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Permanent link: https://doi.org/10.4095/332531

Recommended citation

Brouard, E., Campbell, J.E., Godbout, P.-M., Renaud, N.-M., McMartin, I., Roy, M., Kelley, S.E., and Crowell, C., 2024. Report of 2023 field activities for the GEM-GeoNorth West-central Keewatin Glacial Dynamics activity, Nunavut; Geological Survey of Canada, Open File 9159, 1 zip file. https://doi.org/10.4095/332531

ISSN 2816-7155
ISBN 978-0-660-69673-7
Catalogue No. M183-2/9159E-PDF

Report of activities for the 2023 field season of the West-central Keewatin Glacial Dynamics Activity

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Abstract

The landscapes we see today in northern Canada are the results of the dynamics of former continental glaciations of the Quaternary. As the environment evolved with the cyclic growth and decay of ice sheets, it is paramount to understand the history of these glacial cycles to provide a robust framework for geological and environmental studies. Much is known about these glaciations in southern Canada, but in northern Canada, extensive regions remain poorly studied because of their remoteness and hence knowledge of past glaciations there remains somewhat limited. West-central Keewatin, for example, critically lacks field data on glacial geology in many sectors. Hence, as part of the GEM-GeoNorth West-central Keewatin Glacial Activity, field investigations on the glacial geology around Lake Dubawnt in mainland Nunavut were undertaken in 2023. Here, we detail the field methodology used to compile geospatial information and measurements of ice-flow indicators, and to collect till, bedrock, boulder and sediment samples for terrestrial cosmogenic nuclide and luminescence dating. A total of 111 ground observation sites were visited, including the collection of 108 ice-flow measurements and 93 samples. Preliminary interpretations of the relative chronology and spatial relationship of ice-flow indicators suggest that several distinct major ice-flow phases have impacted the region. These interpretations will be complemented with the upcoming results from till compositional data and geochronological analyses. The new field datasets will be used along with remote geomorphological mapping to improve the regional glacial history and enhance success of land-resource based decisions in this part of northern Canada.

Introduction

Paleogeographic reconstructions of the Laurentide Ice Sheet (LIS) provide an essential framework to a wide range of studies including glaciological and glacial isostatic adjustment modeling, sea-level changes, and mineral exploration. Most of the information documenting the evolution of the LIS comes from the study of the depositional and geomorphological records preserved in the present-day landscape that allow former ice extents and dynamics to be reconstructed. However, the vast expanses of northern Canada that hosted all three major dispersal centers (domes) of the LIS remain understudied and significant knowledge gaps remain due to the difficulty of access these regions to collect data and to make field observations. Recent work at the centre of the Keewatin Sector (Keewatin Dome) of the LIS, located in mainland Nunavut and Northwest Territories (fig. 1), has suggested the presence of complex glacial landsystems resulting from migration of ice centres/divides, ice streaming, and old landscape preservation over multiple glacial cycles (McMartin & Henderson, 2004; Campbell et al., 2019, 2020, 2021; McMartin et al., 2021). Broad deglacial reconstructions also suggest that the western half of the Keewatin region deglaciated first, with a delayed deglaciation of the eastern part towards the Keewatin Ice Divide, causing the retreating ice margin to dam drainage networks towards Hudson Bay or Queen Maud Gulf (Bird, 1953; Craig, 1964; Prest et al., 1968; Dyke & Prest, 1987; Stokes & Clark, 2004) and resulting in the development of several glacial lakes (e.g., glacial lakes Thelon, Dubawnt and Kazan; fig. 2). Yet, the landsystems (landforms and sediments making up surficial terrains) associated with the evolution of ice-flow organization and the glaciolacustrine bodies remain mostly unmapped and undated. As a result, they are not correlated at the regional scale, which hampers our understanding of ice-flow histories, landscape evolution, and sediment dispersal which ultimately complicates drift prospecting. Despite recent updates to the continental-scale deglacial chronology (Dalton et al., 2020, 2023), the ice-margin chronology and patterns of ice retreat remain poorly defined in these remote northern areas as they rely on approximate and limited geochronological data (only two radiocarbon ages on basal peat and charcoal exist in the field study area).

To address this deficiency in regional geoscience context regarding the LIS glacial history, the West-central Keewatin Glacial Dynamics Activity was initiated in 2022 as part of Canada's Geo-Mapping for Energy and Minerals (GEM) GeoNorth program (2020-2027). This activity aims to provide a framework for the glacial history of the west-central Keewatin region (fig. 1) supported by field-based investigations (2023 and 2024) and high-resolution digital mapping. In 2023, targeted field investigations were carried out over 15 days in July and August to gather field data in the area surrounding Dubawnt Lake in Nunavut (fig. 2). The field work objectives were to: 1) document and sample till to determine its composition as well as the regional glacial transport distances and patterns; 2) record ice-flow indicators to increase the resolution and support interpretations of the regional ice-flow chronology; 3) sample boulders and bedrock for terrestrial cosmogenic nuclide (TCN) exposure dating to characterize the degree of erosion/weathering of glacial terrains, as well as to provide minimal ages for the retreat of the ice sheet and glacial lakes inundation; and, 4) sample littoral and deltaic sands for infrared-stimulated luminescence (IRSL) dating to increase the overall resolution of the regional deglaciation history. In this report, we provide the methods used during the 2023 field season and present preliminary results from observations, measurements and sampling. Finally, we discuss early highlights, interpretations and future work.

Physical environment

The fieldwork area extends over ~18,350 km^2 between 100-102°W and 61.75-61.94°N, and falls within the Kazan physiographic region of the Canadian Shield (Bostock, 2014), characterized by rugged hilly terrain with elevations ranging from ~150 to ~415 m asl (fig. 3), and hosts large lakes such as the Dubawnt, Angikuni and Kamilukuak lakes. The physiography of the region is in part reflecting the general bedrock geology that is mainly characterized by crystalline rocks (fig. 4) and the differential erosion by glaciers during the glaciation cycles (Batchelor et al., 2019). The main bedrock domains are : i) the Dubawnt Supergroup (Gall et al., 1992; Rainbird & Hadlari, 2000; Rainbird et al., 2003), mainly characterized in the study area by ultrapotassic lamprophyre (minette) lavas (Christopher Island Formation; Donaldson, 1965; Rainbird & Peterson, 1990), by rhyolite and dacite flows (Pitz Formation; Donaldson, 1965), and in the peninsula within Dubawnt Lake by sandstones and conglomerates (Thelon and Kunwak Formation; Donaldson, 1965; Rainbird et al., 2003); ii) the Hearne Craton, marked by by orthogneiss, tonalite and monzogranite to granite (Tella & Eade, 1986; Tella et al., 2007); iii) the Hudson Suite, characterized by mafic syenites (Tella & Eade, 1986); iv) the Nueltin Suite (previously referred to Kamilukuak Igneous Suite in the study area), composed of granites (Tella & Eade, 1986); and, v) the Rae Craton, mainly consisting of granodiorite gneiss (Tella & Eade, 1986; Tella et al., 2007).

The ancient glaciations left a record of different landforms and landscapes that include streamlined ridges, eskers, moraines, and raised beaches which are reported on the Glacial Map of Canada (Prest et al., 1968; fig. 2) and on the available surficial geology maps (Geological Survey of Canada, 2017a, b, 2019; fig. 5). These air-photo interpreted maps show that the fieldwork area is mostly covered by glacial sediments (till and glaciofluvial sediments) and glacio-lacustrine sediments attributed to glacial lake Dubawnt (Prest et al. ,1968). Limited field-based investigations (e.g., Bird & Bird, 1961; Craig, 1964; Kerr et al., 2013; Sharpe et al., 2014; Campbell et al., 2019; Campbell et al., 2021) within the remote-mapping project area show that the west-central Keewatin region has a complex history of shifting ice flows. These different ice flows were interpreted from glacially-inherited landscape characterised by the presence of relict, preserved, and/or palimpsest terrains (Campbell et al., 2019). In the field study area, field measurements of striae show southeast-, south-, southwest-, west- and northwest-trending flows that have been previoulsy interpreted to operate from the Last Glacial Maximum (maybe even prior) to deglaciation (fig. 6; e.g., Boulton & Clark, 1990a; Kleman et al., 2002; McMartin & Henderson, 2004). In the north part of field study area, the large (crag-and-tails, drumlins, mega-scale glacial lineations, etc.) and small-scale (striations, grooves, etc.) landforms are mostly associated to the Dubawnt Ice Stream, which operated during the early deglaciation of the remote-mapping area (9-8 ka; figs. 2 and 6; Stokes & Clark, 2003). In the south part of the field study area paleo-ice-flow indicators (landforms and striae) are associated to westward and southward flows from the decaying Keewatin Dome (figs. 2 and 6; Dyke and Prest, 1987).

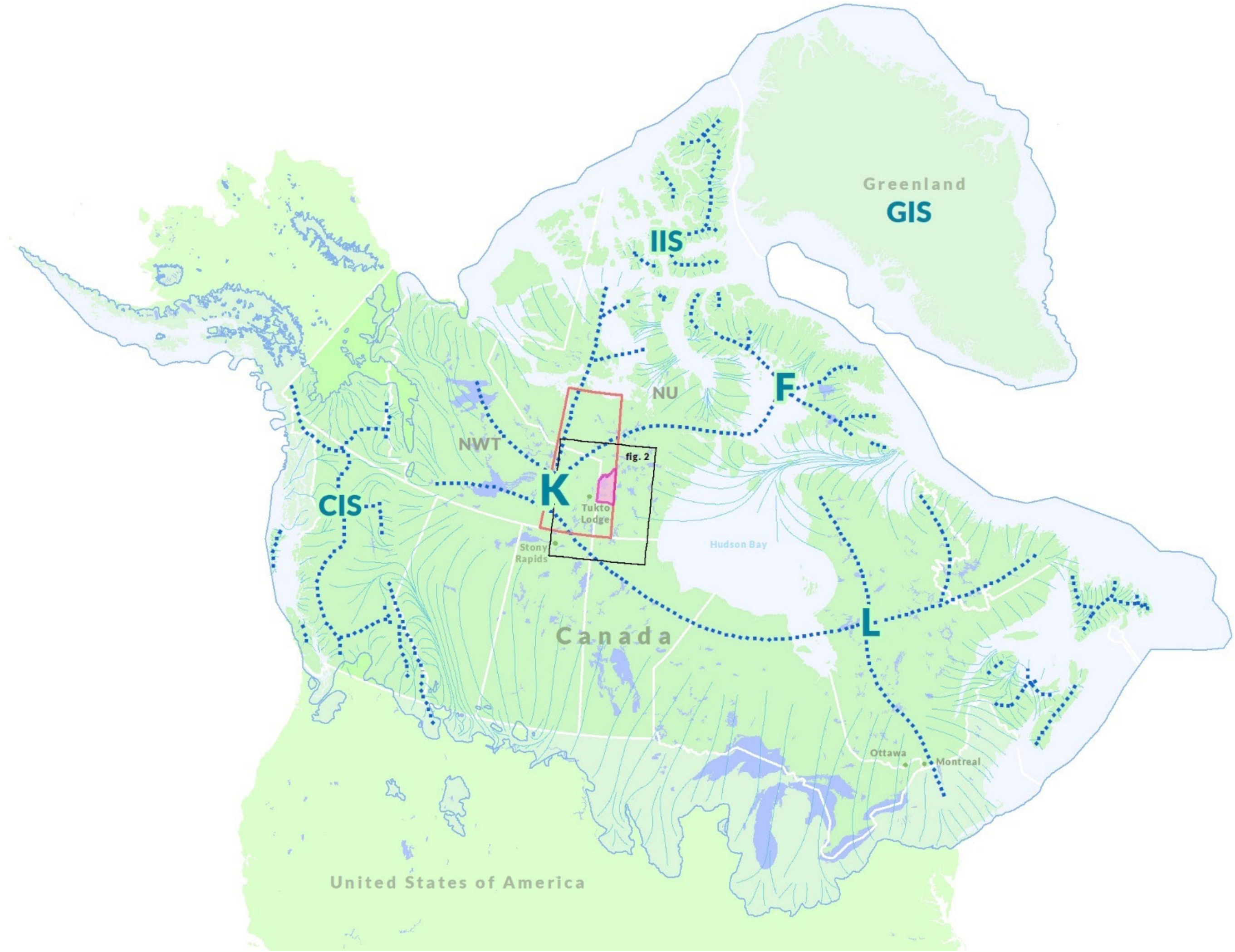

Figure 1. **Extent of the remote-mapping study area for the West-central Keewatin Glacial Dynamics Activity (red outline) and of the 2023 field study area (pink area) with respect to the extent and the domes of the North American ice sheets during the last glacial maximum (Batchelor et al., 2019). Laurentide Ice Sheet: K= Keewatin Dome; L= Labrador Dome; F= Foxe Dome. CIS : Cordillerean Ice Sheet. IIS: Innuitian Ice Sheet. GIS: Greenland Ice Sheet. NU: Nunavut. NWT. Northwest Territories. The dotted lines represent ice saddles/divides (Dyke & Prest, 1987). Countries are from ESRI Map and data (https://hub.arcgis.com/datasets/esri::world-countries-generalized/explore). Province extents are from Topographic Data of Canada - CanVec Series (https://ftp.maps.canada.ca/pub/nrcan_rncan/vector/canvec/). Waterbody extents are from Natural Earth Data (https://www.naturalearthdata.com/).**

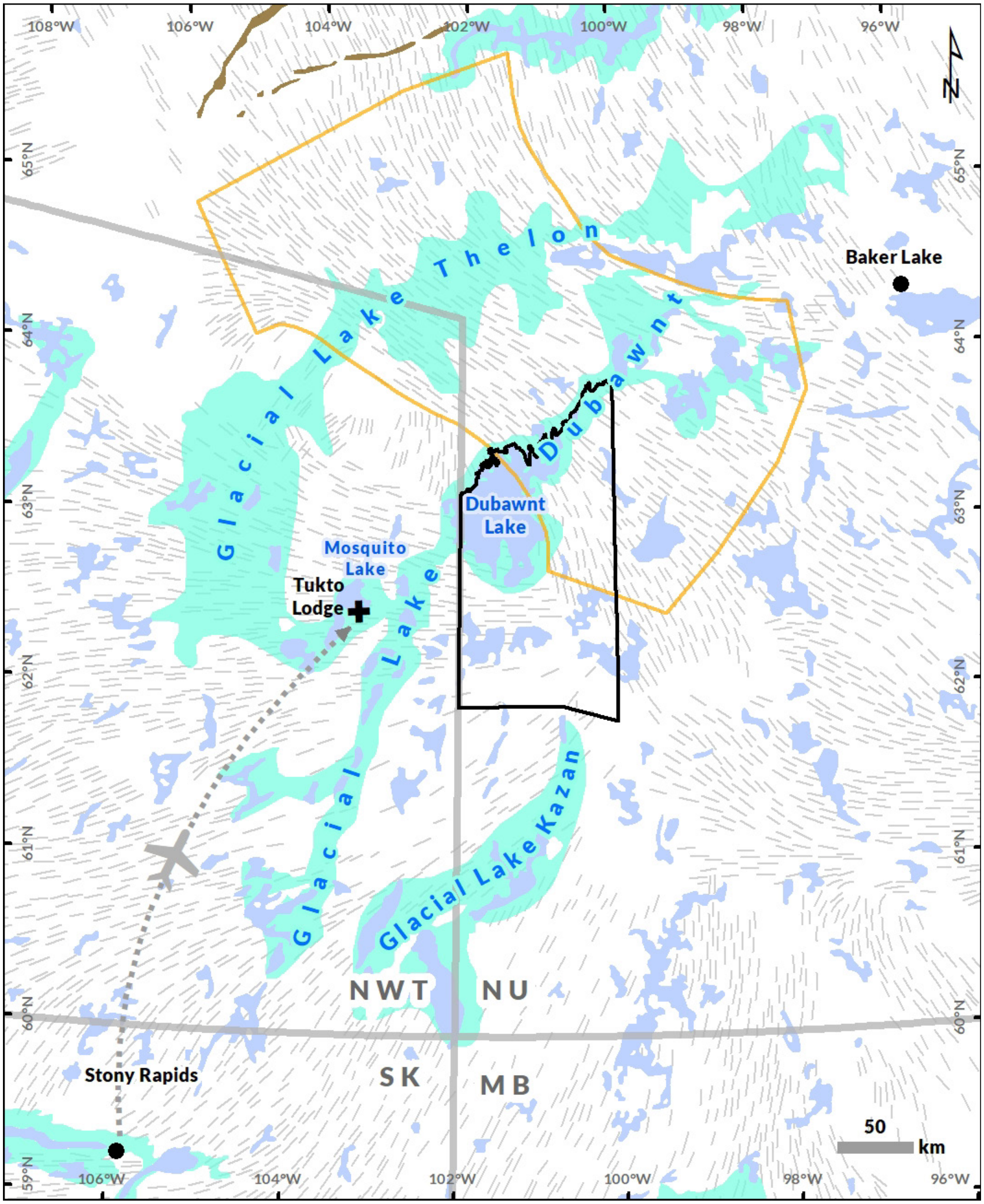

Figure 2. Extent of the 2023 field study area (black outline) and location of the basecamp (Tukto Lodge). NU: Nunavut. NWT: Northwest Territories. SK : Saskatchewan. MB: Manitoba. The small grey lines represent glacial lineations and the turquoise areas represent the extent of glacial lakes as protrayed on the Glacial Map of Canada (Prest et al., 1968). The orange line represents the extent of the Dubawnt Lake Ice Stream (Margold et al., 2014).

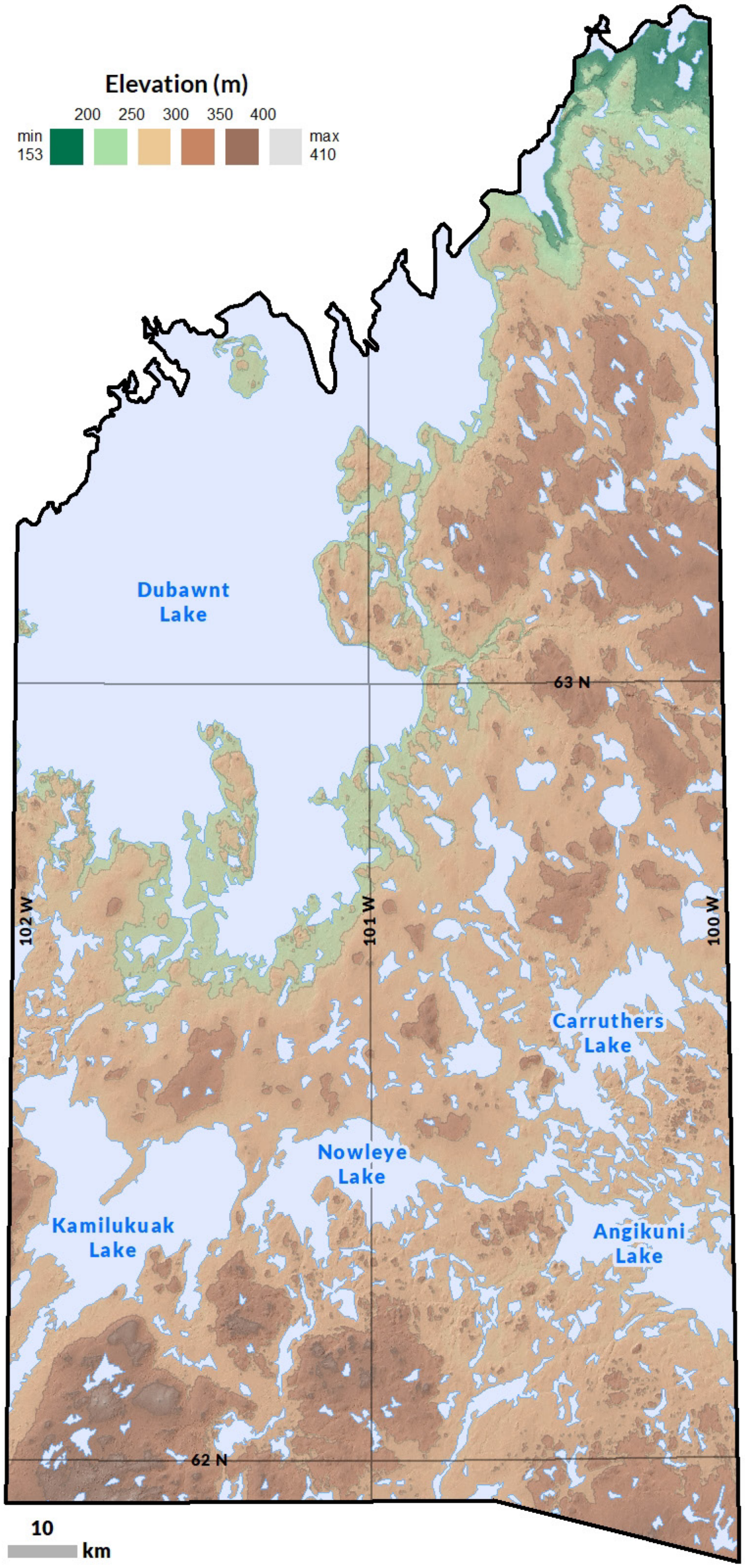

Figure 3. **Topography of the field study area. Elevation data is from the Canadian Digital Elevation Model, 1945-2011 (https://ftp.maps.canada.ca/pub/nrcan_rncan/elevation/cdem_mnec/).**

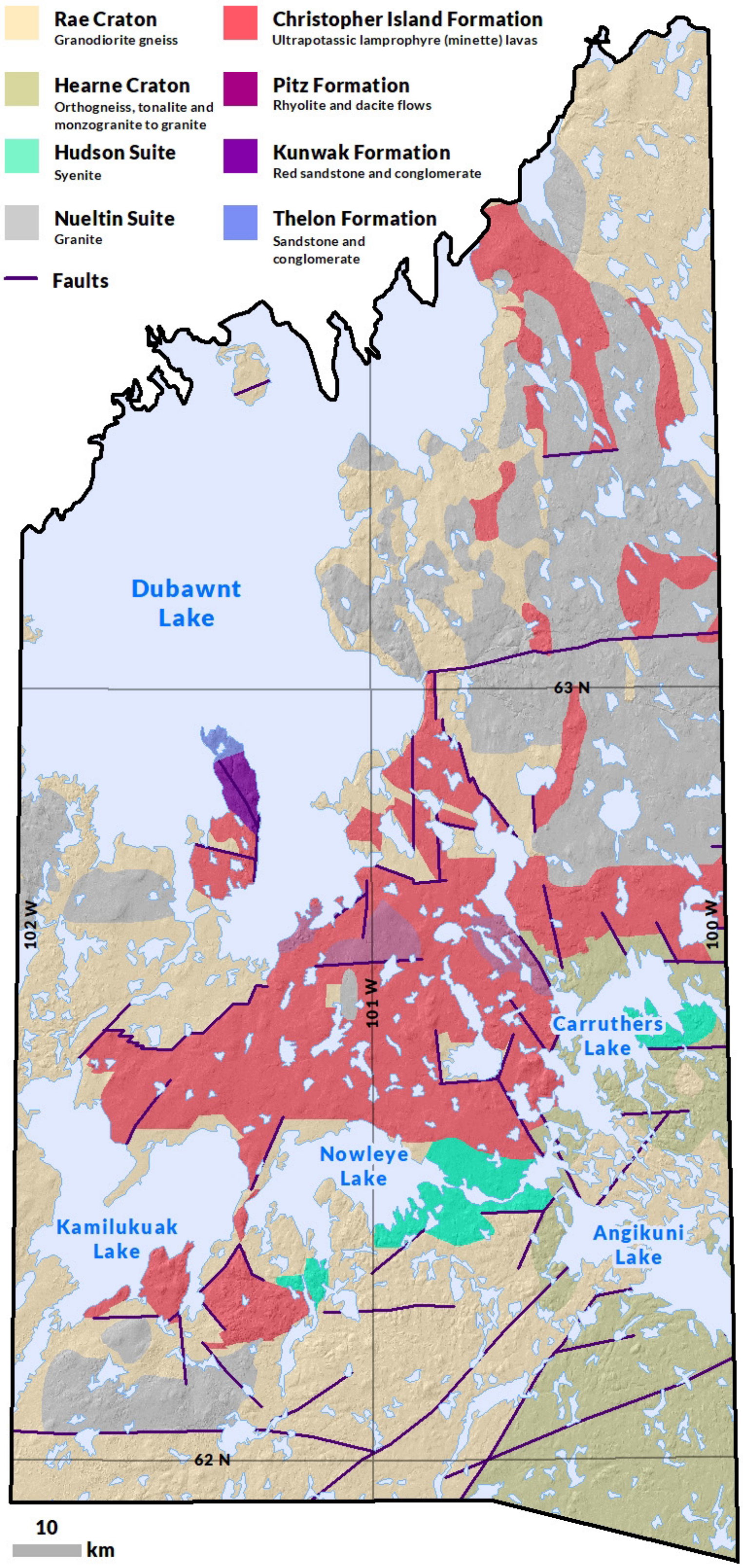

Figure 4. Generalized bedrock geology of the field study area (Behnia et al., 2013). Waterbody extents are are from Topographic Data of Canada - CanVec Series (https://ftp.maps.canada.ca/pub/nrcan_rncan/vector/canvec/). Graticule is from Natural Earth Data (https://www.naturalearthdata.com/).

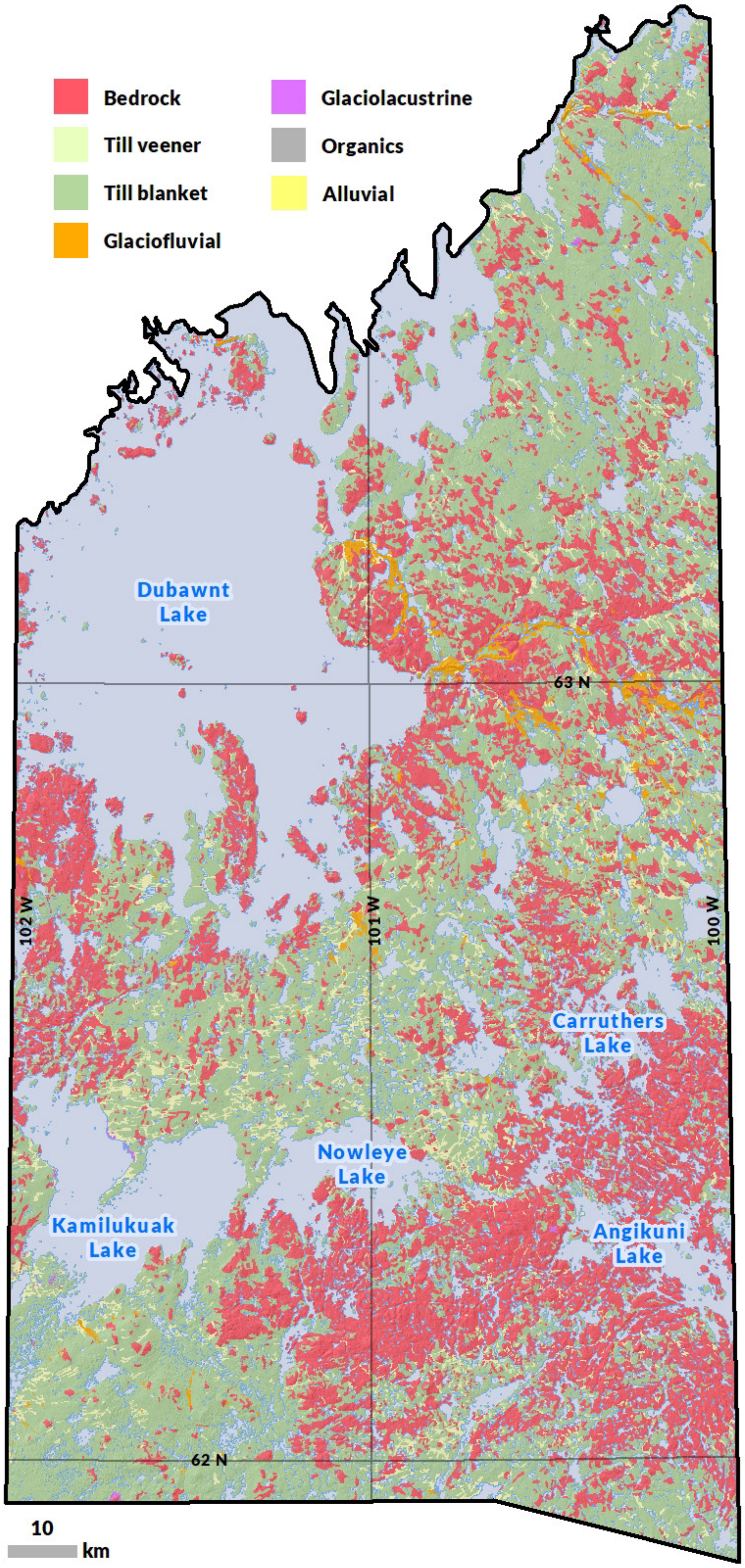

Figure 5. **Generalized surficial geology of the field study area (Geological Survey of Canada, 2017a, b, 2019). Waterbody extents are are from Topographic Data of Canada - CanVec Series (https://ftp.maps.canada.ca/pub/nrcan_rncan/vector/canvec/). Graticule is from Natural Earth Data (https://www.naturalearthdata.com/).**

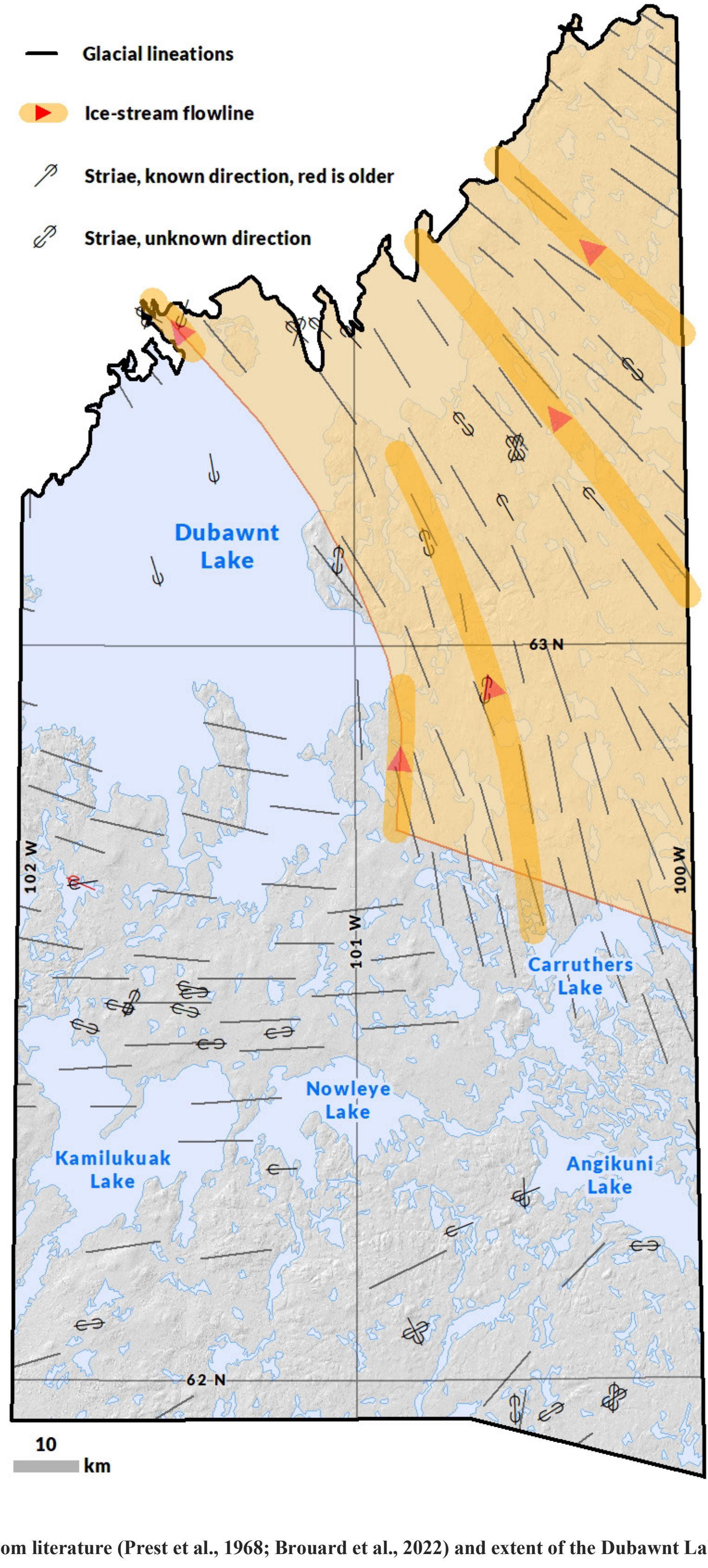

Figure 6. **Paleo-ice flow indicators from literature (Prest et al., 1968; Brouard et al., 2022) and extent of the Dubawnt Lake Ice Stream (Margold et al., 2014).**

Methods

Logistics

The scientific crew consisted of three GSC research scientists (Janet Campbell, Etienne Brouard, and Pierre-Marc Godbout) and a research associate student from the Université du Québec at Montreal (UQAM; Noé-Malcolm Renaud). The crew was supported by a wildlife monitor from Baker Lake, a helicopter pilot and two staff members from the lodge. The scientific crew departed from Ottawa and Montreal on July 26th and reached Tukto Lodge base camp on Mosquito Lake (Northwest Territories, 62.492°N, 103.283°W) the following day. The helicopter-based operations were conducted from the lodge with two fuel caches to support long-distance operations.

Geospatial data acquisition

At each site, ground observations were recorded in the GSC Field Application (Version 2.3; https://github.com/NRCan/GSC-Field-Application) installed on Samsung Toughpads running the Windows 10 Operating System. The GSC Field Application uses the Toughpad built-in GPS to locate individual stations linked to the Surficial Data Model (v2.4; Deblonde et al., 2019) permitting data entries about different geological information (e.g., earth material and sample descriptions, ice-flow indicator measurements, photo IDs, etc.). The application uses a Geopackage data format (.gpkg; SQLite Database) to store information that can be visualized in either ArcGIS Pro or QGIS. The final geopackage and geodatabase resulting from this fieldwork are provided with this report (**suppl. material 1**). Photographs at remote and ground observations sites were taken using either a Nikon Coolpix AW130 or the iPad Pro (3rd generation; iOS 16.2) built-in camera. Custom maps (.tif) were uploaded on the Avenza Maps application (https://www.avenza.com/avenza-maps/) installed on an iPad Pro for navigation, and a handheld Garmin GPS was used for tracking the helicopter position.

Measurements and sampling

Measurement of ice flows indicators

Paleo ice-flow indicators such as landforms (e.g., roches moutonnées) and small-scale erosional features (e.g., striations, chattermarks, crescentic gouges, etc.) were measured at sites with bedrock outcrops to document ice-flow direction, sense (if possible) and relative chronology where applicable (**fig. 7**). The azimuth of each feature was taken with an hand-held compass, set to 0° for the magnetic declination before fieldwork and subsequently corrected for site-specific magnetic declination using the NOAA magnetic declination calculator (www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml). The type, sense (known or unknown), quality, and number of indicators for each landform/feature were recorded in the GSC Field Application. The relative chronology was also recorded in the GSC Field Application where more than one set (direction) of indicators was observed at a site and the inferred relative age of the indicators could be established based on cross-cutting relationships or on their position on protected or faceted surfaces (e.g., Veillette & Roy, 1995; McMartin & Paulen, 2009).

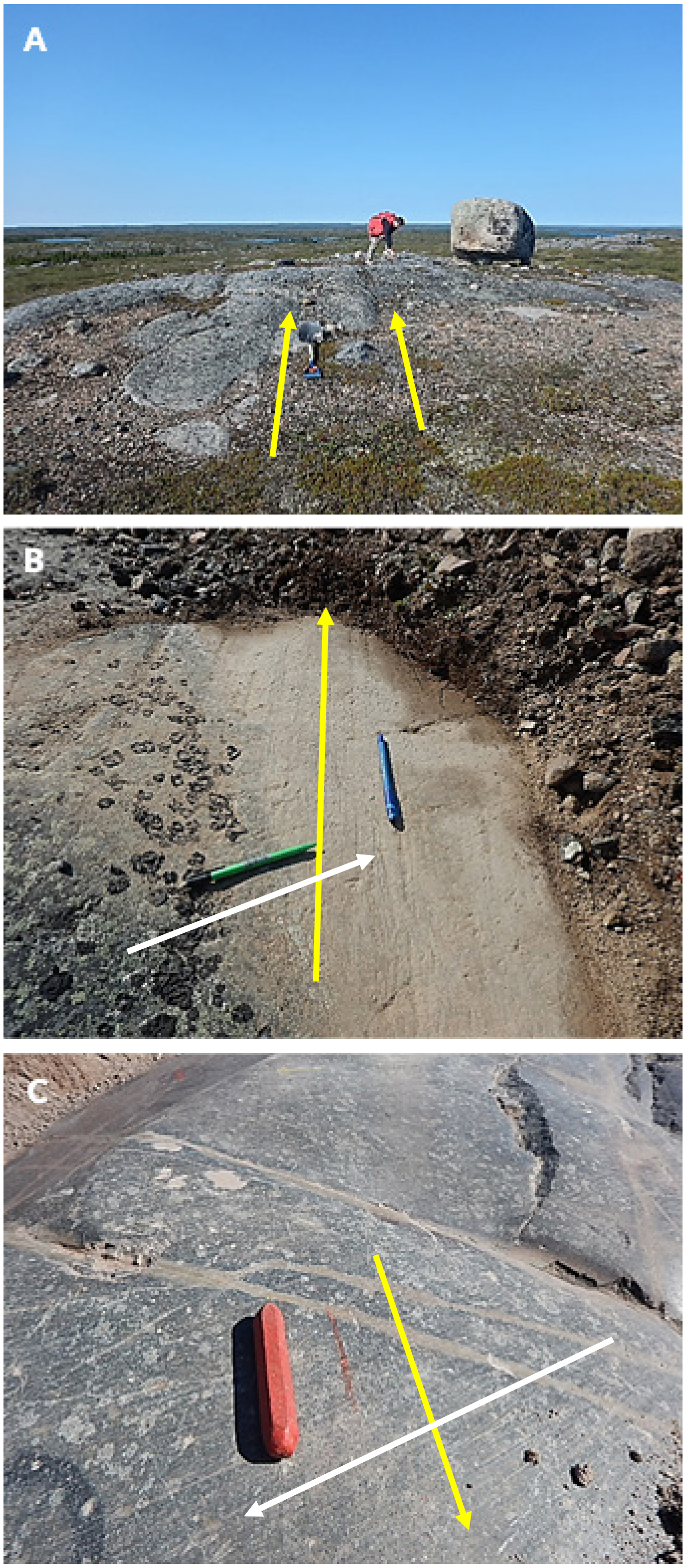

Figure 7. **Examples of ice-flow indicators. A. Grooves on top of ice-molded outcrop, photo 23BVB-C0027P002 (NRCan photo 2023-314). B. Example of small-scale erosional features (striae), photo 23BVB-C0027P012 (NRCan photo 2023-315). C. Example of cross-cutting fine striations, photo 23BVB-B0013P010 (NRCan photo 2023-313). Pen and arrows are use here to show the direction of striations on outcrop. The striations marked by the white arrows crosscut those marked by the yellow arrows.**

Till Sampling

Potential till sampling sites were identified prior to fieldwork using the high-resolution ESRI Worldview imagery to have good geographic coverage and to target gently rolling till plains located on higher grounds and exhibiting well-developed mudboils. The samples were recovered from hand dug active mudboils (fig. 8a-b) following the established till-sampling protocols at the Geological Survey of Canada (McClenaghan et al., 2020). At each site, a small (~3-5 kg) and a large (~10-15 kg) plastic bag of material were collected from the B, C or Cy soil horizon to perform geochemical analyses of the till-matrix fine fraction (silt + clay; <63 µm), and to characterize the heavy mineral and lithological content of the sediment (fig. 8c). Field duplicate samples were also collected at two sites 5-10 m away from the original sample hole for assessment of site variablilty. All dugholes were filled back before leaving the sites. Sample numbers, type, purpose, quality, depths and other relevant information related to the till samples were all recorded in the GSC Field Application. Small till samples will undergo processing at the GSC Sedimentology Laboratory in Ottawa, including < 2mm textural analysis, dry Munsel colour, total carbon content, calcite/dolomite content and preparation of the <63 µm fraction for geochemical analysis.

Figure 8. A. Example of a fresh (active) mudboil prior to sampling, photo 23BVB-B0024P001 (NRCan photo 2023-307). B. Example of a dug hole (~ 60 cm) in a fresh mudboil with the arrow pointing towards the depth of sampling, photo 23BVB-B0030P006 (NRCan photo 2023-309). C. Examples of small and large bags of till sampled in a mudboil, photo 23BVB-B0030P007 (NRCan photo 2023-310).

Sampling for terrestrial cosmogenic nuclide (TCN) dating

At sites identified using satellite imagery, 2 to 4 granitic boulders and/or bedrock outcrops suitable for terrestrial cosmogenic nuclide exposure dating (i.e., with visible quartz grains and a flat top surface) were sampled. The samples were collected by cutting ~2-3 cm-deep grids using a battery-powered portable rocksaw (DeWalt 60V MAX Brushless Cordless 9" Cut-Off Saw) equipped with a water-cooled diamond blade (fig. 9a-b), and by separating rock materials within the grid from the surface using a chisel and a hammer, and then put in plastic bags for transport (fig. 9c). The dip (angle and direction) of the surface and the angle of elevation to the skyline were measured at regular 45° intervals using a compass to calculate the topographic shielding. The topographic shielding values will also be revised against values derived from digital elevation model analyses (Li, 2018). Sample numbers, type, purpose, quality, depths and other relevant information related to the TCN sampling were all recorded in the GSC Field Application.

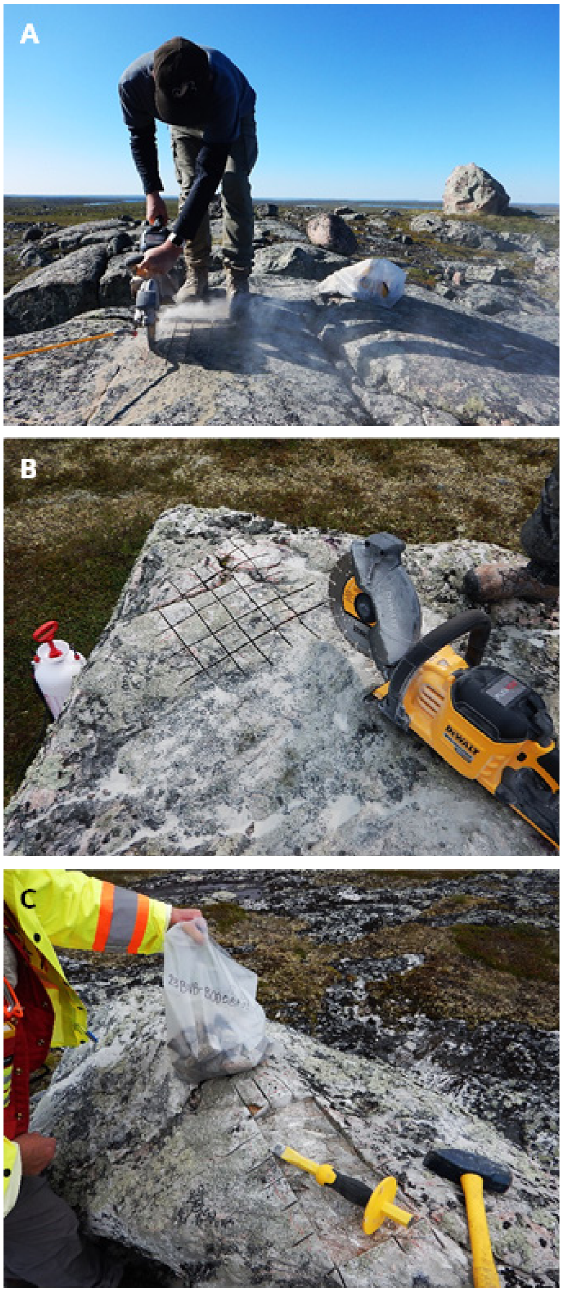

Figure 9. **A. Example of TCN sampling using the portable rocksaw, photo 23BVB-B0025P002 (NRCan photo 2023-308). B. The resulting sampling grid, photo 23BVB-B0007P011 (NRCan photo 2023-304). C. Example of rock samples separated from the surface using a chisel and a hammer, photo 23BVB-B0008P007 (NRCan photo 2023-305).**

Sampling for luminescence

Samples were collected from glaciolacustrine littoral (beach) and/or deltaic sediments to carry out infrared stimulated luminescence (IRSL) dating. At each site, fresh surfaces/exposures were dug to expose horizons composed of fine-to-medium well-sorted sands and from which pairs of samples were collected following the sampling protocol developed by the LUX laboratory at UQAM (Godbout, 2013). Where suitable, 2 samples were collected using a 1½-inch ABS pipe filled with a black plastic (garbage) bag inserted in freshly cleaned exposures (fig. 10). Each sample was accompanied by two ¾-inch copper tubes collected ~10 cm on each side of the main sample for the *in-situ* water content (labeled "WC") and the water content at saturation (labeled "SAT"; fig. 10). The material around the main tube was also sampled to determine the annual dose (labeled as "KUT"- Potassium (K)-Uranium-Thorium).

Figure 10. Example of an IRSL sampling site, photo 23BVB-B0015P018 (NRCan photo 2023-306). WC: Water content sample (copper tube). SAT: Saturation sample (copper tube).

Sampling for lithogeochemistry and hand samples

Hand bedrock samples (~0.5 kg) were collected at different locations for whole-rock geochemical analyses to determine the geochemical signature of distinctive lithologies and as representative examples for visusal pebble count identification (fig. 11).

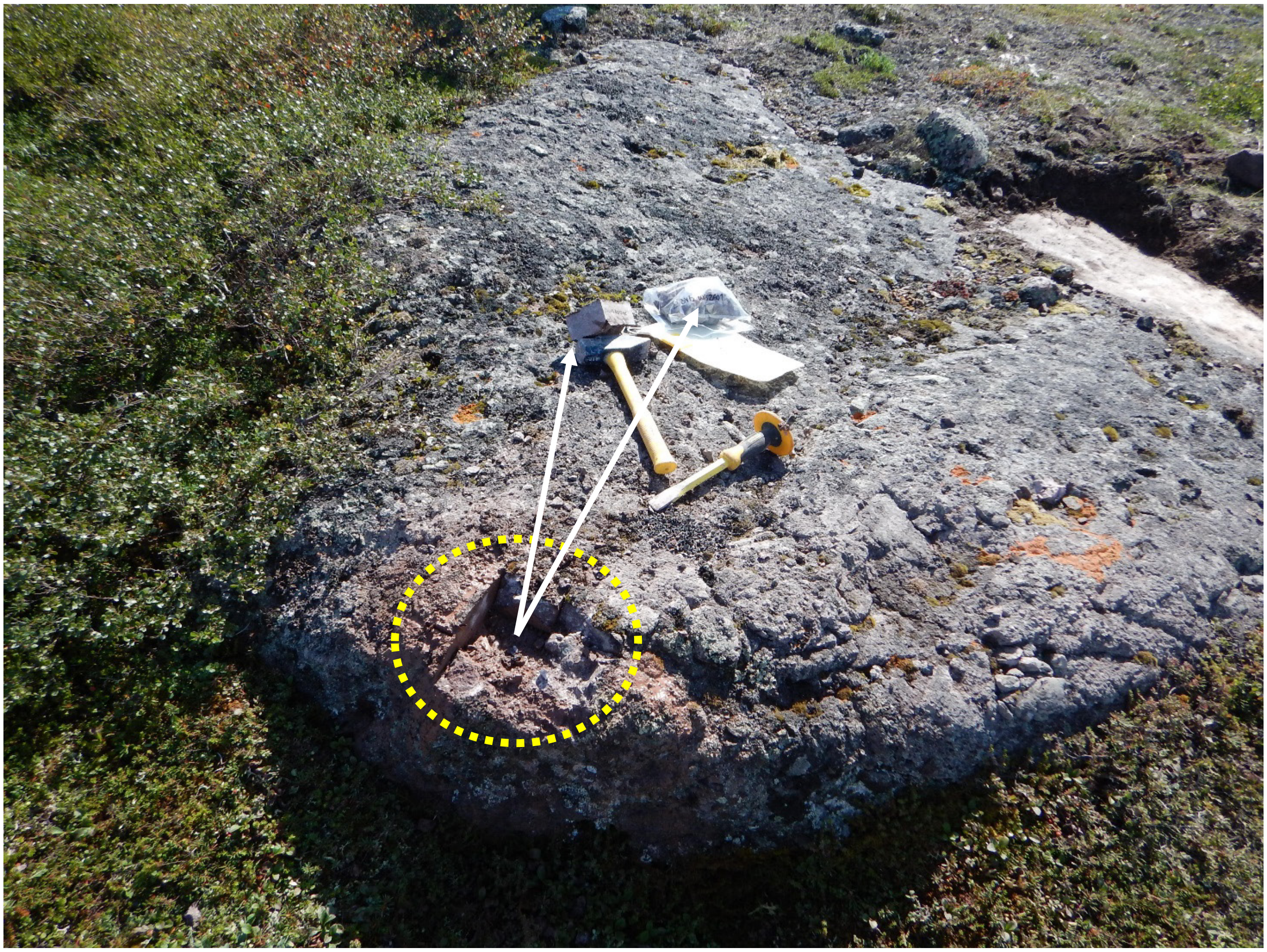

Figure 11. **Example of bedrock hand sample for lithogeochemical analysis, photo 23BVB-B0052P003 (NRCan photo 2023-312).**

Results

Field database, stations, and photographs

The fieldwork led to document ground observations made at 111 disctinct locations (stations) distributed over ~14,000 km^2 (fig. 12). In total, 35 stations were labeled as dugholes, 37 as ice-flow indicators, 1 as a waypoint, 3 as natural exposures, 6 as lithogeochemistry and hand samples, and 29 as geochronology sites. Specifically, 2 stations were on a beach, 21 on bedrock uplands, 2 on deltas, 12 on hills, 1 on a hummock, 23 on an outcrop ridge, 31 on a till plain, 7 on a moraine, 3 on a crag-and-tail, 1 at a washing limit and 8 in a meltwater channel. To complement the database and provide visual support, 684 photographs were taken at and around the various stations.

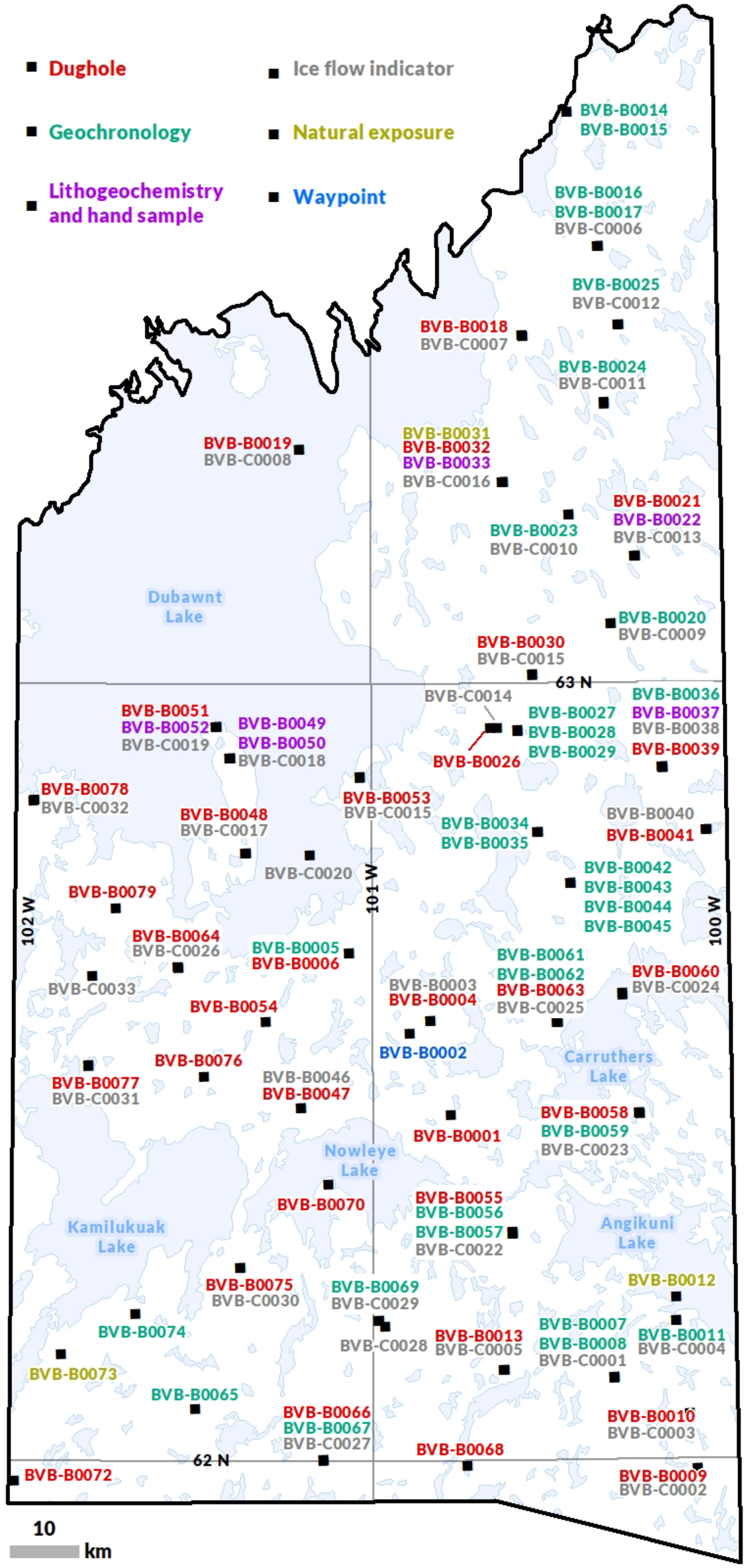

Figure 12. **Location of field observation points (stations). The type of site is indicated by colour. Multiple types of samples/observations were taken at numerous sites (figures 10 to 15).**

Ice-flow measurements

A total of 108 ice-flow measurements on landforms and small-scale erosional indicators were collected from 37 individual stations (fig. 13). These comprised 91 measurements of striations, 5 of stoss and lee topography, 4 of micro-striations, 4 of grooves, 2 of roches moutonnées, 1 of chattermarks, and 1 of nailed-head striae. The sense of the ice flow could be inferred ('known') for 53 of the 108 measurements. The most complex relative ice-flow chronology at a single station included 5 different sets of ice-flow indicators (23BVB-C0007).

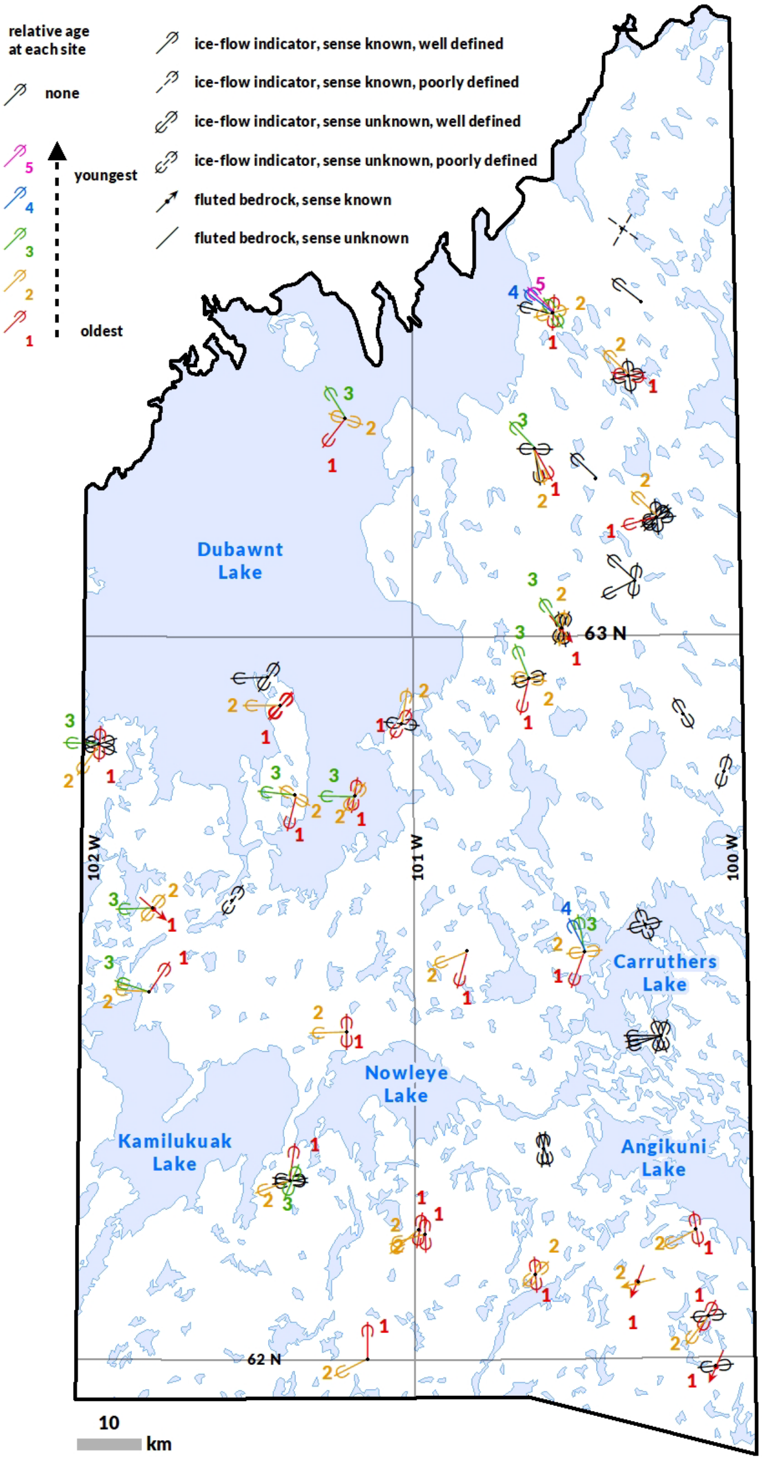

Figure 13. **Distribution of ice-flow measurements.**

Till samples

Thirty-seven tills were sampled from 35 field stations (with 2 field duplicates) for geochemical analysis (~3-kg small bags) and heavy mineral processing (>10-kg large bags; "geochemistry&HM" in GSC Field Application; fig. 14). Based on field estimations, most surface till samples have a moderatly compact fine sand to silty matrix (62%) and a brown or grey primary colour (92% of samples). Interestingly, 62% of the till samples showed a matrix with secondary colours of red or pink. The estimated clast content fraction of the tills varied between 10 and 40% of total volume. The pebble (8-30 mm) fraction of all till samples will be recovered during the sample processing of the large >10 kg indicator mineral samples for lithology counts.

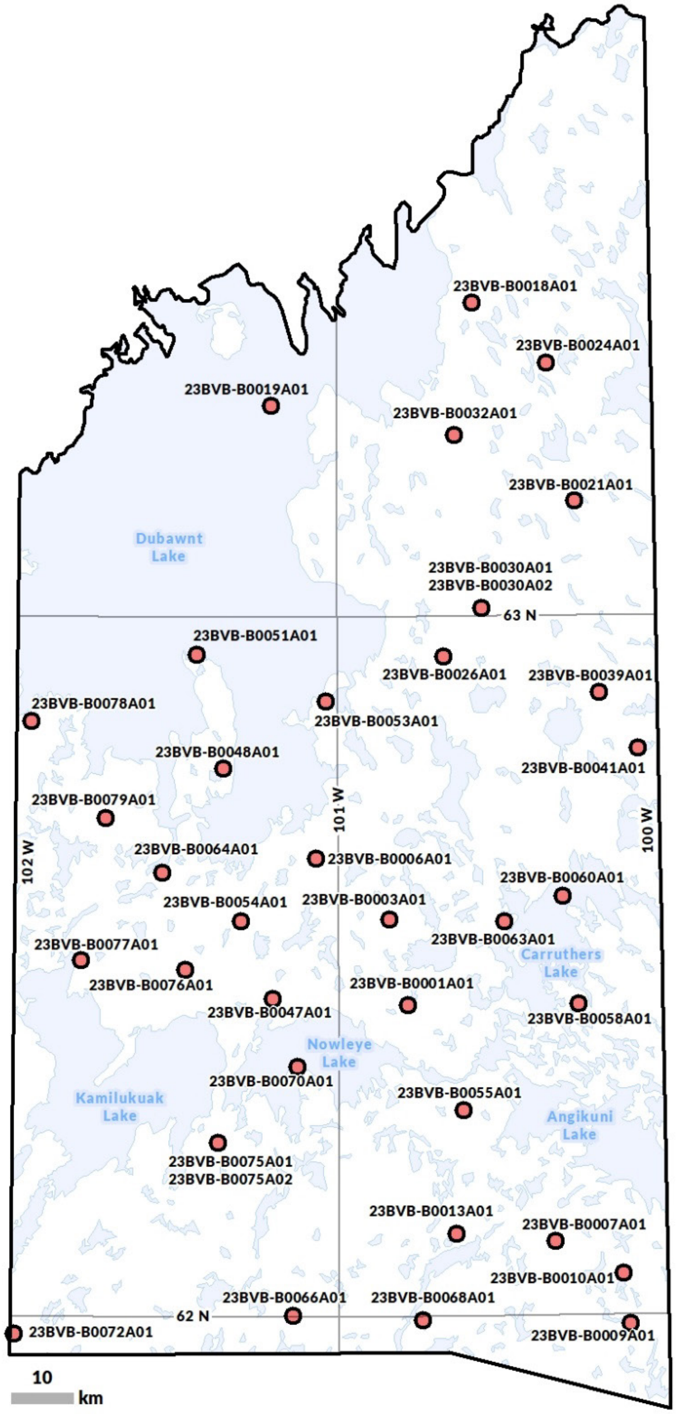

Figure 14. **Distribution of till samples.**

Boulder samples

Twelve boulders were sampled from 11 individual stations for TCN exposure dating (fig. 15). Two boulders were collected to document the history of glacial lakes, seven to characterize the degree of erosion/weathering of glacial terrains and three to provide minimal ages for the retreat of the ice sheet. The seven boulders collected for investigating erosion and weathering in glacial terrains have paired bedrock samples, which were also sampled for TCN dating. One cobble sample was collected for whole-rock geochemical analysis to determine the lithogeochemical signature and provenance.

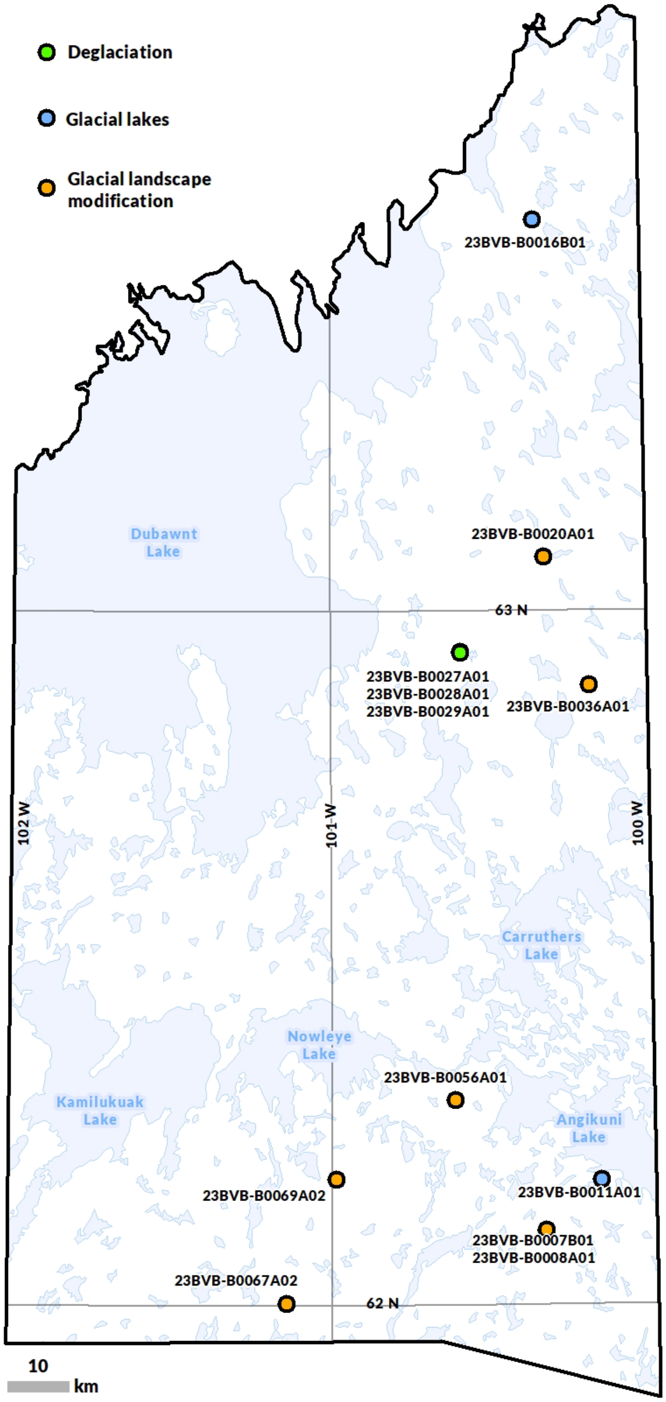

Figure 15. **Distribution of boulder samples by purpose.**

Bedrock samples

Thirty-four bedrock surfaces were sampled from 28 individual stations, either for TCN exposure dating (n=22) or for geochemical analysis on representative lithologies (n=6; fig. 16). For TCN dating (n=28), six bedrock surfaces were collected for investigating glacial lakes history, seventeen to characterize the degree of erosion/weathering of glacial terrains (glacial landscape modification) and four to provide minimal ages for the retreat of the ice sheet. Six bedrock samples collected for whole-rock geochemical analysis were interpreted as derived from the Christopher Island Formation (n=2), the Nueltin Suite (n=1), the Kunwak Formation (n=1), the Pitz Formation (volcanics and conglomerate; n=1) and the Thelon Formation (n=1).

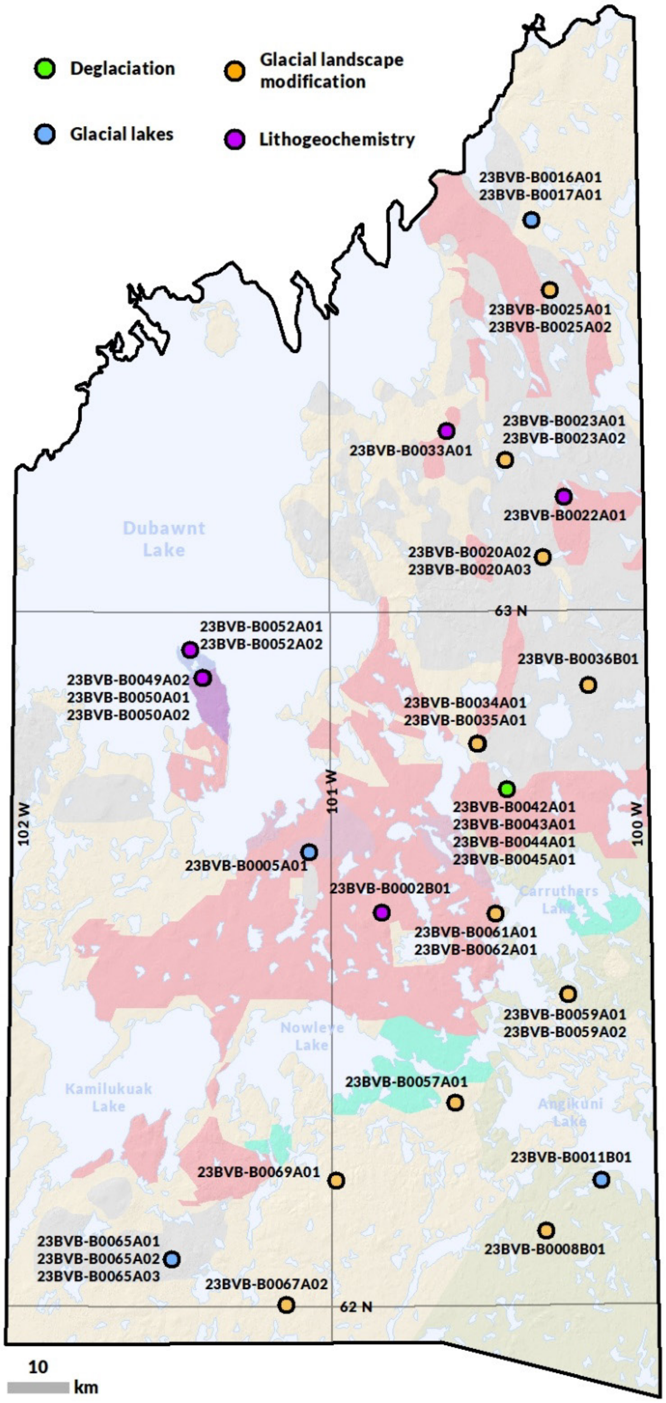

Figure 16. **Distribution of bedrock samples by purpose.**

Cobble sample

One cobble sample was collected for whole-rock geochemical analysis to determine the lithogeochemical signature and provenance (fig. 17).

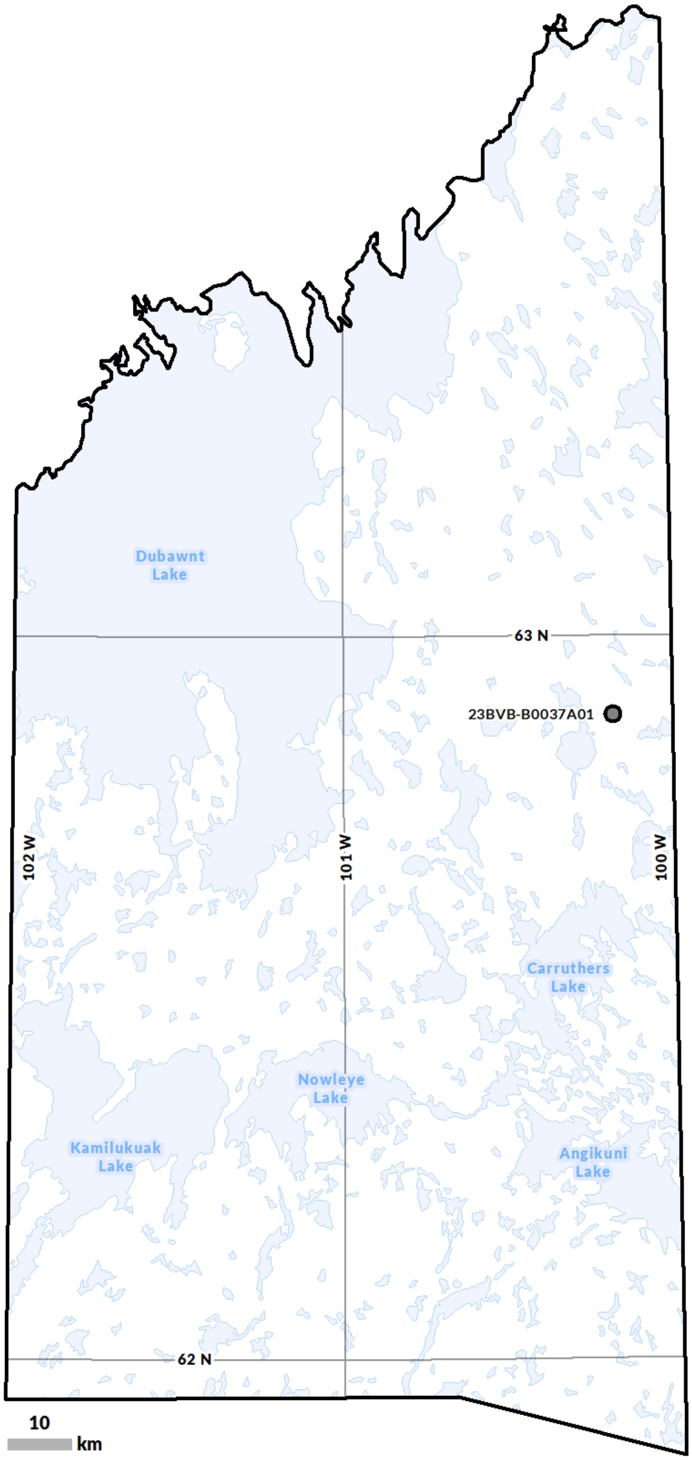

Figure 17. **Location of the cobble sample.**

Sand samples

Six sand samples were collected from 3 individual stations for IRSL dating of the abandonment of distinct glacial lake levels (fig. 18).

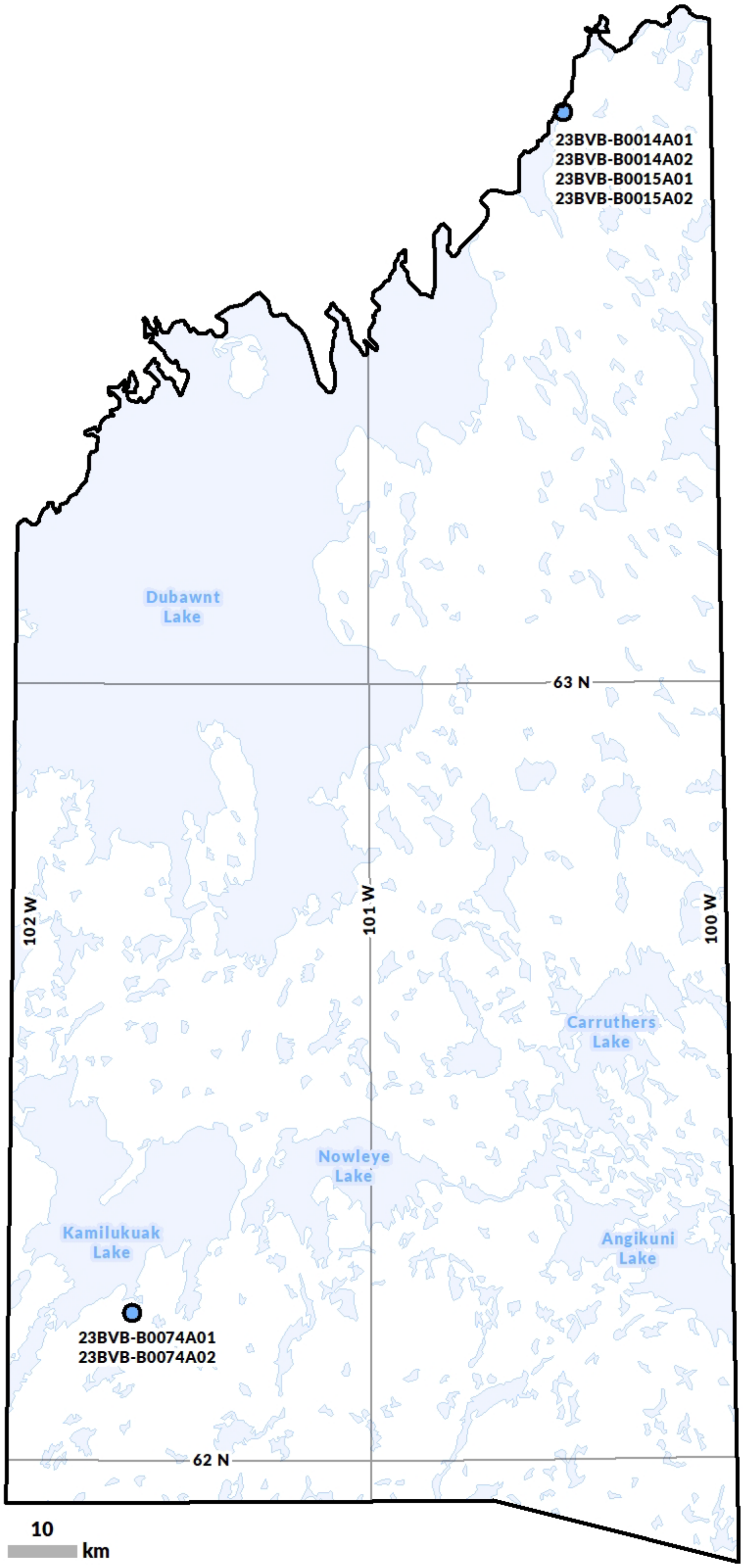

Figure 18. **Location of the sand samples taken in the field for the IRSL dating related to the glacial lake history.**

Discussion

Ice-flow record

The level of preservation of striations in the field was found to be highly dependant on bedrock lithology. In general, where rocks from the Baker Lake Basin (mostly ultrapotassic lamprophyre lavas of the Christopher Island Formation) outcropped, significantly more striations (and distinct flowsets) were preserved in comparison to the outcrop visited in the granitic Nueltin Suite or in the Rae and Hearne cratons (metamorphosed rocks). Hence, there is a possiblity that a lack of preservation of ice flow indicators in some areas may lead to a spatially biased ice-flow reconstruction. However, using the ice-flow indicators from the field and from the preliminary remote mapping dataset, we can delineate distinct ice-flow sets and their relative chronology. The oldest flowset (flowset A) is mainly interpeted from sets of striations and outcrop molding showing a N-S orientation and always superimposed/cross-cut by younger striae (**fig. 19**). The "old" character of these ice-flow features prohibit us to interpret a sense for the direction of flow with certainty but a south flow is suggested at several sites (e.g., 23BVB-C0016) and by earlier interpretations (Kleman et al., 2002). In the southern portion of the study area, just south of Kamilukuak and Nowleye lakes, we documented striae (nailhead and plucking) and outcrop molding that suggest a northward trending flow (flowset A*) and which could be the oldest in the study area (**figs. 19-20**). Even though this flow is the oldest where recorded and shares a similar oriention to flowset A, the spatial and age relationship between A and A* remains unclear and for now, we prefer to consider them as separate flow events. The second oldest flow (flowset B) is interpreted from multiple striae sites showing a SW orientation and sense (**fig. 21**). These SW trending striae are almost all crosscut by younger striae associated with late deglacial flows and/or landforms. The SW trending striae reported here could be associated or correlated to other older-than-deglaciation SW flows reported in neighbouring regions (Boulton and Clark, 1990a; Kleman et al., 2002; McMartin & Henderson, 2004; Kleman et al., 2010; Dalton et al., 2022). Analyzing TCN ^{10}Be/^{26}Al ratios in bedrock surfaces sampled from various locations exhibiting these striae could potentially offer a more precise timeframe for the initiation of the southwest flow. However, until then, it is advisable to regard these micro-landforms as originating simply prior to or at the onset of deglaciation. The third oldest flowset (flowset C) is distinguished by a series of E-W oriented striae that overprint striae from flowset B and are superimposed by NW-trending striae in the northeast region of the study area, as well as SW-trending striae in the southeast portion (**fig. 22**). Although we couldn't definitively establish a sense for this flow in the field, a plausible interpretation in the regional context is that these micro-landforms are similar to early eastward ice-flow indicators associated with ice movement towards Hudson Bay (Campbell, 2002; Dredge et al., 1986; Hardy et al., 2005; McMartin & Henderson, 2004). Nevertheless, we cannot rule out the possibility at this stage that these striae observed in the northern part of the study area result from westward-trending flows, indicating a clockwise transition from SW (flowset B) to northwestward deglacial flows (flowset E), i.e., the Dubawnt Lake Ice Stream (DLIS). Flowset D is interpreted from SW-trending striae that crosscut and overprint flowset B. They are usually the youngest and most abundant on the outcrops in the southern and western halves of the field study area (**fig. 23**). Flowset E is interpreted from NW-trending striae that crosscut flowset B in the northern half of the field study area. They are usually the youngest and most abundant on the outcrops and are aligned with drumlinoid landforms attributed to the Dubawnt Lake Ice Stream (Stokes & Clark, 2003; **figs. 2 and 23**). Evidence of crosscutting relationships between flowsets D and E was documented in the field near the SE end of Dubawnt Lake, suggesting the DLIS onset is probably younger the the establishment of flow D. After the DLIS onset, both flows (D and E) probably operated simultaneously, although probably with different ice velocity. The spatial relationship between the flowsets D and E along with their similar position in the relative chronology could also suggest the occurrence of a SE-NW-oriented division of ice drainage in the Dubawnt Lake-Angikuni Lake axis (Boulton & Clark, 1990b; **fig. 23**).

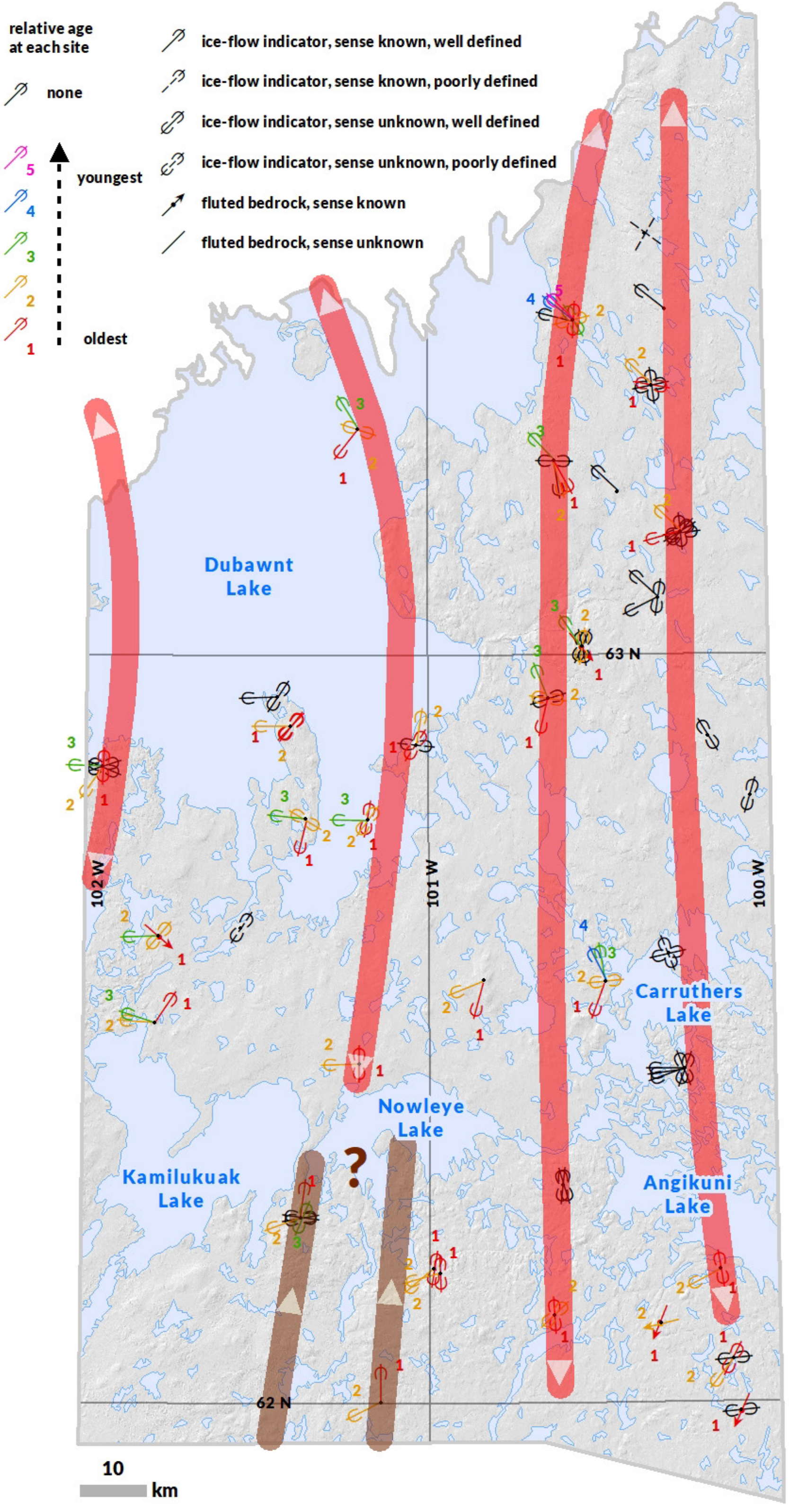

Figure 19. **Flowset A (red) and A* (brown) interpreted from preliminary remote mapping of streamlined landforms and field ice-flow indicators.**

Figure 20. **Example of outcrop molding towards the North associated with flowset A* at station 23BVB-B0067 (NRCan photo 2023-316).**

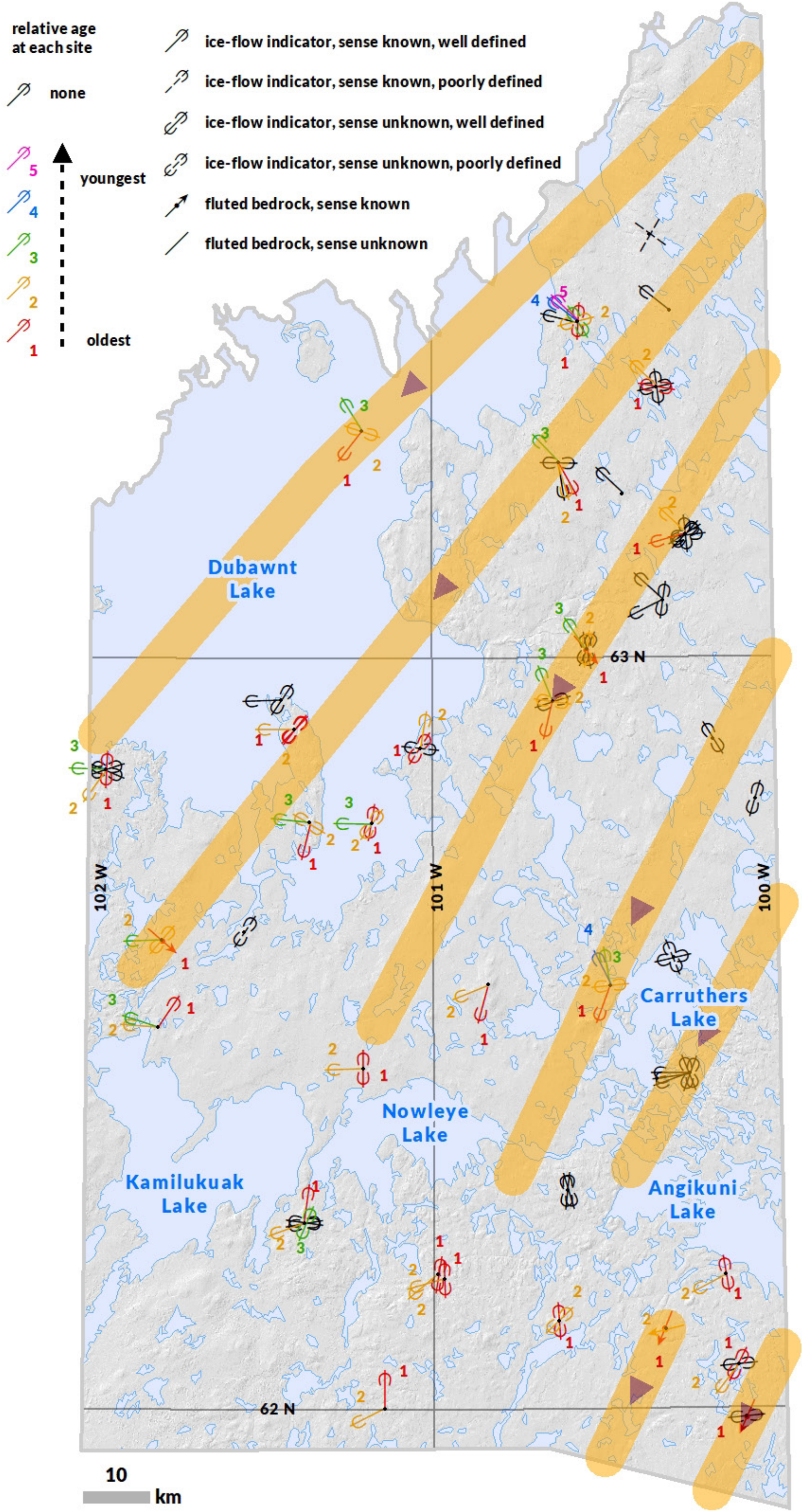

Figure 21. Flowset B interpreted from preliminary mapping and field ice-flow indicators.

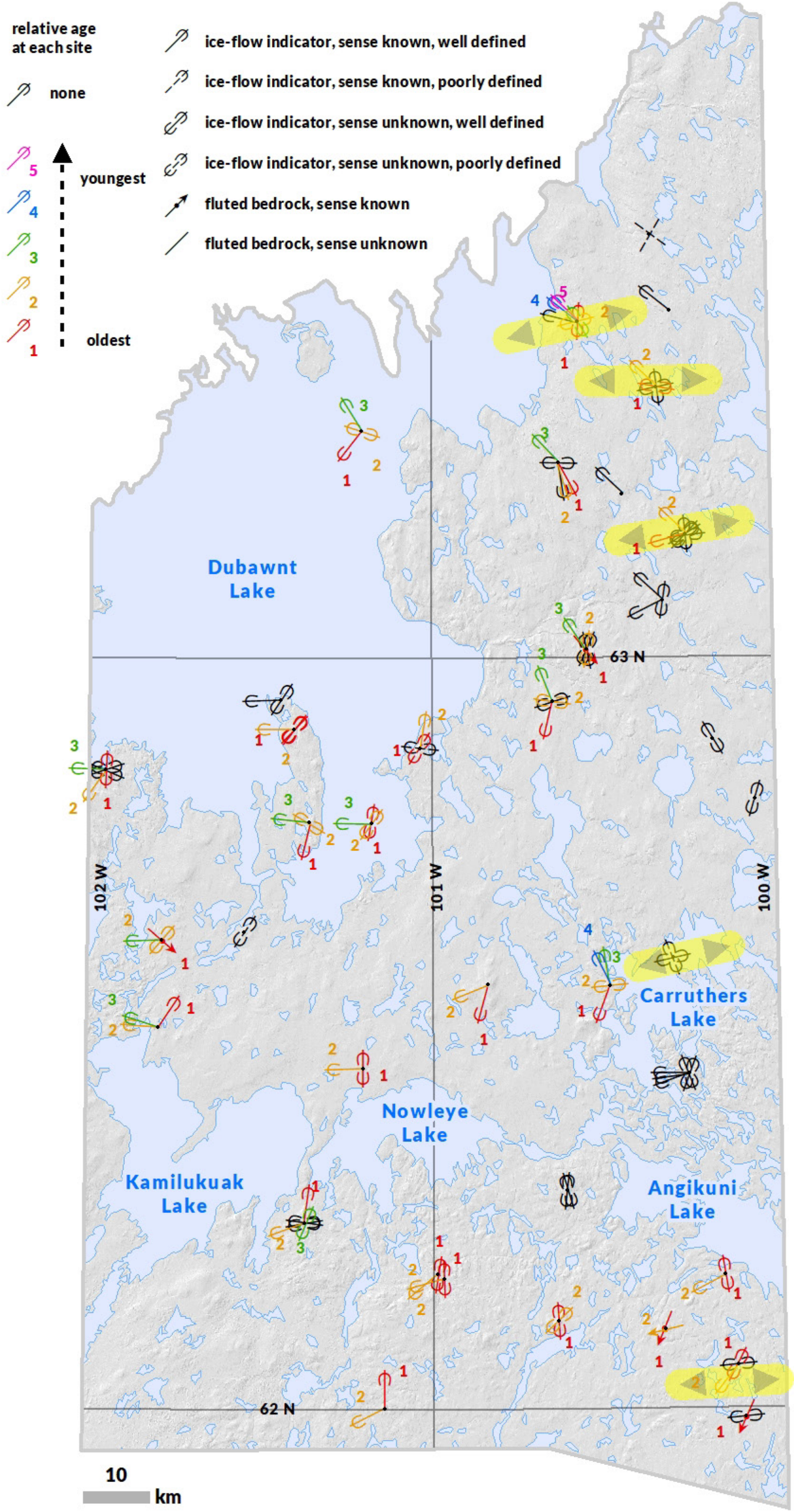

Figure 22. **Flowset C interpreted from preliminary mapping and field ice-flow indicators.**

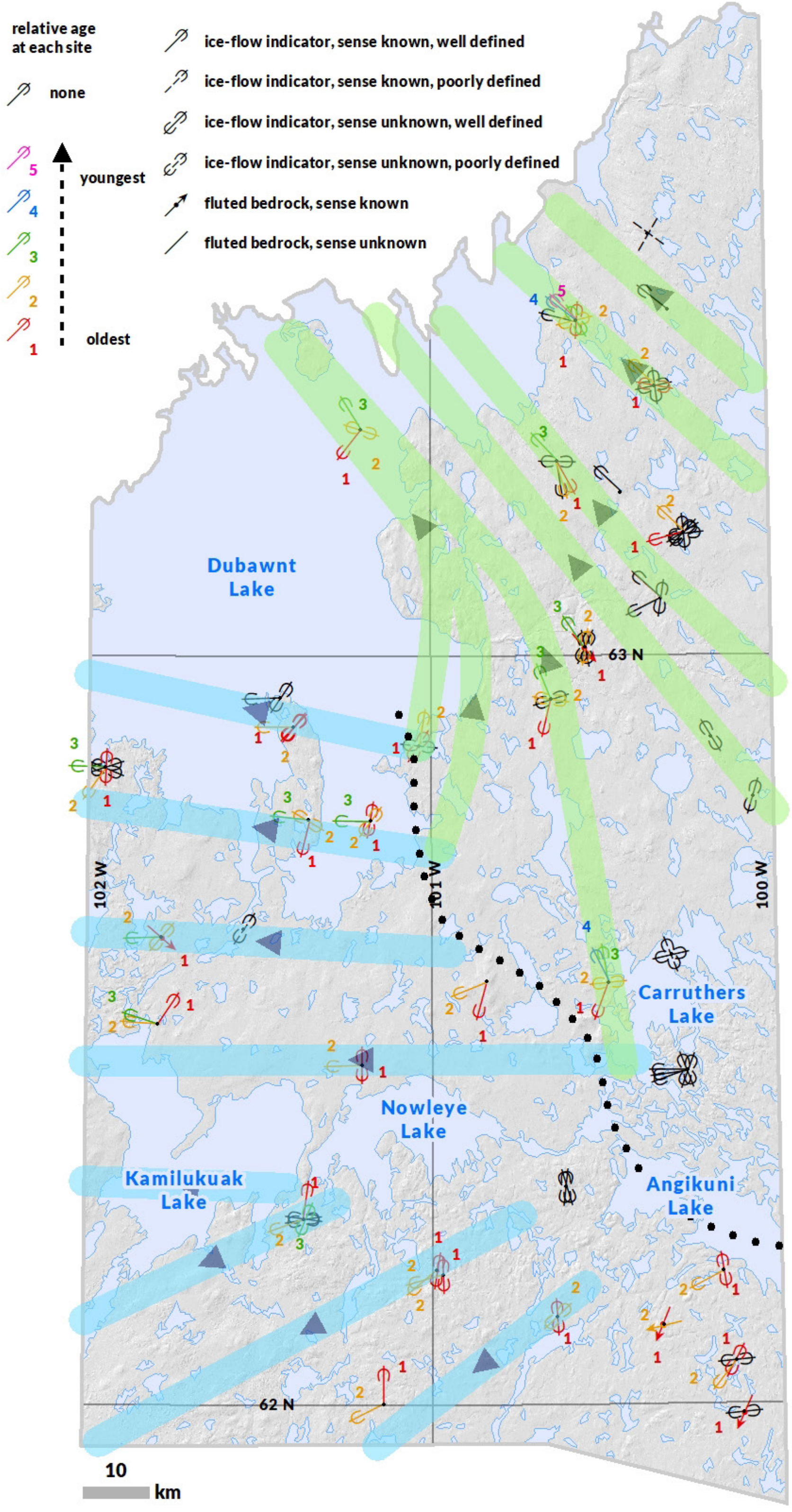

Figure 23. Flowset D (blue) and E (green) interpreted from preliminary mapping and field ice-flow indicators. The dotted line represent the approximiate limit between the two flows, i.e., potential divide, if they operated during the same period.

Landsystems

Overall, the preliminary analysis of the ice-flow erosional marks and landforms derived from field observations and preliminary mapping reveals that the study area can be categorized into four distinct landsystems (**fig. 24**). 1) The northeastern part of the field study area is characterized by a single set of landforms that are associated with DLIS. Within this landsystem, the identification of striations and outcrop molding from diverging flows proved to be challenging, as they were generally poorly defined. 2) The central region of the study area can be considered as a palimpsest streamlined glacial landsystems characterized by superimposed both ice-flow indicators and landforms. Geomorphological mapping remains to be completed in the study area but streamlined landforms showing cross-cutting relationship are visually discernible from elevation data (ArcticDEM). Furthermore, the multi-directional molding of outcrops and the striae record portray major changes in the ice-drainage of the Keewatin Sector of the LIS. 3) The SE corner of the field study area stands out with a relative absence of ice-flow indicators or landforms associated with flowsets D and E. Interestingly, this region only preserves striae from flowsets A and C, which are linked to older ice dynamics. Consequently, the southern part of the study area may be interpreted as a preserved remnant of a warm-based glacial landsystem that was subsequently covered by a younger ice that caused minimal terrain modifications. The occurence of this landscape suggests conditions of low erosion, possibly associated with an ice divide or a saddle, or temporary cold-based ice conditions. 4) Finally the SW part of the study area is characterized by the occurrence of sets of “fresh” rogen moraines and drumlinoid landforms that can be interpreted as a warm-based deglacial landsystem. We found no significant evidence of weathered bedrock that would indicate another landsystem consisting of cold-based terrains. The extent of these landsystems will further be investigated using remote mapping, GIS-based algorithms and TCN dating on bedrock samples.

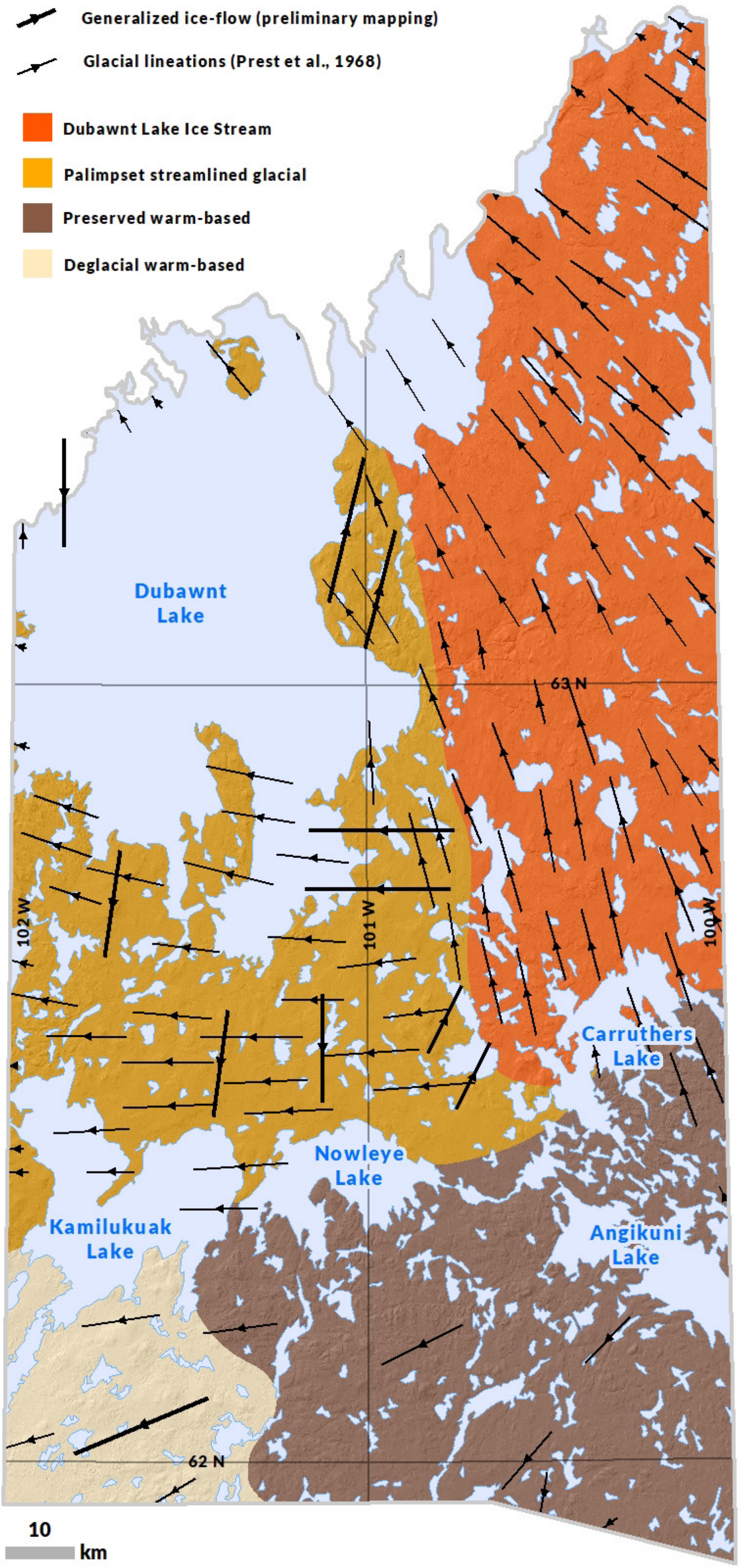

Figure 24. **Premilinary delineation of glacial landsystems in the study area. Brown arrows indicate the general direction of drumlinoids as depicted on the Glacial Map of Canada (Prest et al., 1968), while yellow arrows represent the generalized direction of ice-flow landforms identified through preliminary mapping.**

Glacial lakes

The remote mapping of landforms with ArcticDEM and ESRI World Imagery reveals an abundance of features (beaches, deltas, and spillways) associated with the inundation by glacial meltwater of low-elevation terrains surrounding Dubawnt, Angikuni, Nowleye and Kamilukuak lakes. Although the different landforms – especially beaches – were easily discernable on remote imagery, they turned out to be rarely suitable for either IRSL or TCN sampling in the field because of the grain size composition of these landforms (fig. 25). Beaches were generally too coarse grained for IRSL sampling yet too fine grained for TCN sampling. Therefore TCN samples of bedrock surface in meltwater channels associated to a distinct lake level were collected rather than cobbles from beaches. Overall, 9 TCN and 6 IRSL samples were collected at different elevations for age dating and hence should reflect different lake levels or lake basins. These new chronological datasets will provide, together with the digital mapping, a geochronological framework for the extent, development and drainage of these bodies of meltwater in the study area.

Figure 25. **Example of a set of beaches and spits (pointed by the black arrows) near Kamilukuak Lake (NRCan photo 2023-317).**

Distinctive cobble

The cobble sample, collected in a till deposit, is identified as a green quartzite (fig. 26) and will be further analyzed for whole-rock geochemistry to evaluate its composition and provenance. It is distinctive compared to locally observed bedrock and boulder lithologies and may prove to be a potential indicator of glacial transport direction if its source rock can be identified.

Figure 26. **Photograph (23BVB-B0037P002) of the vibrant green quartzite cobble as it was found in the field at the surface of glacial (till) sediments (NRCan photo 2023-311).**

Conclusions

Fieldwork was completed as part of the GEM-GeoNorth's West-central Keewatin Glacial Dynamics project in a northern remote area of mainland Nunavut to document and better constrain the regional glacial history. A total of 111 stations were visited from which we collected 108 ice-flow indicator measurements, 37 till samples for geochemistry and 40 samples for geochronology. Preliminary interpretations of the ice-flow measurements and ongoing remote mapping of the glacial geomorphology indicates that the study area went through several different major phases possibly representing 6 different ice flow events. The next steps for this project will involve the analysis of the different samples to provide a context for the field and mapping datasets. Forthcoming till compositional data will provide a regional framework for drift prospection and environmental applications. Finally, integrating these new field datasets with remote geomorphological mapping will strengthen the regional glacial history framework, resulting in a deeper understanding of the history of the LIS and, consequently, enhancing the success for mineral exploration in this northern Canadian region.

Acknowledgments

We are grateful for the opportunity to base our field operation out of Tukto Lodge and wish to thank our host Curt Enns for his hospitality and support. We thank Menno and Tamara Bergen for their relentless work and kind support at the lodge. We are thankful for the hard work and exceptional skills of pilot Ray Roy-Gervais, and we are grateful for the helicopter support provided by Great Slave Helicopter. We thank Christopher Nakoolak for his monitoring of wildlife, for his help with sampling and for sharing his knowledge and experiences. Special thanks go to the Baker Lake Hunters and Trappers Organization for their support in the hiring process of a wildlife monitor and for their valuable input before our fieldwork. We thank the Field Equipment Unit (FEU) of Polar Continental Shelf Program for their logistical support. We greatly appreciated Adam and Julie Duff of Scott's General Store, Stony Rapids for their help with groceries, supplies and fuel, and Ed White of the Waterfront Lodge for his hospitality. We thank Wings over Kississing for providing fixed wing support. We finally thank GSC collegues Louis Robertson, Anushika Da Silva, Danny Wright, Rebecca Pearson, Miranda Adam, Tom Kingdon, Michel Plouffe and Geneviève Marquis for their enthusiastic support for the project and assistance prior to and after the field work. We would like to acknowledge Roger Paulen for his critical review, which contributed to the improvement of this manuscript.

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