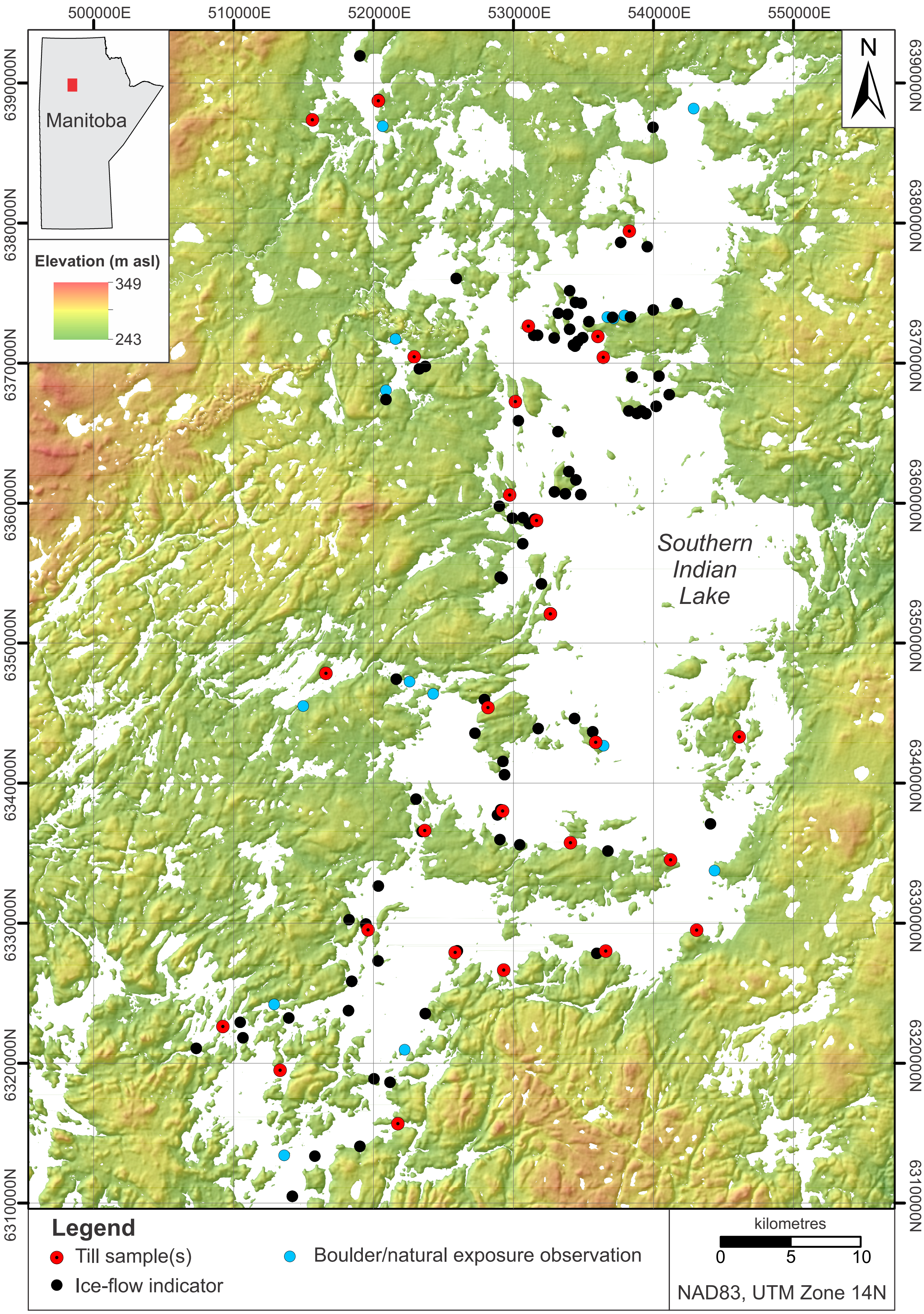

Figure 1: *Field and till sampling stations within the Southern Indian Lake area, north-central Manitoba. The background hillshade image was generated using the Canadian digital surface model (Natural Resources Canada, 2015).*

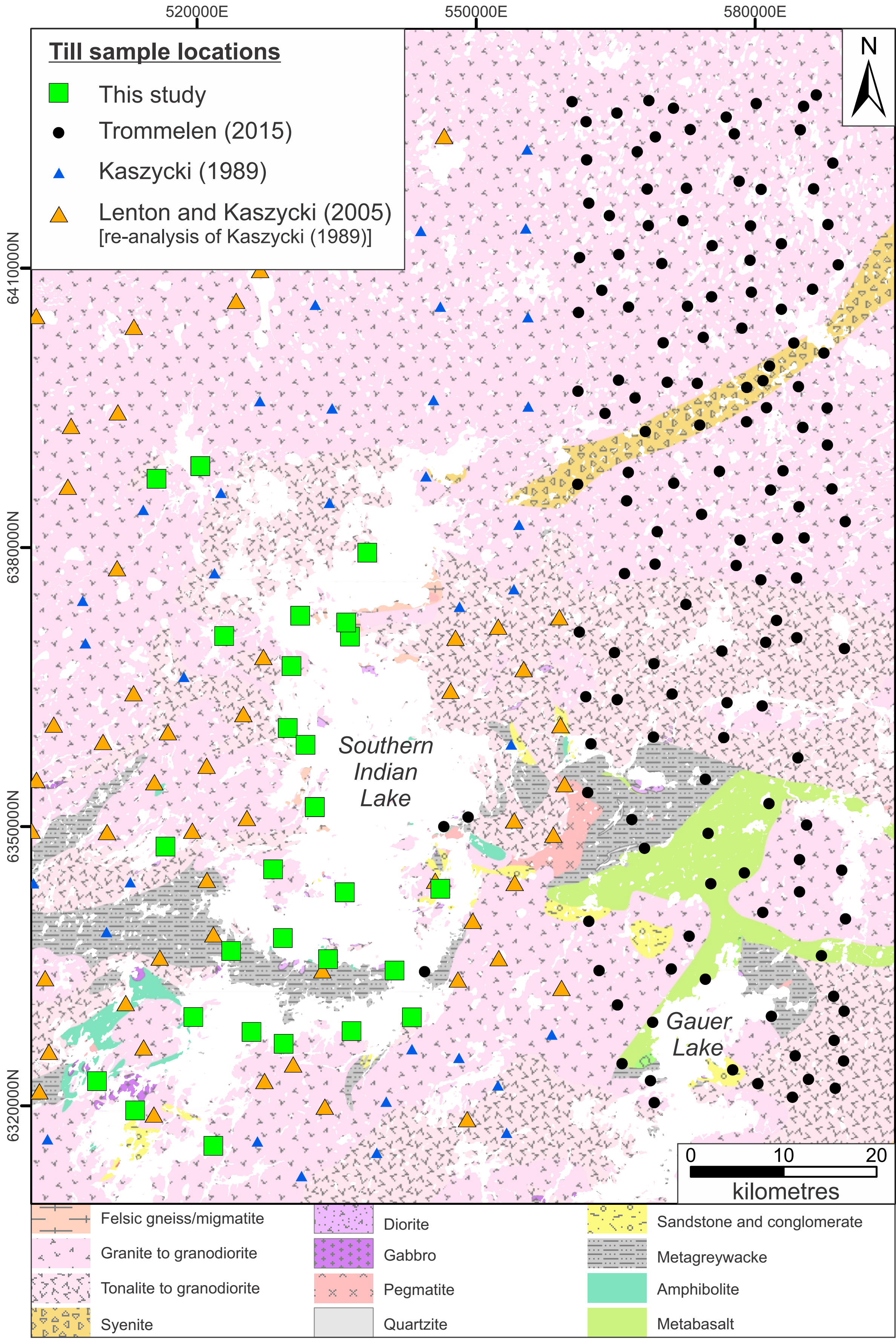

Figure 2: *Bedrock geology of the SIL area, showing locations of till samples collected during this study and by previous workers. Bedrock geology is modified from unpublished Manitoba Geological Survey bedrock compilation (2015, scale 1:250 000).*

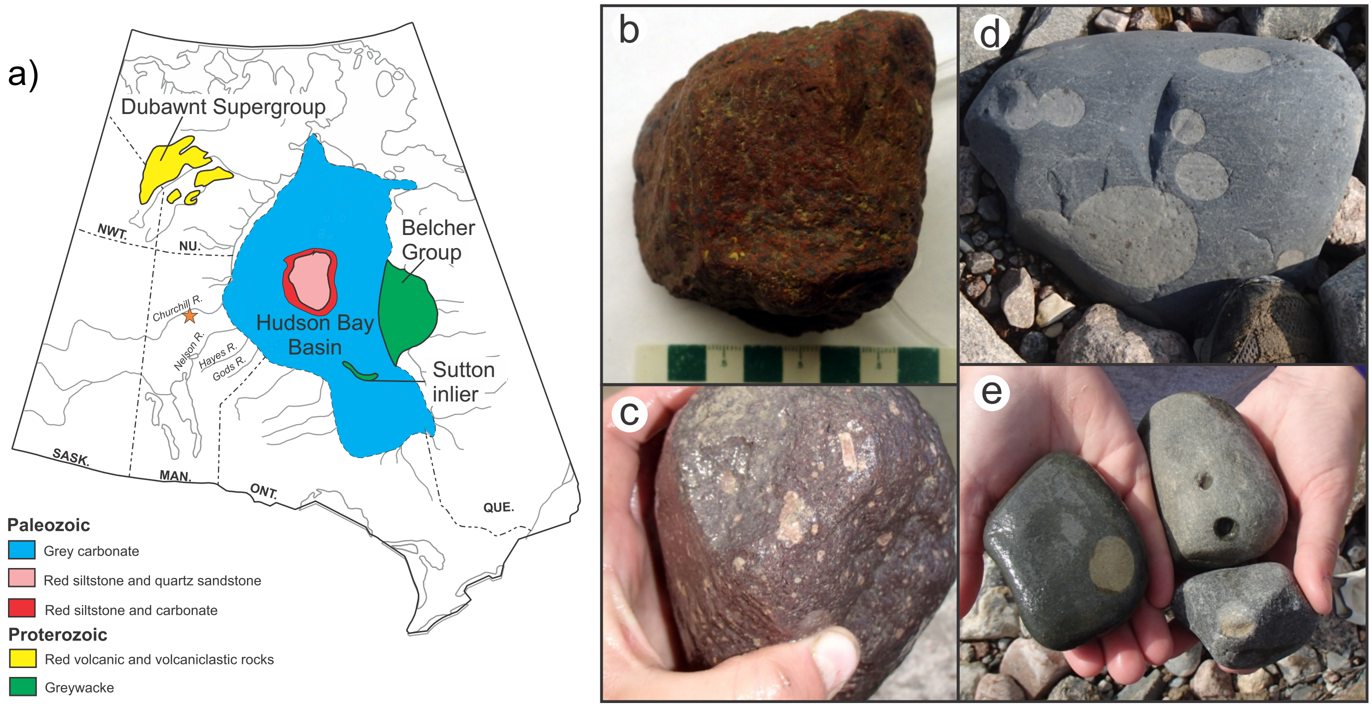

Figure 3: *Distinctive erratics observed in the SIL area:* ***a)*** *regional map showing the source of the erratics observed in the study area (modified from Kaszycki et al., 2008). Study area marked by the orange star;* ***b)*** *example of an oolitic jasper erratic interpreted to be derived from the Kipalu Formation which outcrops at the Sutton inlier;* ***c)*** *example of an erratic from the Dubawnt Supergroup (Pitz Formation);* ***d)*** *and* ***e)*** *examples of erratics from the Omarolluk Formation of the Belcher Group. Abbreviations: MAN., Manitoba; NU., Nunavut; NWT., Northwest Territories; ONT., Ontario; QUE., Quebec; SASK., Saskatchewan.*

control structure and within the Gauer Lake to Wishart Lake area (NTS 64H, 5, 12, 13; Trommelen, 2015) recognizing six ice-flow phases. This relative-age reconstruction included early southeast-, west- and southwest-trending ice flow, which is following by south- and southwest-trending ice-flow and late-glacial southeast- to southwest-trending ice-flow (Trommelen, 2015).

Methods

Field-data collection

Boat-accessible field stations along the shorelines of SIL were investigated for bedrock ice-flow indicators and wave-cut exposures of Quaternary sediments were described. The abundance of glaciolacustrine sediments at surface in the study area (Figure 4), as well as thick occurrences of these sediments in many regions (Figure 5a, b), impeded surficial sampling of till at many of the stations visited. Shoreline fieldwork conducted during this study proved advantageous to easily access till buried beneath post-glacial sediments (Figure 5c, d). Section exposures also provide additional lateral stratigraphy and sedimentology observations that are not readily evident through surface auger or dug holes. The 2015 field season concentrated on the northern area and the 2016 field season focused on the central area of the SIL basin. Fieldwork was conducted in coordination with bedrock geology mapping both field seasons (Martins, 2015b, 2016b). Site locations, descriptions and sample details are provided in Appendix 1.

Till sampling

A total of 27 wave-cut shoreline sections of Quaternary sediments were described in detail and 31 C-horizon till samples collected in the summers of 2015 and 2016. Till samples were processed for textural, clast lithology and till-matrix geochemistry analysis. At 19 of the till sampling stations, an additional 22.7 L (6 US gallons) of till was collected for kimberlite-indicator mineral (KIM) processing. KIM samples were collected at a reconnaissance-scale (1–2 samples per 100 km^2) during the 2016 field season to assess the regional diamond potential (Hodder, 2016) and results were released in early 2017 (Hodder, 2017). Figure 6 provides examples of till sampled in the study area. Detailed stratigraphic observations for each exposure investigated and sampled are provided in Appendix 2 along with stratigraphic columns.

Ice-flow indicator mapping

Erosional paleo–ice-flow indicators, such as striae, grooves, chattermarks and crescentic gouges were mapped along shoreline bedrock exposures. The orientation of streamlined outcrops (i.e., roches moutonnées) were also mapped. Many outcrops exhibited multiple paleo–ice-flow indicators, and the relative chronology of these ice-flow phases was deciphered using the crosscutting and outcrop relationships of facets and striae (Figure 7; McMartin and Paulen, 2009). The excellent, fresh bedrock exposures at SIL created a unique opportunity to map in detail and interpret the relative ice-flow history in the study

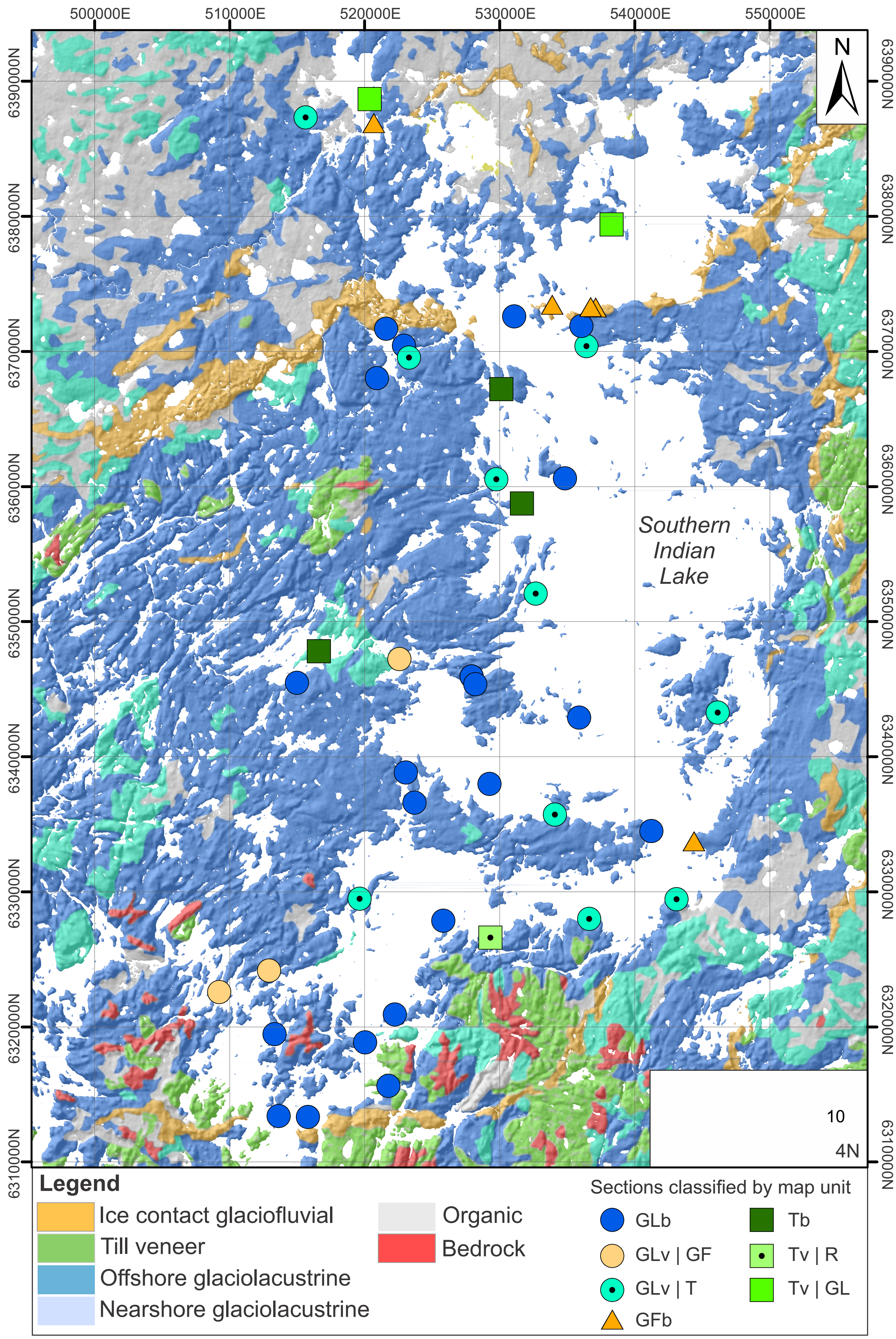

Figure 4: *Surficial geology of the SIL area (modified from Matile and Keller [2006a, b] after Kaszycki and Way Nee [1990a, b]). Stations where surficial sediments were observed are included and classified according to a corresponding map unit. The background hillshade image was generated using the Canadian digital surface model (Natural Resources Canada, 2015). Abbreviations: GF, glaciofluvial; GFb, glaciofluvial blanket; GL, glaciolacustrine; GLb, glaciolacustrine blanket; GLv, Glaciolacustrine veneer; R, bedrock; T, till; Tb, till blanket; Tv, till veneer.*

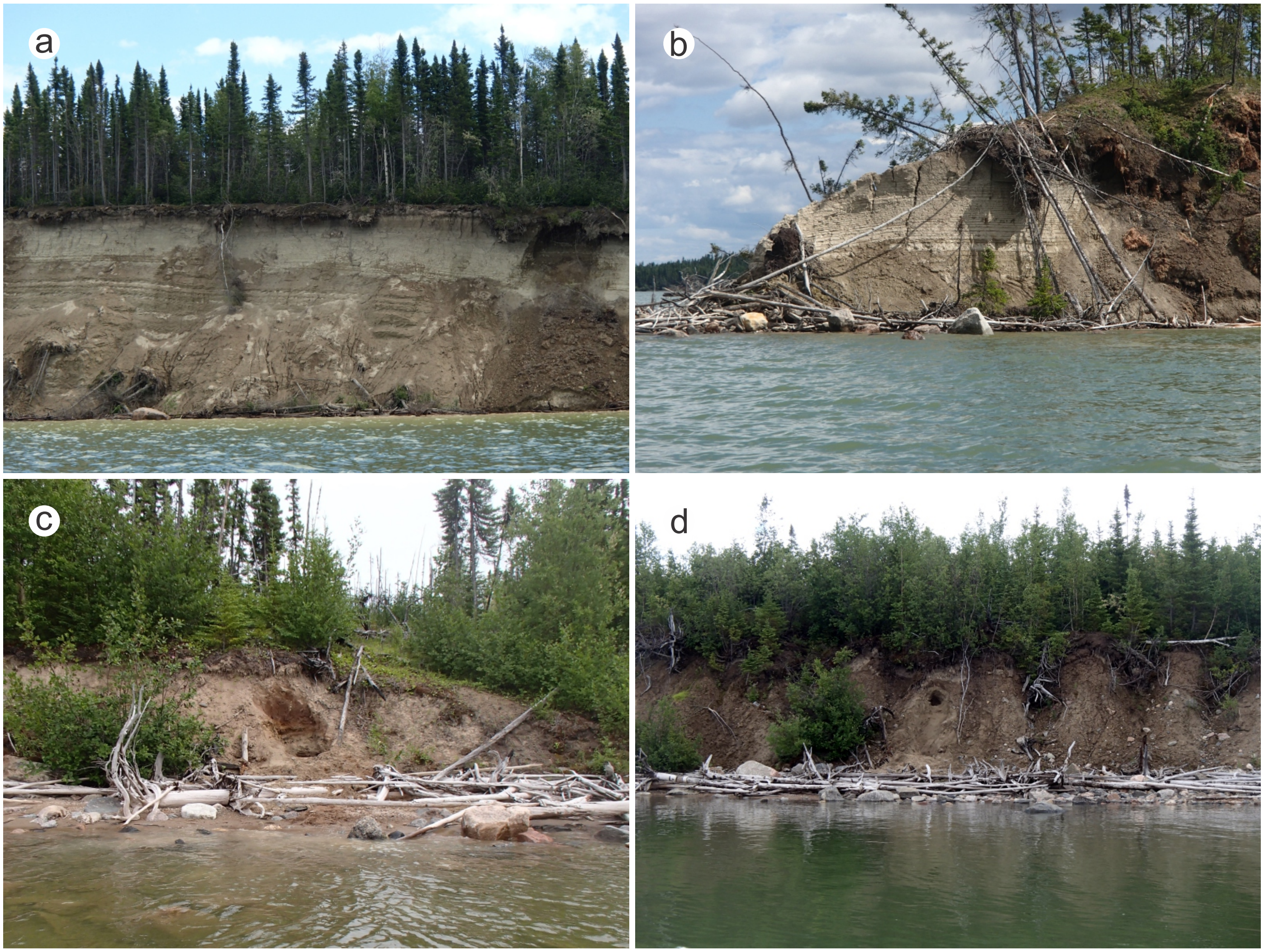

Figure 5: *Examples of Quaternary sections observed in the SIL area:* ***a)*** *thick (>10 m) exposure of rhythmically bedded glaciolacustrine sediments. Till was not exposed at lake level;* ***b)*** *glaciolacustrine varves observed at station 112-16-344. Till was not exposed at lake level;* ***c)*** *Quaternary sediments exposed at section 112-16-310 consisting of 1.2 m of post-glacial sediments overlying 0.3 m of till on bedrock;* ***d)*** *Quaternary sediments exposed at section 112-16-327 consisting of 0.3 m of post-glacial sediments overlying a complex sequence of till and sub-till sand.*

area. Ice-flow indicators were observed at 101 stations and observations are provided in Appendix 3.

Clast-fabric analysis

The long-axes orientation, or fabric, of clasts and particles within till are used as a proxy for ice-flow orientation because they are often aligned parallel to ice-flow from shear stress imparted on the sediment by the overlying ice. To provide ice-flow information at three sections, clast-fabrics were conducted at till sample locations. Clast-fabrics measured the a-axis orientation of 30 clasts that had an a:b axis ratio of >1.5. Measurements, statistics, stereoplots, rose diagrams and interpretations are provided in Appendix 4.

Laboratory analytical procedures

Collected till samples were analyzed for clast lithology, textural and till-matrix geochemistry analysis. Clast-lithology counts were conducted during the fall and winter of 2015–2017 by MGS staff. Till-matrix texture (<2 mm size-fraction) and till-matrix geochemistry (<63 µm size-fraction) analysis was conducted at the Saskatchewan Research Council Geoanalytical Laboratory (SRC) and Activation Laboratories Ltd. (Actlabs) for the 2015 and 2016 field seasons, respectively. Certain analytical procedures were only conducted on 2015 samples and these are noted within the text. Two radiocarbon samples were submitted for dating at the University of California.

Clast-lithology counts

Clast-lithology counts were conducted for each till sample to aid in the determination of provenance. Clasts larger than 2 mm were initially sieved into 2–4, 4–8 and 8–30 mm size-fractions and counts conducted on each fraction with the assistance of an optical microscope. Clasts were separated into the 14 rock types presented in Table 1. In Appendix 5, clast counts are expressed as the number of clasts for each rock type in a separate table for each size-fraction. The size-fractions were then summed

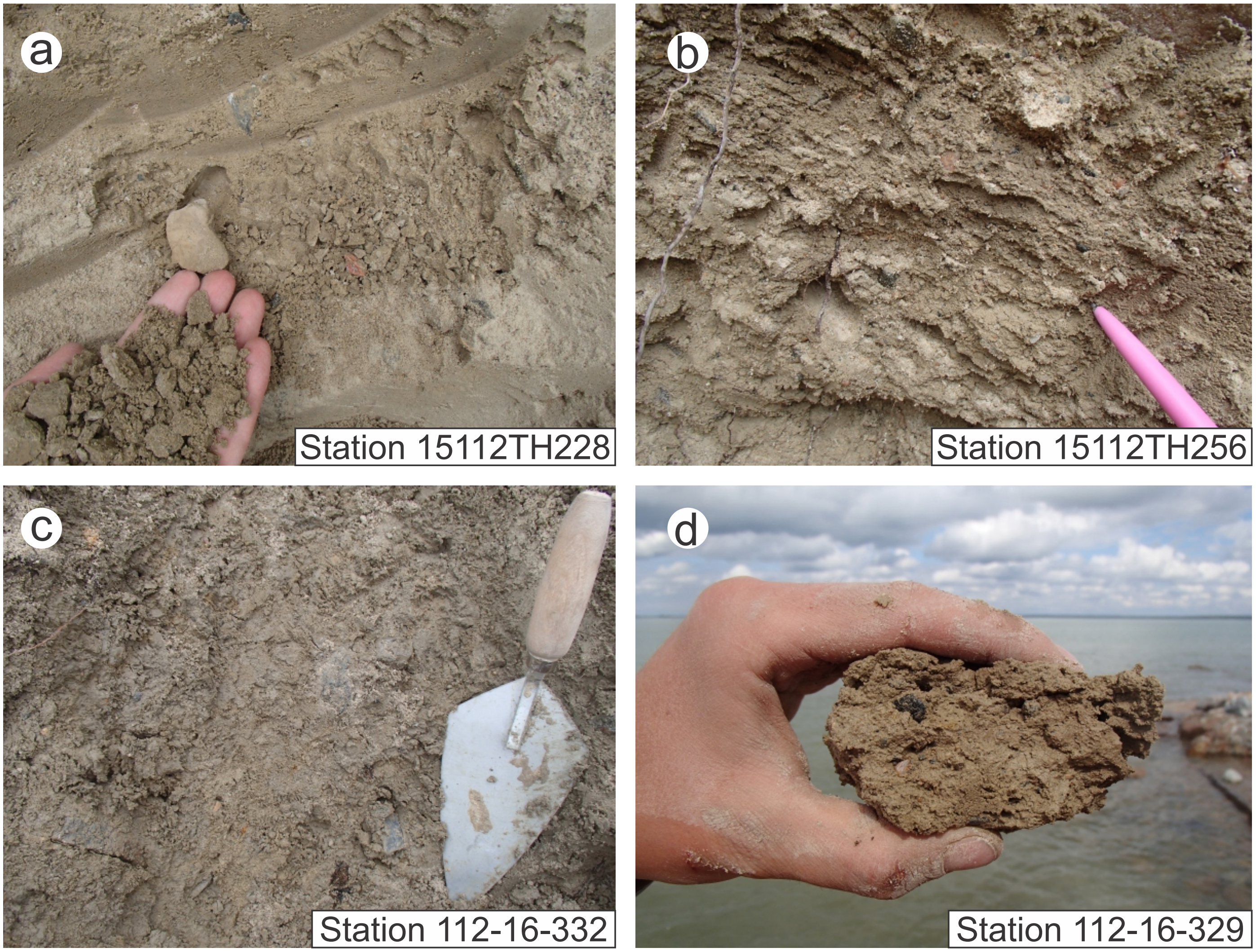

*Figure 6: Example of till sampled in the SIL area: **a)** silty-sand till sampled at station 15112TH228; **b)** silty-sand till with minor sand stringers present sampled at station 15112TH256; **c)** sandy till sampled at station 112-16-332; **d)** sandy till sampled at station 112-16-329.*

(2–30 mm; Table 11, Appendix 5) and expressed as a count-percentage (ct. %) of the total number in another table (Table 12, Appendix 5). An average of 498 clasts were counted from the 2–30 mm size-fraction for each sample. Photos of sorted 2–4 mm size-fractions are presented in Appendix 6.

Till-matrix texture

At SRC, an aliquot of <2 mm sampled material was transferred to a flask and an aliquot of Calgon® was added. De-ionized water was then added to the flask and the flask was shaken until the contents were thoroughly mixed. The contents of the flask were sieved through a screen into a graduated cylinder. An aliquot of sample was immediately removed. A second aliquot of clay was removed from the cylinder after a certain period of time; the time period is dependent on the ambient room temperature. The sieved sand and aliquots of sample material were dried and reweighed. Calculations were performed to determine the percentage of sand, silt and clay in the sample based on the total weight. An SRC standard was prepared and inserted into the group every 12 samples. Replicate samples were inserted after every 40 samples or at the end of smaller groups.

At Actlabs, an aliquot of the sample was initially sieved into >2 and <2 mm size-fractions. The <2 mm size-fractions was further sieved to determine the weight proportion of silt/clay (<63 µm size-fraction) and sand (63–2000 µm size-fraction). The <63 µm size-fraction was analysed using a laser particle size analyzer to determine the proportion of silt and clay. Till-matrix textural results for all till samples are expressed in weight percent and provided in Appendix 7.

Till-matrix geochemistry

Ca and Mg method for carbonate content

The results for till carbonate content, expressed as weight percent, are provided in Appendix 8. At SRC and Actlabs, an aliquot of the till-matrix (<63 µm size-fraction) was digested using HCl and analyzed for Ca and Mg by inductively coupled

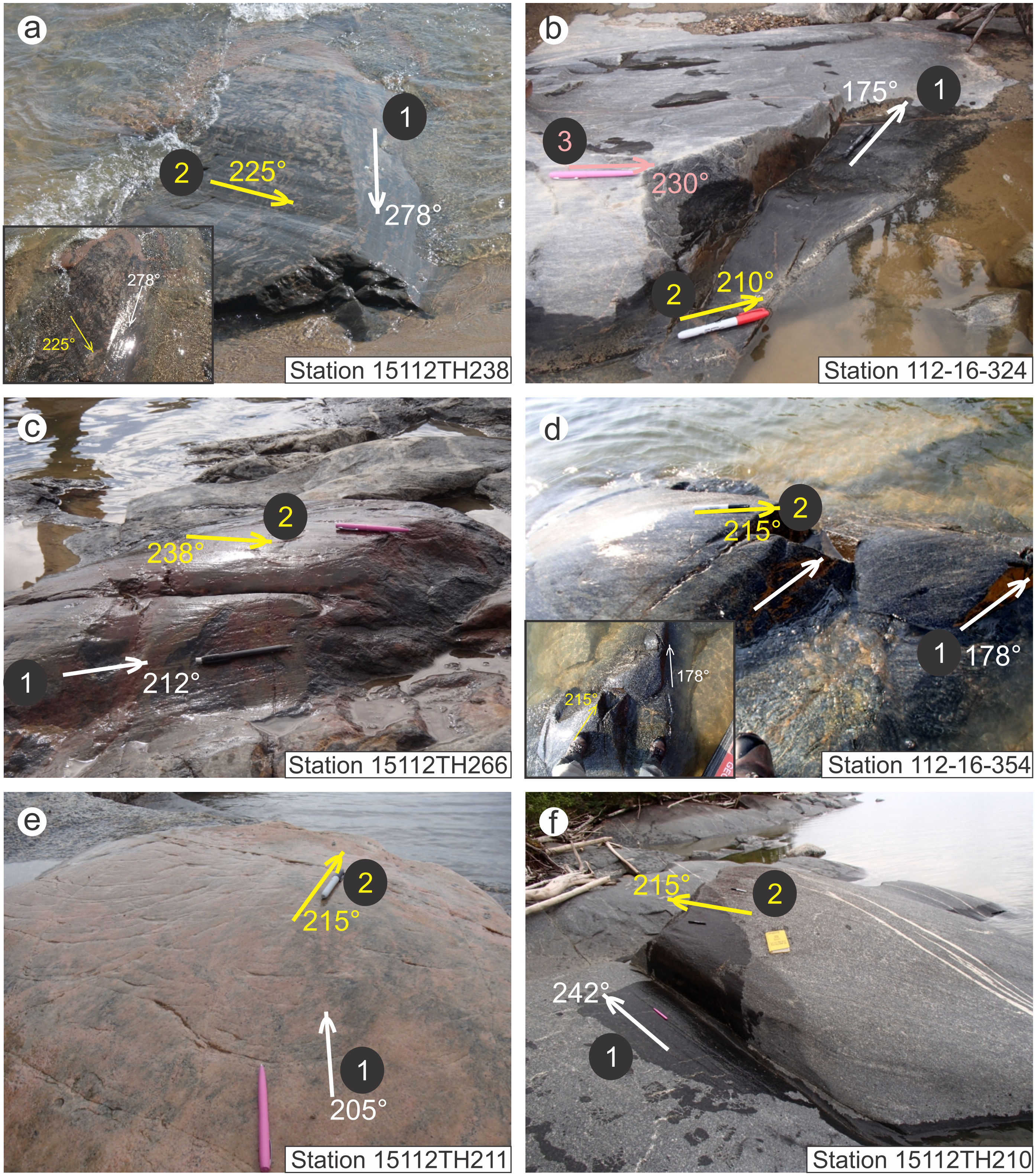

***Figure 7:** Example of ice-flow indicators and age-relationships observed in the SIL area: **a)** striae and grooves trending toward 278° are protected from later striations trending toward 225°; **b)** striations trending 175° are present on a facet protected from a later 210° ice flow. Striations on the top surface indicate an ice flow toward 230°, representing the last ice flow recorded at this station; **c)** grooves toward 212° are protected from a later ice flow toward 238°; plucked lee side of outcrop defines directional sense; **d)** protected facets are grooved and striated indicating paleo–ice flow toward 178°. The top surface of the outcrop is striated indicating ice-flow toward 215°; **e)** crescentic fractures indicate ice-flow toward 205° are cross-cut by striae indicating ice-flow toward 215°; plucked lee side of outcrop defines directional sense; **f)** protected facet is grooved indicating an earlier 242° ice-flow phase. Grooves indicating 215° ice-flow on top of the outcrop, representing the last ice flow recorded at this station; roches moutonnée morphology defines directional sense.*

Table 1: Detailed and simplified classes used for clast-lithology analysis. Simplified classes are bolded with detailed classes listed below.

Granitoid	**Undifferentiated greenstone**	**Paleozoic carbonate**	**East exotic**	**North exotic**
Granitoid, granodiorite	Undifferentiated greenstone and greywacke	Grey, tan, white carbonate	Omarolluk Formation	Red/purple volcanic (Dubawnt)
Gabbro	Quartz arenite	Pink carbonate	Chert	
Quartz	Quartzite		Unmetamorphosed sedimentary	
			Paleozoic fossil	
			Oolitic jasper (Kipalu)	

plasma–optical emission spectroscopy (ICP-OES). The proportion of calcite and dolomite were then calculated (wt. %).

Partial digestion till-matrix geochemistry

At SRC, an aliquot of the <63 µm size-fraction was digested in a two-acid (HNO_3:HCl) mixture. At Actlabs, an aliquot of the <63 µm size-fraction was digested in an aqua regia (1:3 HNO_3:HCl) mixture. Following digestion, samples were analyzed by inductively coupled plasma–mass spectrometry (ICP-MS) and by ICP-OES techniques for 41 and 63 elements at SRC and Actlabs, respectively. The two-acid ($HNO_{3:}$HCL) leach used at SRC is weaker than aqua regia (1:3 HNO_3:HCl) and, as such, elemental concentrations cannot be directly compared. The analytical results are presented in Appendix 9, together with summary statistics and analytical data for control reference standards, analytical and field duplicates, and blanks.

Near-total digestion till-matrix geochemistry

At SRC, an aliquot of the <63 µm size-fraction was digested in a three-acid (HF:HNO_3:$HClO_4$) mixture. At Actlabs, an aliquot of the <63 µm size-fraction was digested in a four-acid (HF:HNO_3:$HClO_4$:HCl) mixture. Following digestion, samples were analyzed by ICP-MS and ICP-OES techniques for 49 and 58 elements at SRC and Actlabs, respectively. The three-acid leach used at SRC is weaker than the four-acid leach at Actlabs and, as such, elemental concentrations cannot be directly compared. The analytical results are presented in Appendix 10, together with summary statistics and analytical data for control reference standards, analytical and field duplicates, and blanks.

INAA

For the determination of Au plus a 34-element suite, a 30 g aliquot of the <63 µm size-fraction for each sample was sent Actlabs. The aliquots underwent instrumental neutron activation analysis (INAA), which measures gamma radiation induced in the sample by irradiation with neutrons. This method was only used for the 2015 samples for comparison with previous studies conducted in the area (Lenton and Kaszycki, 2005, Trommelen, 2015) and analytical results are presented in Appendix 11.

Loss-on-ignition

Loss-on-ignition (LOI) gives an estimate of the total organic content, and can help to give a measure of the degree to which the sample geochemistry has been modified by post-depositional weathering. The LOI analysis was only conducted on 2015 samples and results included in Appendix 12. At SRC, an aliquot of till-matrix (<63 µm size-fraction) was weighed into the crucible and the total initial weight was recorded. The sample was placed in a muffle oven to dry at 1000°C. It was then removed from the oven, allowed to cool and reweighed. The detection limit for the LOI method is 0.1%.

Carbon and sulphur determination

To determine C and S, an aliquot of the till-matrix (<63 µm size-fraction) was combusted at SRC in a LECO induction furnace with an oxygen supply. Total C, organic C and S was only conducted on 2015 samples and results are included in Appendix 13. The percentage of organic carbon is determined from the percentage of inorganic carbon (in an aliquot of sample) using the LECO induction furnace with an argon supply. The detection limit for carbon, sulphur and organic carbon is 0.01%.

Fire assay for Au

Gold was analyzed by fire assay at the SRC for the 2015 samples. An aliquot of the <63 µm size fraction was mixed with their standard fire assay flux in a clay crucible and a silver inquart was added prior to fusion. After the mixture was fused, the melt was poured into a form, which was cooled. The lead bead was then recovered and cupelled until only the precious metals bead remained. The bead was then parted in dilute HNO_3. The precious metals were dissolved in aqua regia and then diluted for analysis by ICP-MS. The analytical results are presented in Appendix 14. The detection limit for Au was 2 pbb.

Radiocarbon dating

Two wood samples were collected for radiocarbon dating during the 2015 field season from section 15112TH204 (Appendix 15). Samples were first prepared using a gentle spray of tap water to remove loose adhering sediment by Paleotec Services (Ottawa, Ontario). Cleaned samples were then submitted to the University of California, Irvine, Keck Carbon Cycle Accelerator Mass Spectrometer (AMS) facility for radiocarbon dating. Radiocarbon sample photos and results are presented in Appendix 15.

Results

Ice-flow history

Ice-flow indicators were observed at 101 field stations in the SIL area. Detailed field observations documented the relative age-relationships present at each outcrop and these relationships are summarized in Figure 8. The relative ice-flow history of the region was produced based on these detailed observations and is presented in Figure 9. Additional maps depicting each ice-flow phase separately are presented in Appendix 3.

At least eight ice-flow phases are recorded in the study area. The earliest observed ice-flow event (Phase I) is southeast-trending (120–160°). These ice-flow indicators are relatively rare, but were observed in the north and central parts of SIL (Figure 8). It is noted that at SIL, south of Long Point, no old southeast ice-flow indicators were observed, but these older indicators were described at Gauer Lake (Figure 8; Trommelen, 2015). The second ice-flow event observed (Phase II) is west- to northwest-trending (260–300°). These ice-flow indicators are relatively rare compared to later ice-flow events, but were observed across the study area. Old southwest-trending (220–255°) ice-flow (Phase III) is recorded across the study area, but are rare compared to more recent ice-flow indicators, likely due to a poor preservation potential as result of erosion during subsequent ice-flow events with a similar trajectory or difficulty discerning the necessary age-relationships. Figure 7f provides an example of an observed age-relationship between old southwest (242°) ice-flow and later south-southwest ice-flow (215°).

The early ice-flow events (Phases I through III) are followed by south-trending (166–184°) ice-flow (Phase IV). A clockwise transition is then recorded in the ice-flow data throughout the study area as evidenced by progressively younger south-southwest trending (186–202°) ice-flow (Phase V), southwest-trending (202–223°) ice-flow (Phase VI) and southwest to west-southwest (216–255°) trending ice-flow (Phase VII). Southwest-trending ice-flow (Phases VI and VII) is the dominant erosional indicator at outcrops visited in the SIL area.

Phase VIII is interpreted as late-glacial southeast- and southwest-trending ice-flow events. Late-glacial southwest ice-flow in the northern area of SIL are likely related to the deglacial Quinn Lake ice stream. This interpretation is supported by till overlying sand at section 15112TH256 (Figure 27, Appendix 2), where a clast fabric suggests the till was deposited by south (185°) trending ice-flow. Trommelen (2015) observed compositionally distinct tills separated by glaciolacustrine sediments in the Gauer Lake to Wishart Lake area interpreted to be a result of deposition by the Quinn Lake ice stream.

Till composition

Till-matrix carbonate content

Determining the concentration of carbonate detritus present in local tills is important because there is no local limestone or dolomite source. Carbonate detritus are interpreted to have been transported at least 180–230 km from the Hudson Bay Basin, east of the study area and therefore can be used as an indication of the proportion of far-travelled detritus present in tills. The carbonate content of till can be evaluated from a till-matrix geochemistry or clast content perspective, and both are discussed within this report.

The majority (n=29/31) of samples have a till-matrix (<63 µm size-fraction) carbonate content ranging from 22.76–34.82 wt. %, suggesting a relatively consistent till-matrix carbonate content across the study area (Figure 10). One of the exceptions to this range is a value of 9.67 wt. % for sample 15112TH204A01, also with a low carbonate clast count (4.2 ct. % from the 2–30 mm size-fraction). This sample is from a diamict lens within a glaciofluvial sediment unit at section 15112TH204 (Figure 19, Appendix 2) and is not considered a basal till sample representative of the local till composition. Till-matrix carbonate content in the Gauer Lake to Wishart Lake area exhibits a much larger variation ranging from 0.36–41.56 wt. %, which is partially due to greater late-glacial overprinting from the Quinn Lake ice stream (Trommelen, 2015).

Clast-lithology composition

Clasts within till can assist interpreting the provenance of tills and distances of glacial transportation. Glacial dispersal can be mapped at varying scales, from continental (hundreds of kilometres) to regional (tens of kilometres) to local (less than 10 kilometres).

Carbonate clasts

Carbonate clast content within till ranges from 4.2–48.0 ct. %. Samples 15112TH218B01 (Figure 11a) and 15112TH232B01 are from the northwest area of SIL and have elevated carbonate clast content, relatively to the regional values (Figure 12).

Undifferentiated greenstone clasts

Undifferentiated greenstone clast content within till ranges from 3.4–21.8 ct. % (Figure 13). These clasts can be either locally sourced from supracrustal rocks within the study area (e.g. Pukatawakan Bay and/or Partridge Breast Lake assemblages; Figure 13), sourced from distal greenstone belts or from greywacke of the Omarolluk Formation of eastern Hudson Bay (Figure 3a). The latter are difficult to discern since the defining characteristic of Omar clasts (calcareous concretions; Figure 3d, e) is generally only recognizable in cobble- or boulder-sized clasts. The highest proportion of undifferentiated greenstone and greywacke clasts within till is from the same sample (15112TH218B01) with the highest carbonate clast content at SIL, suggesting that a significant proportion of these clasts are distally-sourced.

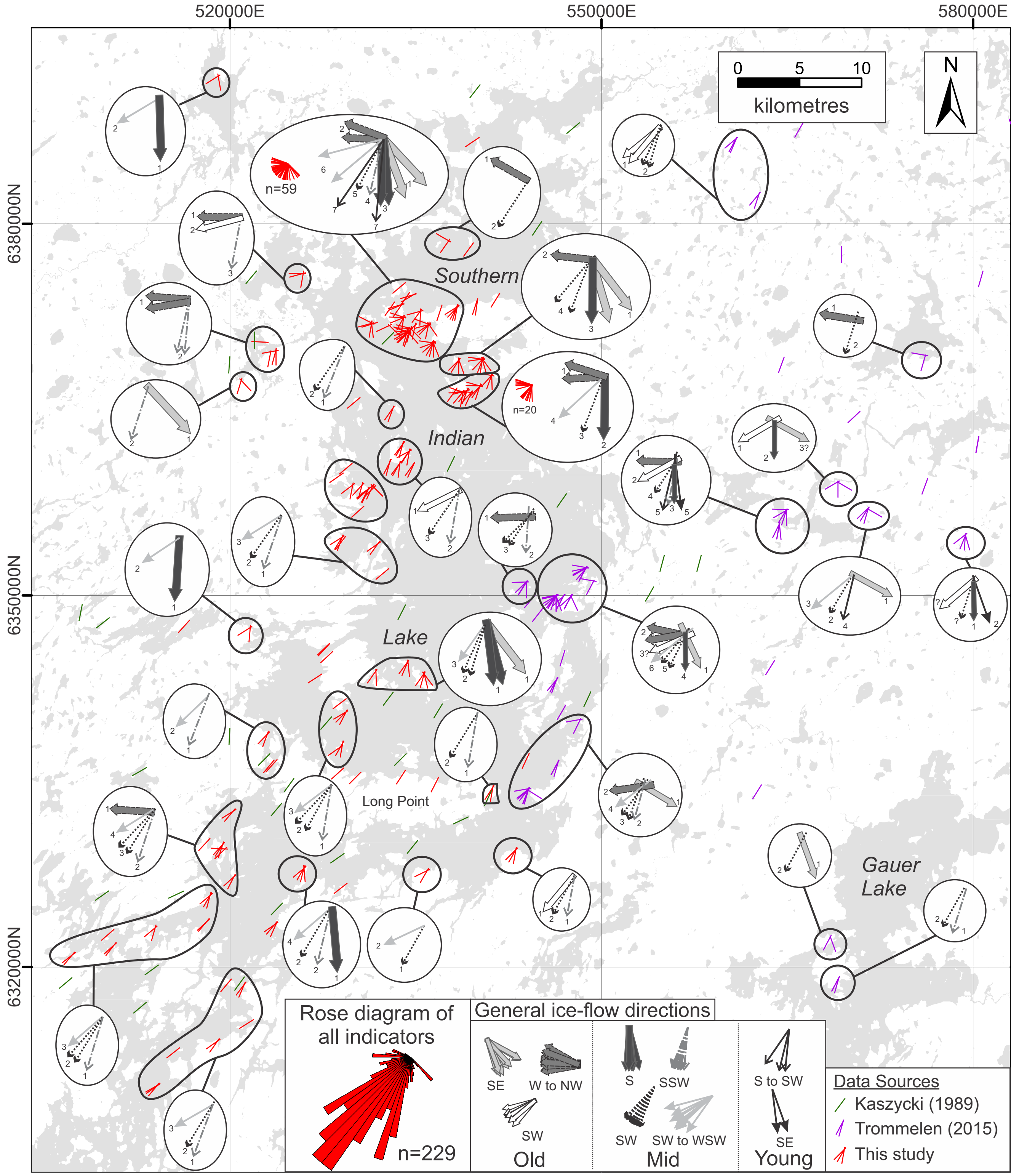

Figure 8: *Summary of the relative age-relationships identified from outcrop-based field observations in the SIL area.*

Distinctive erratics

In the study area, Omar erratics were observed at nearly all till-derived shorelines examined in detail, and are ubiquitous across the SIL area. Dubawnt erratics were observed at eight till-derived beaches and alongside Omar erratics at seven of the eight beaches across the SIL area. A single Kipalu clast was observed in the south-central area of the lake, on Long Point (Figure 14).

These observations, together with the regional carbonate content of till, indicate a significant input of detritus derived from the Hudson Bay region to the east. The presence of distinctive, far travelled, northern and eastern erratics throughout

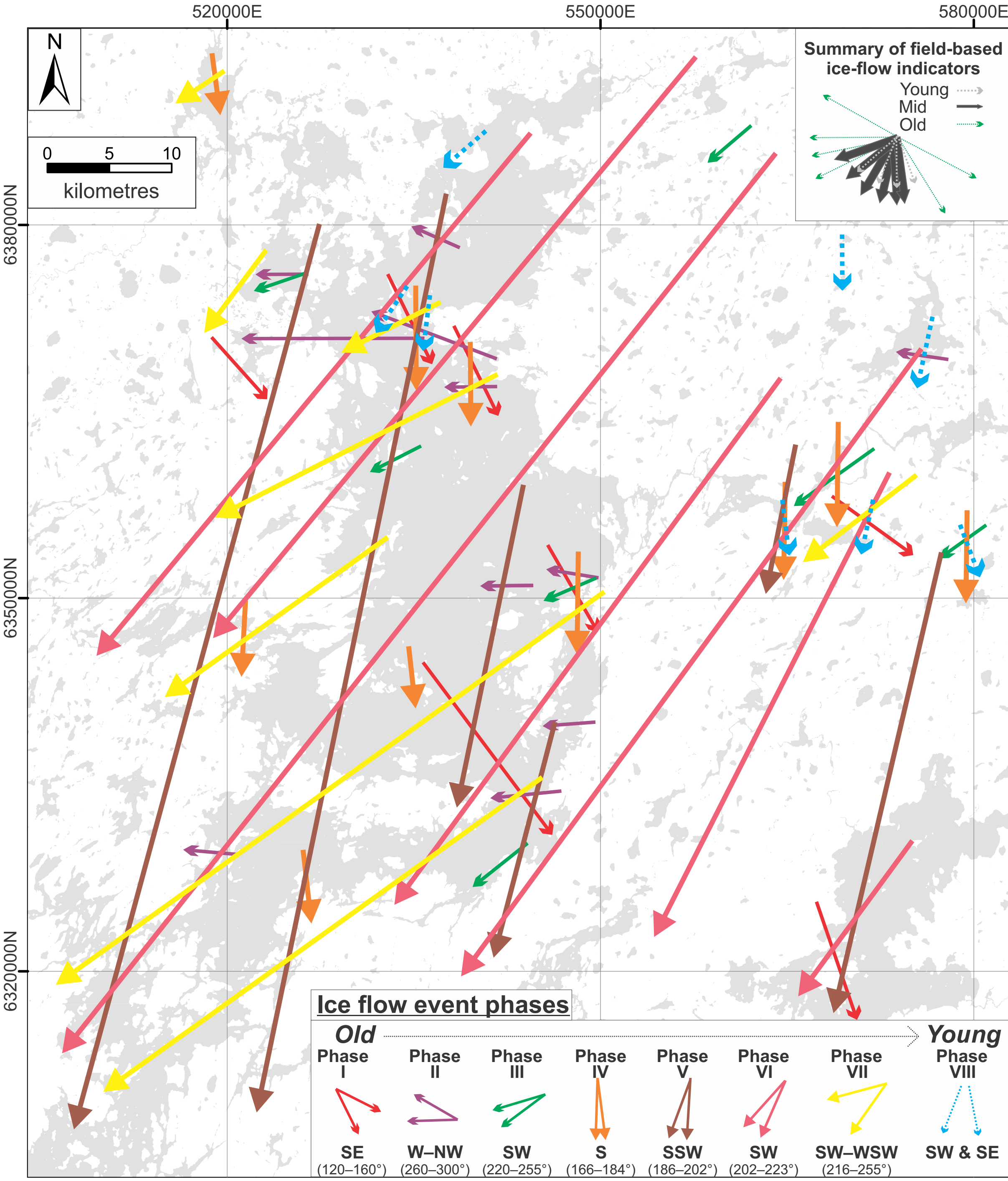

Figure 9: *Relative ice-flow history reconstruction in the SIL area.*

the SIL area, often at the same field station (Figure 15), is one example of the net effect that shifting ice-flow trajectory over time has on till composition.

Till-matrix geochemistry

Till-matrix geochemistry results presented in this report provide background till-matrix geochemistry values for the SIL area, which aid in determination of till provenance and drift prospecting exploration programs. Elements of economic interest, including Cu, Pb, Zn, Au and Ag, are not regionally elevated within this dataset; however, readers are encouraged to further explore available geochemistry datasets. Several elevated Ni values at SIL are highlighted below.

Elevated Ni values

Two till samples from the south region of SIL contain regionally elevated Ni concentrations (Figure 16). The highest value (50.7 ppm by partial-digestion ICP-MS analysis; sample 112-16-329-C1) is from till sampled overlying migmatitic garnet greywacke gneiss (Kremer et al., 2009a). The second

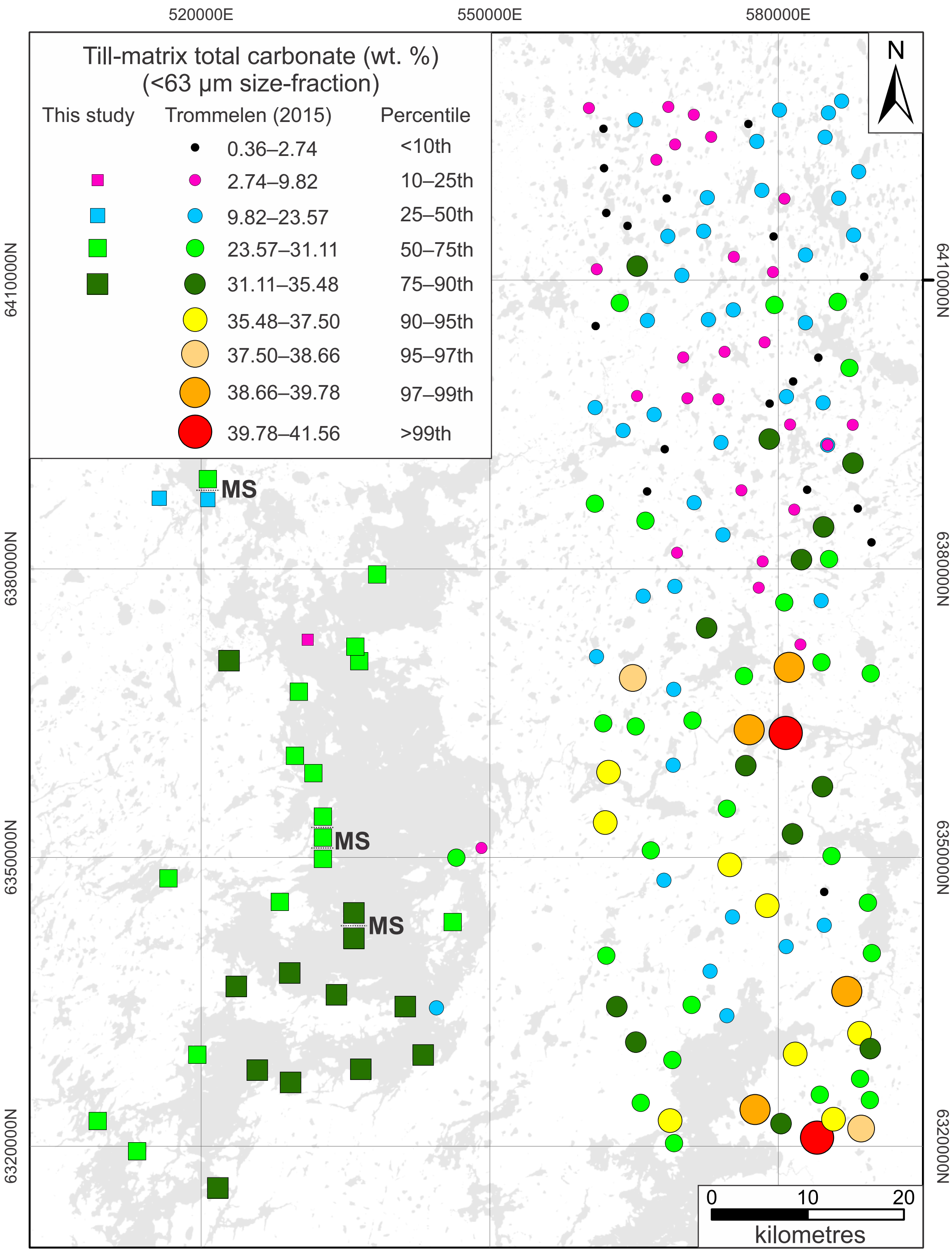

Figure 10: *Till-matrix (<63 µm size-fraction) carbonate content. Sections with multiple samples are displayed as stacked symbols. Abbreviations: MS, multi-sample site.*

elevated value (43.5 ppm by partial-digestion ICP-MS analysis; sample 112-16-317-B1) is from till sampled overlying basalt of the Pukatawakan Bay assemblage (Kremer, 2008a).

Kimberlite-indicator minerals

A total of 106 KIM grains, ranging from 1–13 per sample, were recovered from nineteen till samples in the SIL area (Hodder, 2017). Carbonate clast concentration within till KIM samples ranges from 12.2–35.7 ct. %. There is no apparent correlation with carbonate clast content and KIM concentrations (Figure 17). For instance, till with similar concentrations of carbonate clast content, 30.4 and 31.6 ct. %, contain 1 and 11 KIMs, respectively. This suggests that not all of the KIMs are far-travelled and derived from the Hudson Bay Basin. The minimal KIM recovery from till sampled in the Hearne Province of the Archean-Rae craton to the north (260 to 325 km north of this study; Böhm et al., 2008), indicates a significantly higher diamond potential in the SIL area. The reconnaissance-scale

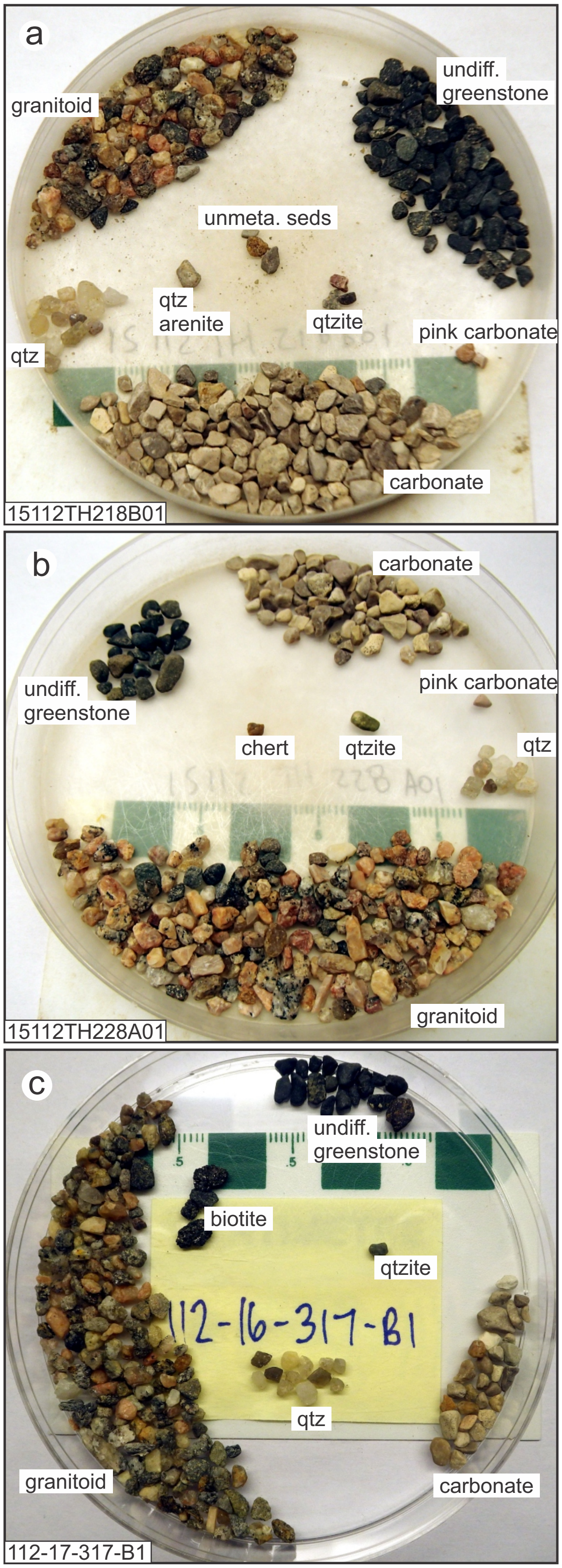

***Figure 11:** Examples of sorted 2–4 mm size-fraction lithologies from till samples in the SIL area: **a)** regionally elevated carbonate-rich till (48.0 ct. %); **b)** typical granitoid-rich (63.8 ct. %) hybrid till; **c)** typical granitoid-rich (80.8 ct. %) till. Abbreviations: qtz, quartz; qtzite, quartzite; undiff., undifferentiated; unmeta, unmetamorphosed.*

design of this survey (1–2 samples per 100 km^2) inhibits the delineation of any dispersal trains and follow-up work is recommend to tighten the sampling grid in the SIL area.

Radiocarbon dating

Two radiocarbon samples from section 15112TH204 (Appendix 2, Figure 19) returned infinite radiocarbon ages (>54 700 ^{14}C BP). The purpose of age-dating these wood fragments was to potentially obtain an age for a late-glacial event of the LIS. Although this objective was not accomplished, these dates do provide evidence for the presence of old organic-bearing material within the SIL study area.

Discussion

Relationships between ice-flow record and till-composition

North-central and north-east Manitoba has experienced a complex ice-flow history (Campbell et al., 2012; Trommelen, 2013a; Trommelen, 2013b, 2014) and this is well documented in the SIL area where at least 9 ice-flow events were observed. The most recent ice-flow events leave a dominant imprint on the geomorphic record, but earlier ice-flow events have an important influence on the till-composition in this region of Manitoba and have been suggested to be an important contribution to the carbonate content of till (McMartin et al., 2016).

In the SIL area, the importance of relatively early ice-flow events, and their influence on net till composition is demonstrated at section 15112TH218 (Figure 18). For example, sample 15112TH218B01 had the highest carbonate clast content (48.0 ct. %) within the study area and is regionally elevated (>98th percentile) when compared to the Gauer Lake to Wishart Lake area (Trommelen, 2015). Furthermore, till sampled at this station is in contact with striated bedrock indicating west-trending (273°) ice-flow, with no other ice-flow indicators observed (Figure 18). The high carbonate content, along with the local bedrock ice-flow indicator, suggests this till has a Hudson Bay Basin provenance and was deposited during west-trending (273°) ice-flow. Considering this ice-flow phase was followed by at least 6 ice-flow phases (Figure 9), this suggests that station 15112TH218 is an example of a region with high inheritance, that experienced limited reworking during latter ice-flow phases (e.g., Trommelen et al., 2013).

Section 15112TH218 demonstrates the intimate relationship between bedrock ice-flow indicators and till-composition, and the importance of documenting the till-composition to gain valuable insight into till provenance. These observations and interpretations result in a significant impact on the application of drift prospecting. For example, at this section the up-ice source for any elevated signature of economic interest in till would likely be to the east and not the northeast, as suggested by the regional dominant ice-flow.

Exotic erratics

The widespread presence of Omar erratics in the SIL area indicates significant input of detritus as a result of west-trending ice-flow (Figure 3a). Ice-flow phases succeeding this early west-trending ice-flow would have re-worked material derived from Hudson Bay Basin to some degree, while incorporating new detritus.

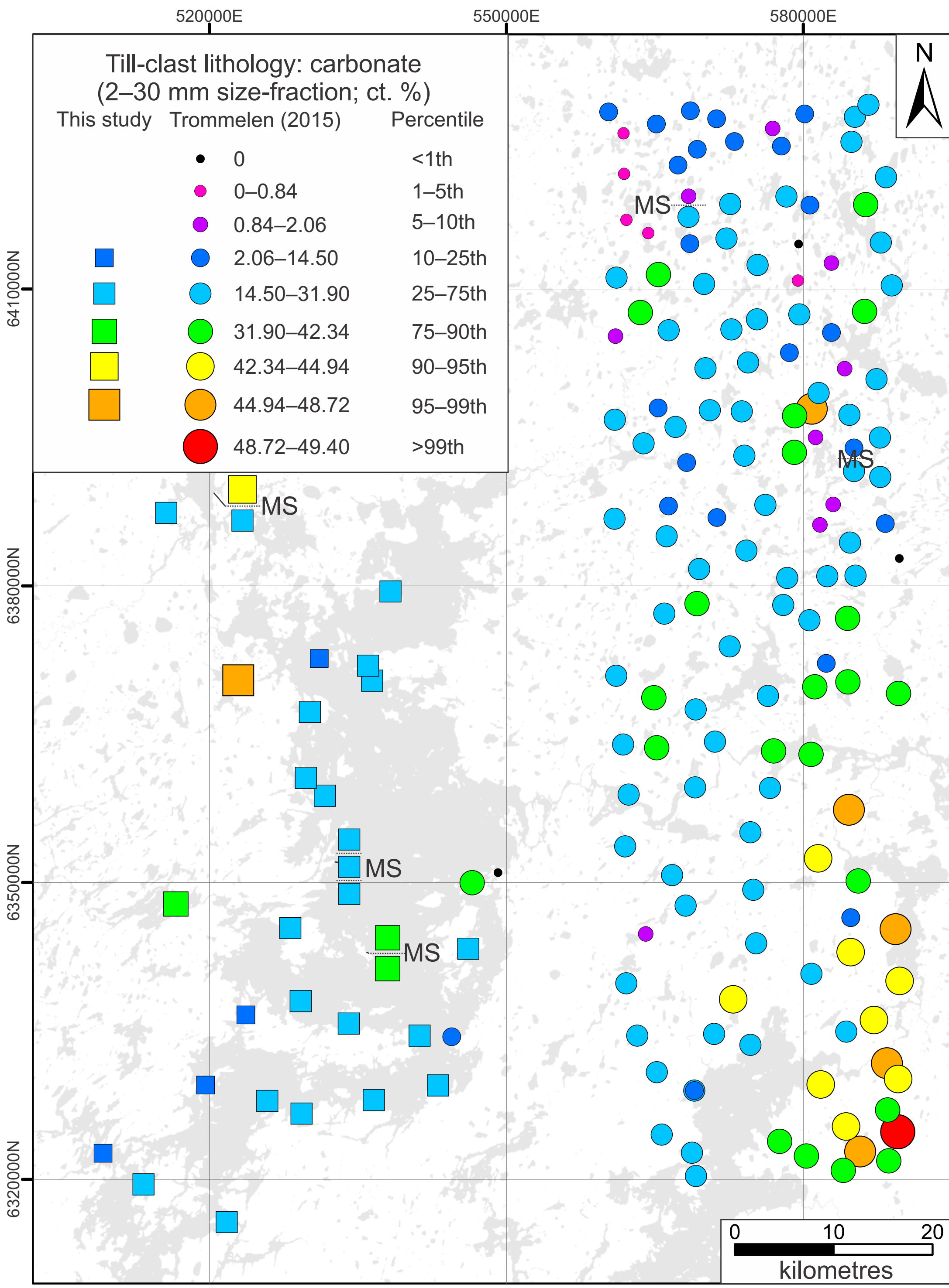

Figure 12: *Distribution of carbonate clasts in the SIL area. Sections with multiple samples are displayed as stacked symbols. Abbreviations: MS, multi-sample site.*

The resultant till could be then considered a hybrid till as suggested by Trommelen et al. (2013). Additionally, the presence of Dubawnt erratics in the study area, attests to south- or southeast-trending glacial dispersal, which is supported by the ice-flow record. The presence of Dubawnt and Omar erratics at seven field stations (which have spatially distinct provenances, c.f. Figure 3a) is the clearest, simplest example that till in the SIL study area are hybrid tills, which compositionally reflect varying degrees of overprinting and inheritance over the glacial history of the area.

Recommendations for future exploration

Reconnaissance-scale KIM sampling in the SIL area has suggested the presence of kimberlite detritus (Hodder, 2017). Those results add to data from others authors that have been

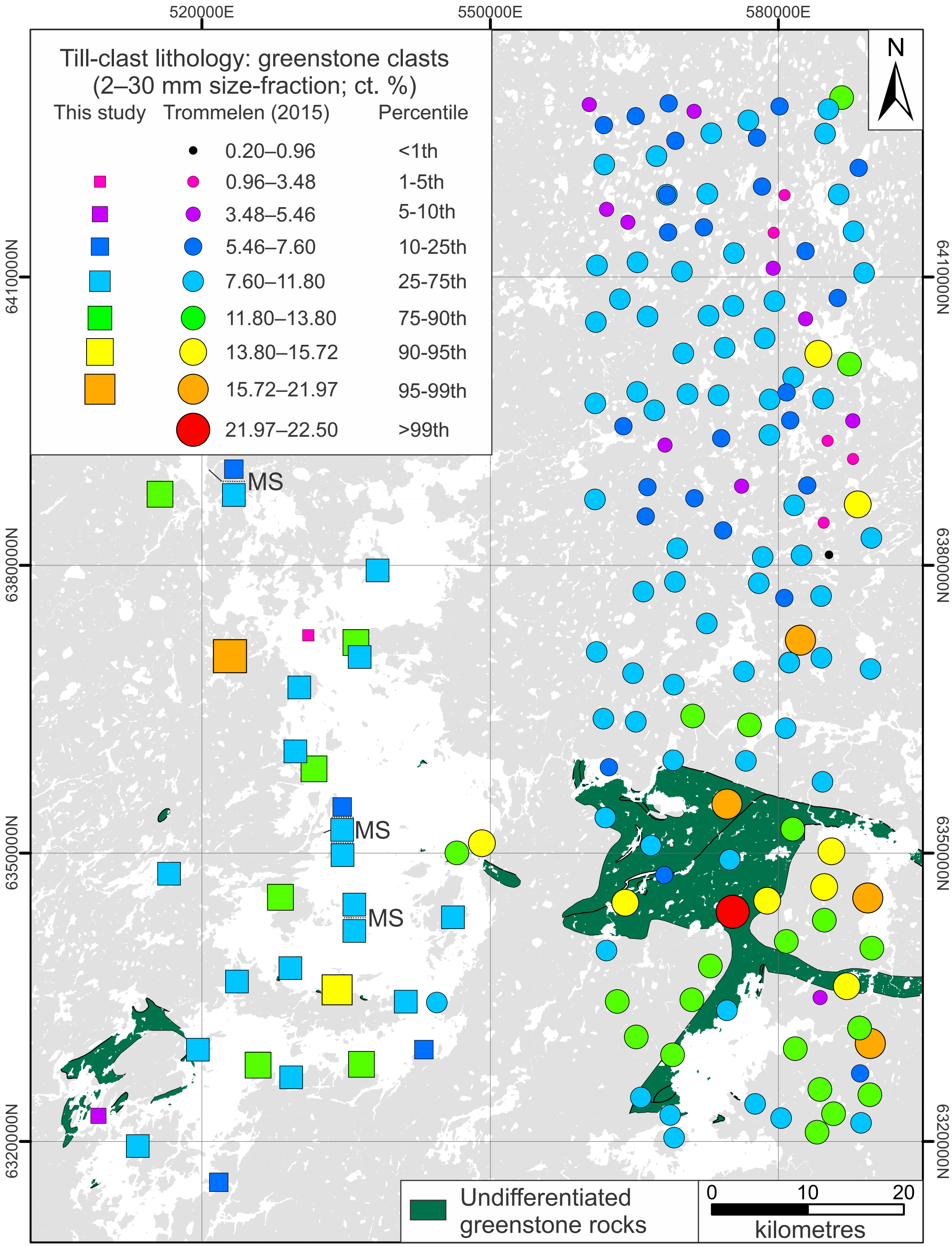

Figure 13: *Distribution of undifferentiated greenstone clasts in the SIL area. Sections with multiple samples are displayed as stacked symbols. Abbreviations: MS, multi-sample site.*

suggesting diamond potential in this area based on regional mapping and geochronological studies (e.g., Corrigan et al., 2007; Kremer et al. 2009b). Based on this, it is recommended that additional till KIM sampling is carried out to tighten the regional-scale sampling grid and generate favourable exploration targets. Boat-assisted work allows for easy access to till deposits located beneath glaciolacustrine sediment cover. Areas in the south and west-central part of the study area where till and bedrock are mapped at surface are also recommended regions to easily conduct follow-up sampling.

As a comparison, the Pikoo project, located approximately 380 km southwest of SIL, is the closest known kimberlite occurrences to this study. Armstrong and Kupsch (2016) recently presented indicator-mineral results associated with these kimberlite occurrences, which allows for an estimation of glacial dispersal distances from source, an important parameter to consider for any drift prospecting survey. Preliminary data from the Pikoo project indicates recognizable indicator-mineral dispersal trains of 2–8 km. Another important observation is that samples down-ice from the kimberlite source are not all

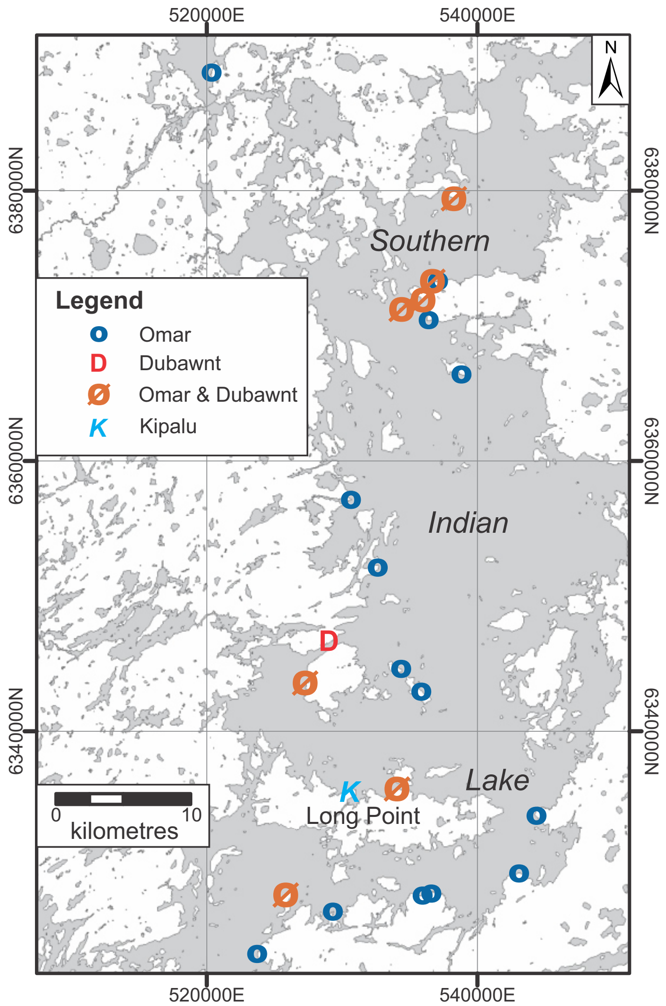

***Figure 14:** Distribution of distinctive exotic erratics identified at till-derived beaches in the SIL area.*

elevated in indicator-minerals and there is a heterogeneous dispersal pattern. These observations can provide a rough guideline of what to anticipate when conducting drift prospecting in the SIL area.

Regionally elevated Ni values were returned from two till samples in the south region of the SIL area. The potential for magmatic Ni-Cu-platinum-group element deposits in the SIL area has been noted by Kremer et al. (2009b) based on bedrock mapping near Turtle Island on the east-central shore of SIL. Additional till sampling at a tighter grid spacing near these anomalies could elucidate the potential for this type of deposit and assist with generating exploration targets in the SIL area.

The dominant ice-flow direction in the SIL area is towards the southwest (210–244°) and likely is the dominant dispersal trend of glacial detritus. The complex ice-flow history of the area dictates that earlier ice-flow phases—south-, west-, northwest- and southeast-trending ice-flow phases—cannot be ignored and that the potential for complex palimpsest dispersal trains is a real possibility. This study clearly demonstrated that earlier ice-flow events have influenced the till composition in some areas of SIL, and in some cases (e.g., 15112TH218) have experienced little modification by subsequent ice-flow events resulting in an inherited till composition. All of these aspects have to be taken into account for a successful drift prospecting program in the SIL area.

Acknowledgments

T. Martins is thanked for use of her remote camp on Southern Indian Lake during the 2015 and 2016 field seasons, as well as thoughtful discussion and advice throughout this study. De Beers Group of Companies are thanked for their continued analytical support for Quaternary studies at the MGS. A. Schmall and D. Shaw from the University of Manitoba, M. Klapheke and C. Norris-Julseth from Brandon University are thanked for field assistance throughout the project. A. Schmall is also thanked

***Figure 15:** Distinctive exotic erratics present at station 15112TH256. Abbreviations: O, Omarolluk Formation erratic; D, Dubawnt Supergroup erratic. Yellow field book is 19.0 cm in length.*

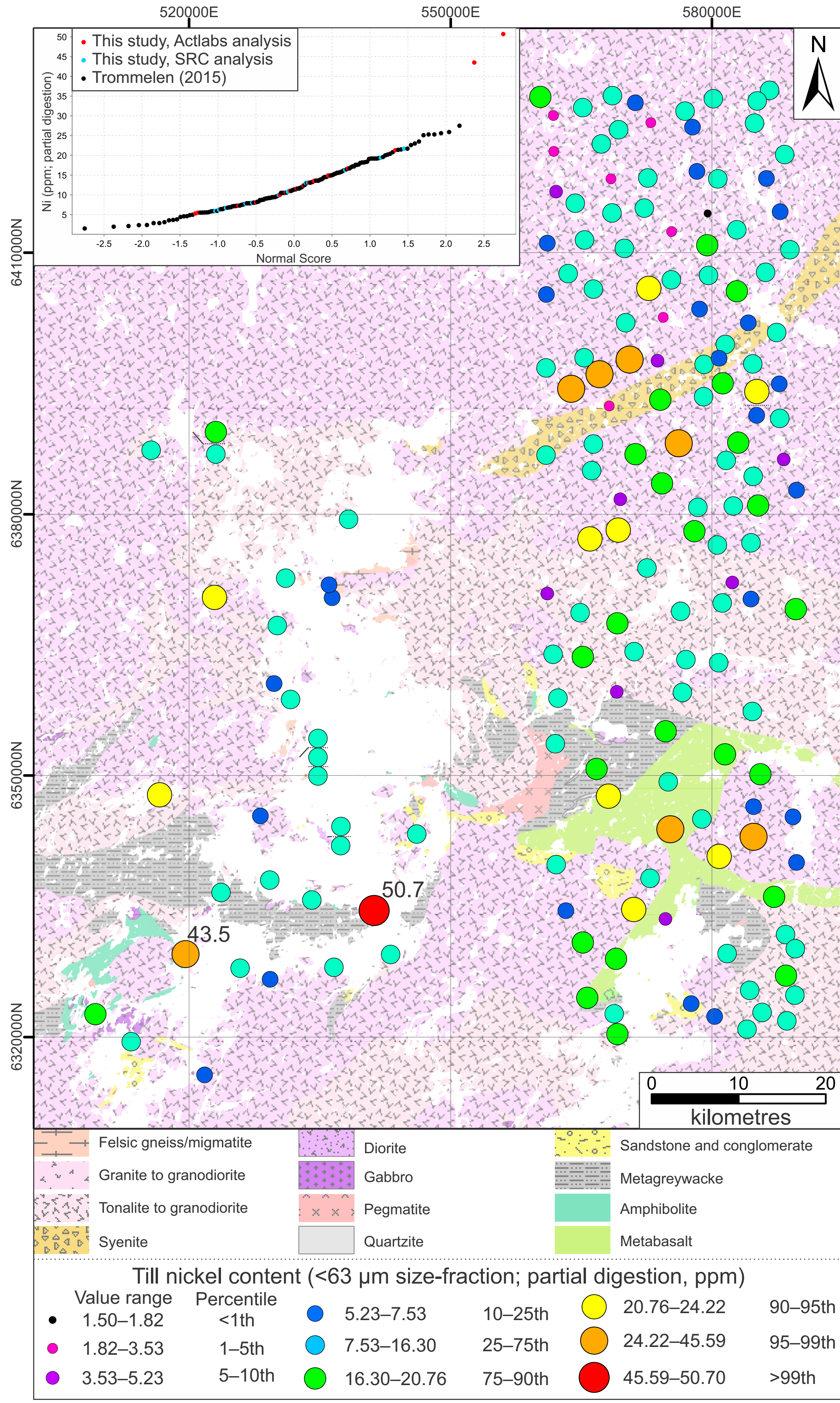

***Figure 16:** Nickel values for till samples in the SIL (this study) and Gauer Lake to Wishart Lake study area (Trommelen, 2015).*

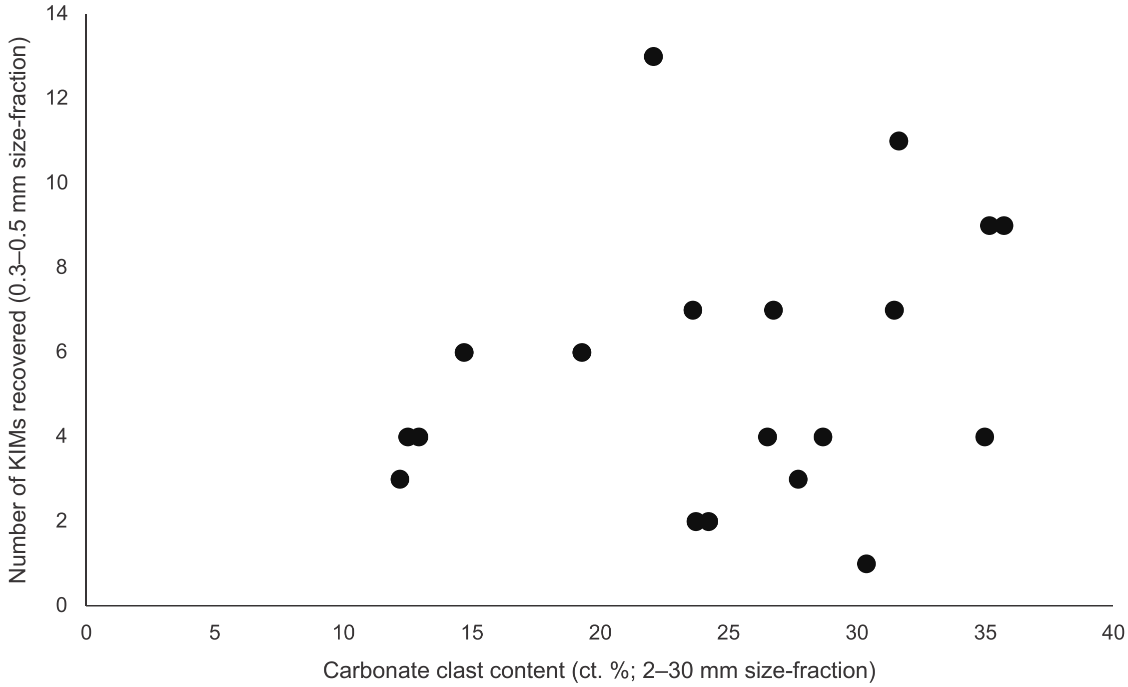

Figure 17: *KIM concentration (0.3–0.5 mm size-fraction) plotted against till carbonate clast content (2–30 mm size-fraction) for 19 till samples in the SIL area.*

for assisting with 2016 clast lithology counts. N. Brandson, E. Anderson, C. Epp, G. Benger and V. Varga are thanked for logistical and sample processing assistance. Wings over Kississing provided air support during this study. M. Gauthier is thanked for her advice and assistance provided throughout this study. T. Martins, M. Nicolas and C. Beaumont-Smith are thanked for their review of this open file report.

References

Armstrong, K. and Kupsch, B. 2016: Pikoo diamond project – 2016 exploration update; Saskatchewan Geological Survey, Saskatchewan Ministry of the Economy, Open House 2016, Saskatoon, Saskatchewan, November 28–30, 2016, PowerPoint® presentation, 20 p.

Benn, D.I. 1994: Fabric shape and the interpretation of sedimentary fabric data; Journal of Sedimentary Research, v. A64, no. 4, p. 910–915.

Böhm, C.O., Anderson, S.D., Matile, G.L.D. and Keller, G.R. 2008: Geochemical and kimberlite-indicator-mineral results for till samples from the Nejanilini, Kasmere and Putahow lakes areas, northern Manitoba (NTS 64N, 64O, 64P); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Open File OF2008-13, 10 p.

Campbell, J.E., Trommelen, M.S., McCurdy, M.W., Böhm, C.O. and Ross, M. 2012: Till composition and ice-flow indicator data, Great Island–Caribou Lake area (parts of NTS 54L, 54M, 64I, and 64P), northeast Manitoba; Geological Survey of Canada, Open File 6967, Manitoba Geological Survey, Open File OF2011-4, 26 p.

Corrigan, D., Galley, A.G. and Pehrsson, S. 2007: Tectonic evolution and metallogeny of the southwestern Trans-Hudson Orogen; in Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods, W.D. Goodfellow (ed.), Geological Association of Canada, Mineral Deposits Division, Special Publication 5, p. 881–902.

Dredge, L.A. and McMartin, I. 2011: Glacial stratigraphy of northern and central Manitoba; Geological Survey of Canada, Bulletin 600, 27 p.

Hicock, S.R., Goff, J.R., Lian, O.B. and Little, E.C. 1996: On the interpretation of subglacial till fabric; Journal of Sedimentary Research, v. 66, no. 5, p. 928–934.

Hodder, T.J. 2016: Till sampling and ice-flow mapping in the central area of Southern Indian Lake, north-central Manitoba (parts of NTS 64G1, 2, 7–10, 64B15); *in* Report of Activities 2016, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 196–202.

Hodder, T.J. 2017: Kimberlite-indicator-mineral results derived from glacial sediments (till) in the Southern Indian Lake area of north-central Manitoba (parts of NTS 64B15, 64G1, 2, 7, 8); Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, Open File OF2017-2, 6 p.

Jackson, G.D. 2013: Geology, Belcher Islands, Nunavut; Geological Survey of Canada, Open File 4923, 159 p.

Kaszycki, C.A. 1989: Surficial geology and till composition, northwestern Manitoba; Geological Survey of Canada, Open File 2118, 50 p.

Kaszycki, C.A., Dredge, L.A. and Groom, H. 2008: Surficial geology and glacial history, Lynn Lake - Leaf Rapids area, Manitoba; Geological Survey of Canada, Open File 5873, 105 p.

Kaszycki, C.A. and Way Nee, V.J. 1990a: Surficial geology, Brochet, Manitoba; Geological Survey of Canada, Map 1760A, scale 1:250 000.

Kaszycki, C.A. and Way Nee, V.J. 1990b: Surficial geology, Granville Lake, Manitoba; Geological Survey of Canada, Map 1759A, scale 1:250 000.

Kremer, P.D. 2008a: Bedrock geology of the Pukatawakan Bay area, Southern Indian Lake, Manitoba (part of NTS 64G2); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Preliminary Map PMAP2008-3, scale 1:25 000.

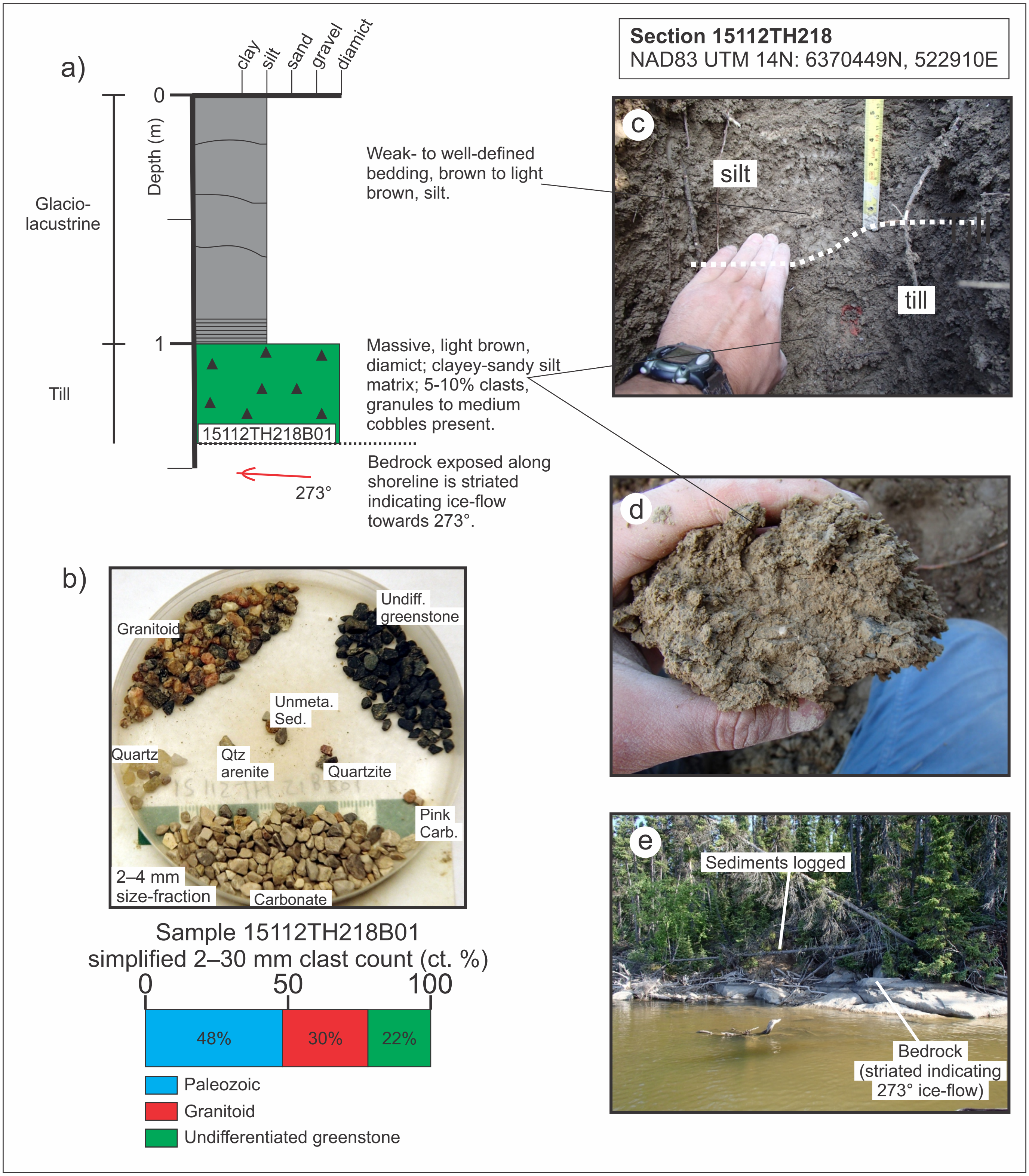

Figure 18: *Quaternary sediments and till composition at section 15112TH218:* ***a)*** *stratigraphic log of section 15112TH218. Till sample number and location is portrayed by the white box;* ***b)*** *results from the 2–4 mm size-fraction clast lithology count for sample 15112TH218B01;* ***c)*** *view of the contact between the silt and till;* ***d)*** *close-up photo of till exposed at section 15112TH218;* ***e)*** *lake view of the exposed Quaternary sediments exhibiting the relationship between sediments and bedrock ice-flow indicator.*

Kremer, P.D. 2008b: Geological investigations of the Pukatawakan Bay belt, Southern Indian Lake, Manitoba (part of NTS 64G2); *in* Report of Activities 2008, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 87–98.

Kremer, P.D., Corkery, M.T. and Lenton, P.G. 2009a: Bedrock geology of the Partridge Breast Lake belt, Manitoba (parts of NTS 64G1, 2, 8, 64H4, 5); Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Preliminary Map PMAP2009-2, scale 1:50 000.

Kremer, P.D. and Martins, T. 2014: Geology of the Northern Indian Lake area, Manitoba (parts of NTS 64H3, 5, 6); Manitoba Mineral Resources, Manitoba Geological Survey, Preliminary Map PMAP2014-6, scale 1:50 000.

Kremer, P.D., Rayner, N. and Corkery, M.T. 2009b: New results from geological mapping in the west-central and northeastern portions of Southern Indian Lake, Manitoba (parts of NTS 64G1, 2, 8, 64H4, 5); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 94–107.

Lenton, P.G. and Kaszycki, C.A. 2005: Till geochemistry in northwestern Manitoba (NTS 63N, 64B, 64F and 64G and parts of 63K, 63O, 64A and 64C); Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, Open File Report OF2005-2, 1 CD-ROM.

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

Martins, T. 2015a: Bedrock geology of the northern basin of Southern Indian Lake, north-central Manitoba (parts of NTS 64G7, 8, 9, 10); Manitoba Mineral Resources, Manitoba Geological Survey, Preliminary Map PMAP2015-4, scale 1:50 000.

Martins, T. 2015b: Geological mapping in the northern basin of Southern Indian Lake, north-central Manitoba (parts of NTS 64G7, 8, 9, 10); *in* Report of Activities 2015, Manitoba Mineral Resources, Manitoba Geological Survey, p. 79–88.

Martins, T. 2016a: Bedrock geology of central Southern Indian Lake, Manitoba (parts of NTS 64G1, 2, 7, 8); Manitoba Growth, Enterprise and Trade, Preliminary Map PMAP2016-6, scale 1:50 000.

Martins, T. 2016b: Geological investigations at central Southern Indian Lake, north-central Manitoba (parts of NTS 64G1, 2, 7, 8); *in* Report of Activities 2016, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 126–134.

Matile, G.L.D. and Keller, G.R. 2006a: Surficial geology of the Big Sand Lake Lake map sheet (NTS 64G), Manitoba; Manitoba Science, Technology Energy and Mines. Manitoba Geological Survey, Surficial Geology Compilation Map Series, SG-64G, scale 1:250 000.

Matile, G.L.D. and Keller, G.R. 2006b: Surficial geology of the Uhlman Lake Lake map sheet (NTS 64B), Manitoba; Manitoba Science, Technology Energy and Mines, Manitoba Geological Survey, Surficial Geology Compilation Map Series, SG-64B, scale 1:250 000.

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, R.C. Paulen and I. McMartin (ed.), Geological Association of Canada, GAC Short Course Notes 18, p. 15–34.

McMartin, I., Campbell, J.E., Dredge, L.A. and Robertson, L. 2010: A digital compilation of ice-flow indicators for central Manitoba and Saskatchewan: datasets, digital scalable maps and 1:500 000 scale generalized map; Geological Survey of Canada, Open File 6405, 1 DVD.

McMartin, I., Dredge, L.A., Grunksy, E. and Pehrsson, S.J. 2016: Till geochemistry in west-central Manitoba: interpretation of provenance and mineralization based on glacial history and multivariate data analysis; Economic Geology, v. 111, p. 1001–1020.

Munsell Color–X-Rite, Incorporated 2015: Munsell Soil Color Book; Pantone LLC, Carlstadt, New Jersey, 42 p.

Natural Resources Canada 2015: Canadian digital surface model; Natural Resources Canada, URL <http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/34f13db8-434b-4a37-ae38-03643433fbbb.html> [September 2015].

Prest, V.K., Donaldson, J.A. and Mooers, H.D. 2000: The Omar story: the role of Omars in assessing glacial history of west-central North America; Géographie physique et Quaternaire, v. 54, no. 3, p. 257–270.

Rainbird, R.H., Hadlari, T., Aspler, L.B., Donaldson, J.A., LeCheminant, A.N. and Peterson, T.D. 2003. Sequence stratigraphy and evolution of the Paleoproterozoic intracontinental Baker Lake and Thelon basins, western Churchill Province, Nunavut, Canada; Precambrian Research v. 125, p. 21–53.

Sladen, W.E. 2011: Permafrost; Geological Survey of Canada, Open File 6724.

Stott, G.M., Buse, S., Davis, D.W. and Hamilton, M.A. 2010: The Sutton inliers – a Paleoproterozoic succession in the Hudson Bay Lowland; *in* Summary of Fieldwork and Other Activities 2010, Ontario Geological Survey, Open File Report 6260, p. 19-1–19-14.

Trommelen, M.S. 2013a: Field-based ice-flow indicator data, Gauer Lake–Wishart Lake area, north-central Manitoba (NTS 64H4, 5, 12, 13, parts of 64G1, 8); Manitoba Mineral Resources, Manitoba Geological Survey, Data Repository Item DRI2013003, Microsoft Excel® file.

Trommelen, M.S. 2013b: Field-based ice-flow indicator data, Gillam to Split Lake, north-central Manitoba (NTS 54D, 64A); Manitoba Mineral Resources, Manitoba Geological Survey, Data Repository Item DRI2013005, Microsoft Excel® file.

Trommelen, M.S. 2014: Field-based ice-flow indicator data, Gillam to Gull Lake, north-central Manitoba (NTS 54D5, 6, 7); Manitoba Mineral Resources, Manitoba Geological Survey, Data Repository Item DRI2014003, Microsoft® Excel® file.

Trommelen, M.S. 2015: Till composition and glacial history, Gauer Lake – Wishart Lake, Manitoba (NTS 64H4, 5, 12, 13); Manitoba Mineral Resources, Manitoba Geological Survey, Geoscientific Paper GP2014-1, 32 p. plus 14 appendices.

Trommelen, M.S., Ross, M. and Campbell, J.E. 2013: Inherited clast dispersal patterns: implications for paleoglaciology of the southeast Keewatin Sector of the Laurentide Ice Sheet; Boreas, v. 42, no. 3, p. 693–713.