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Report of 2024 field activities for the GEM-GeoNorth West-central Keewatin Glacial Dynamics Activity, Nunavut

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Past glaciations remain poorly studied in many remote areas of northern Canada, particularly in regions like mainland Keewatin where access is difficult and data on glacial geology are scarce. As part of the GEM-GeoNorth West-central Keewatin Glacial Activity, field investigations around Dubawnt Lake were undertaken in 2023. Despite a successful campaign, significant gaps in the spatial distribution of field sites necessitated another field season in 2024 to improve site coverage and visit additional targets. Here, we detail the 2024 field methodology used to collect ice-flow indicator measurements, till samples for compositional and provenance studies, and bedrock and boulder samples for geochronological studies. A total of 88 ground observation sites were visited and 75 ice-flow measurements and 69 samples were collected. Our preliminary data supports previously reported relative ice-flow chronology. The new datasets, along with till compositional data and geochronological analyses, will be integrated with remote geomorphological mapping to enhance our understanding of the regional glacial history and support effective land-resource planning decisions in this part of northern Canada.

Introduction

Palaeogeographic reconstructions of the Laurentide Ice Sheet (LIS) are essential for advancing research in glaciology, glacial isostatic adjustment modelling, sea-level changes, and mineral exploration. Despite significant progress in understanding the LIS by studying its depositional and geomorphological records, the glacial history of vast areas of northern Canada, particularly those that hosted the major dispersal centres (domes) of the LIS, remains poorly understood. In 2022, the West-central Keewatin Glacial Dynamics Activity was initiated under Natural Resources Canada's GEM-GeoNorth program to map the glacial geomorphic features and terrains over the West-central part of the Keewatin region (100–108°W and 60–68°N; **fig. 1**), which hosted the Keewatin Dome, one of the three principal dispersal centres of the LIS. Targeted field investigations were also planned as part of the project to collect data necessary to inform the interpretation of the glacial processes that drove the landscape modification, which include changes in paleo-ice dynamics (ice sheet geometry, ice-flow organization, and basal thermal regime), sediment dispersal patterns, and glacial lake development and drainage. In 2023, fieldwork was conducted around Dubawnt Lake in the core region of the Keewatin Dome (100–102°W and 61.75-63.94°N; **fig. 1**) with the objectives of: (1) documenting and sampling tills to assess their composition and regional glacial transport patterns, (2) recording ice-flow indicators to refine the regional ice-flow chronology, and (3) collecting boulder and bedrock samples for terrestrial cosmogenic nuclides (TCN) for exposure dating and to understand the degree of erosion and weathering of glacial terrains, as well as to estimate the minimum ages for the ice-sheet retreat and glacial lake inundation (Brouard et al., 2024).

The 2023 investigations documented various ice-flow indicators, sets, and till compositions that together established a preliminary framework for understanding ice flow events and sediment distribution (Brouard et al., 2024; **fig. 3**). Regional ice flows observed in 2023 include an early SW-oriented flow believed to date back to the Last Glacial Maximum or earlier (e.g., Boulton and Clark, 1990; Kleman et al., 2002; cf. flow A of McMartin and Henderson, 2004); followed by a W to E flow (cf. flow C of McMartin and Henderson, 2004); which was followed by a NW flow associated with the Dubawnt Lake Ice Stream (DLIS), characterized by distinct mega-scale glacial lineations (MSGLs), crag-and-tail landforms and drumlins, as well as smaller features such as striations and grooves that formed during early deglaciation (9-8 ka; Stokes and Clark, 2003; **figs. 2 and 3**); and, finally, late-glacial flows from the retreating and decaying Keewatin Dome as it evolved into the Keewatin Ice Divide, characterized by a range of W- and SW-trending ice-flow indicators (Dyke and Prest, 1987; cf. flow F of McMartin and Henderson, 2004; **fig. 2**). While the regional ice-flow patterns identified in 2023 mostly align with those observed in neighbouring areas, some ice-flow indicators deviate from the established regional models. Notably, S-N flow indicators—among the oldest identified at their respective sites—introduce additional complexity to the ice-flow chronology (flow A and A*; **fig. 3**). Overall, the preliminary relative ice-flow chronology from 2023 relies on scattered measurements and requires increased observational and spatial constraints, especially across the Dubawnt and Angikuni lake axis, where an ice divide likely existed during the last glacial cycle (Dyke and Prest, 1987; Brouard et al., 2024; **fig. 2**). Eventually, compositional analyses of the 37 till samples collected in 2023 will also contribute to refining the ice-flow chronology by revealing trends in sediment dispersal. However, detecting dispersal patterns will likely require a higher number and density of samples. Thus, collecting additional till samples to fill in existing gaps would significantly enhance the chances of uncovering clear dispersal trends (**fig. 3**).

The measurement of ice-flow indicators and their attendant relative chronology are intricately linked to the region's physiography and underlying bedrock geology. The regional substratum predominantly consists of crystalline lithologies, which have influenced the patterns of differential glacial erosion across the landscape. As noted in 2023, the study area can be tentatively divided into four distinct landsystems based on their apparent glacial erosion history/thermal basal regime: The Dubawnt Lake Ice Stream landsystem, characterized by a single set of large, well-defined landforms, is found in the northeast; the palimpsest landsystem, marked by superimposed and cross-cutting ice-flow indicators, occupies the central and northwest regions; the preserved warm-based glacial remnant landsystem, with low-erosion features, defines the southeast; and the warm-based deglacial landsystem, featuring rogen moraines and drumlinoid landforms, characterizes the southwest of the area (**fig. 3**). Terrestrial cosmogenic nuclide (TCN) samples were collected in 2023 to investigate spatial disparities in glacial erosion, but additional TCN samples are needed to better delineate the spatial distribution of landsystems, especially the interpreted "preserved warm-based" landsystem.

Large areas around Dubawnt Lake show evidence of glaciolacustrine sediment deposition and erosion at various elevations, suggestive of extensive inundation by one or multiple glacial lakes, including Glacial Lake Dubawnt (Prest et al., 1968; **fig. 2**). As part of this activity, the spatial distribution and chronology of the glaciolacustrine landforms are being investigated using modern techniques such as remote mapping with imagery derived from high-resolution satellite data (e.g., Arctic-DEM; Porter et al., 2018; and ESRI World Imagery), infrared-stimulated luminescence (IRSL) dating, and TCN exposure age dating. In 2023, nine TCN and six IRSL samples were collected at various elevations to date different lake levels or basins. These samples, however, are concentrated in three separate basins and on two types of landforms (wave-washed lake limits and spillway bottoms; **fig. 3**). Therefore, additional sampling toward the centre and northwest parts of the study area, as well as targeting different glaciolacustrine landforms (e.g., boulders on deltas), are required to provide a more complete and robust portrait of landform formation (e.g., beaches, deltas, spillways, wave-washed bedrock surfaces) in the area.

This report details the methods employed during the 2024 field season to fill remaining gaps and presents preliminary results and highlights from our observations, measurements, and samples, along with a discussion on the ice flow record, glacial landscape evolution, glaciolacustrine sampling, and plans for future work.

Figure 1 | Extent of the field study area for the West-central Keewatin Glacial Dynamics Activity (shaded in orange) within the broader context of North American ice sheet coverage during the last glacial maximum (Batchelor et al., 2019). The larger orange rectangle indicates the remote mapping study area, while the smaller orange-filled area represents the specific field study region near Tukto Lodge, Nunavut (NU). Key ice sheet regions are labelled: Keewatin Dome (K), Quebec-Labrador Dome (QL), Foxe Dome (F), Cordilleran Ice Sheet (CIS), Innuitian Ice Sheet (IIS), and Greenland Ice Sheet (GIS). Dotted lines indicate ice divides and saddles, while thin blue lines illustrate generalized ice flow directions (Dyke and Prest, 1987). National (ESRI) and provincial boundaries (CanVec), and major waterbodies (Natural Earth Data) are also included for reference.

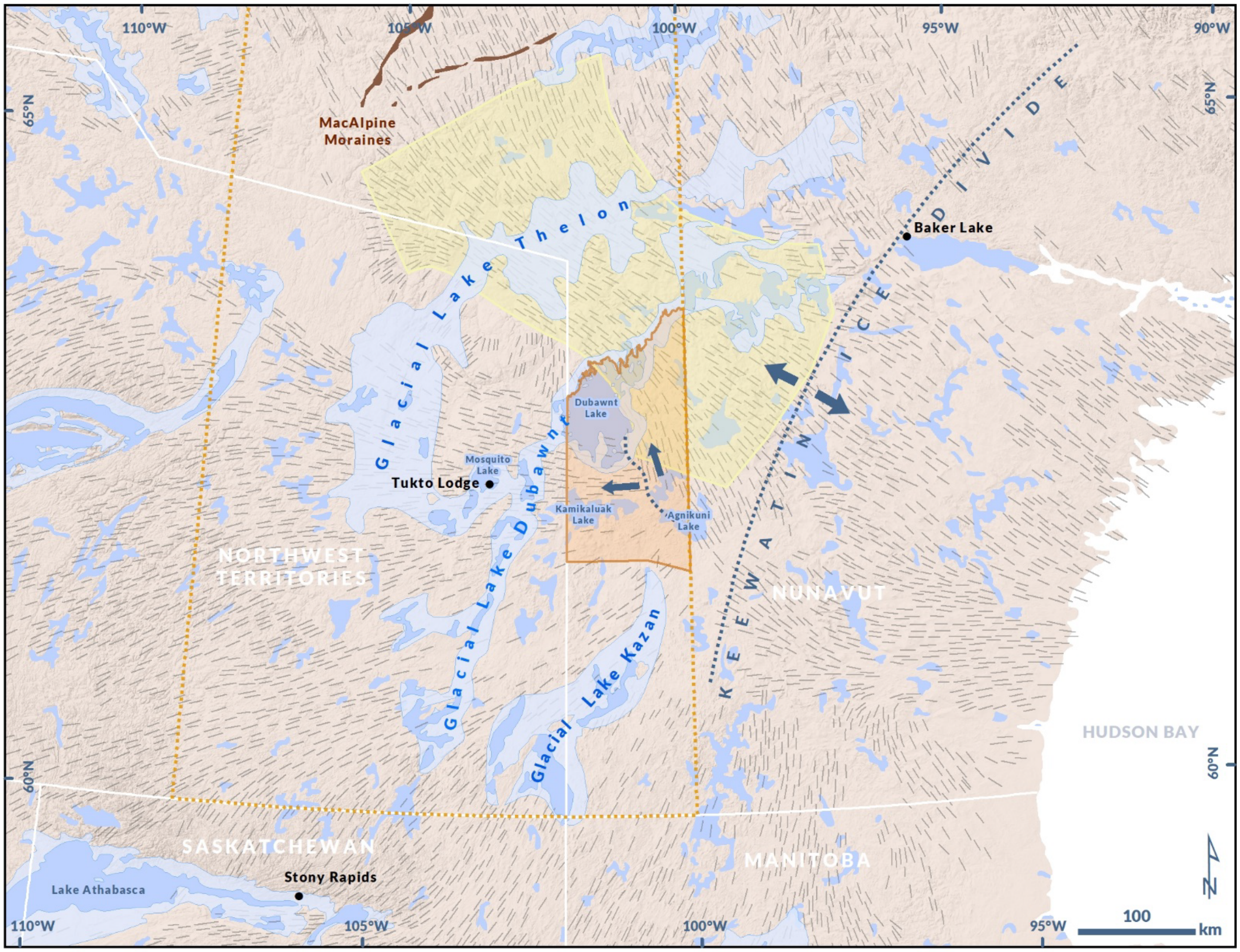

Figure 2 | 2024 field study area (orange-filled polygon), remote mapping project area (dotted orange line), and location of the base camp at Tukto Lodge, Mosquito Lake. Thin grey lines indicate glacial lineations, and light-blue areas show the extent of glacial lakes as depicted on the Glacial Map of Canada (Prest et al., 1968). The yellow polygon delineates the Dubawnt Lake Ice Stream extent (Margold et al., 2014). Dotted lines show approximate late position for the Keewatin Ice Divide (McMartin et al., 2017) and the position of the ice-flow divergence along the Dubawnt-Angikuni lakes axis (small blue dotted line; Brouard et al., 2024).

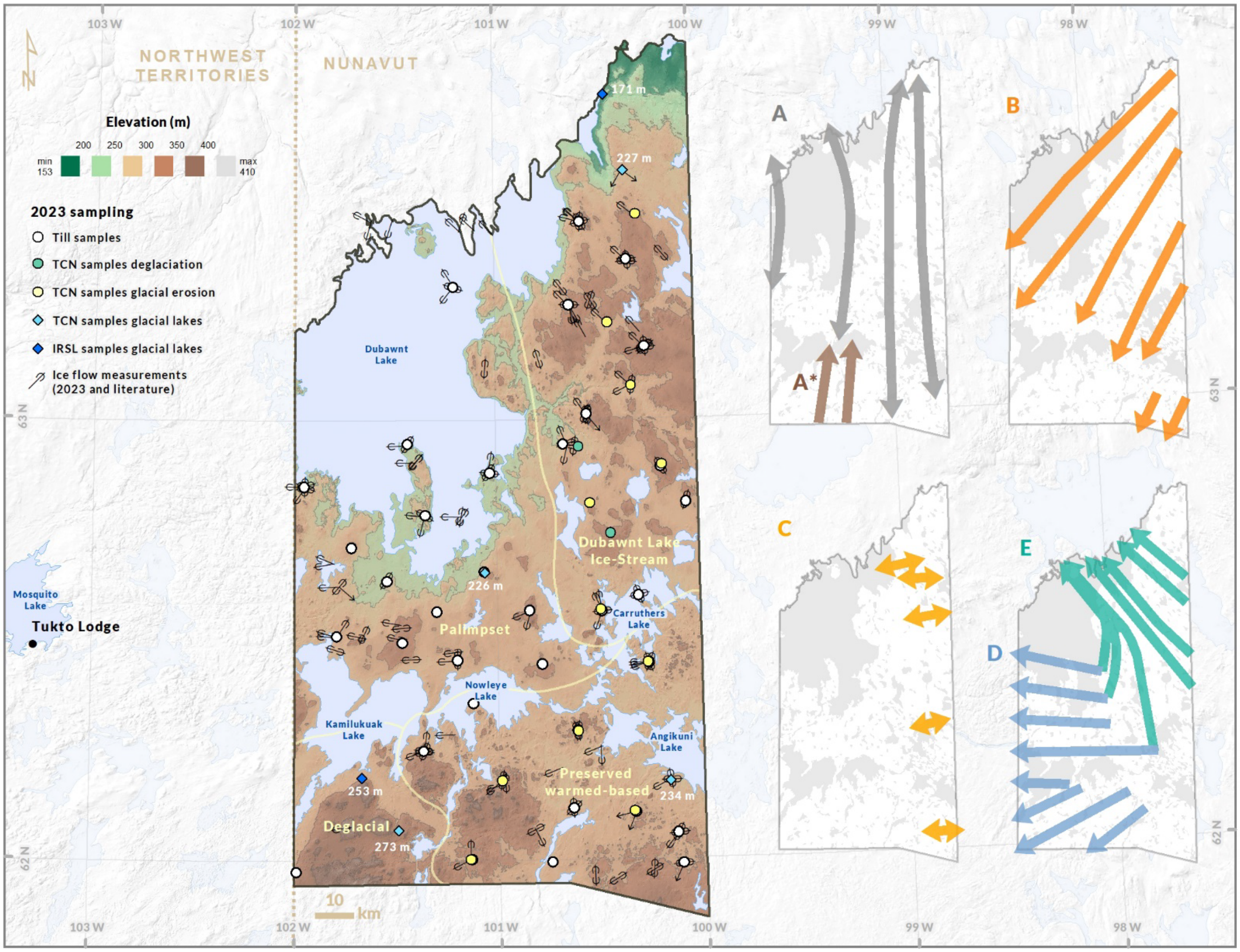

Figure 3 | Summary of 2023 fieldwork, showing elevation and locations of various sample types (TCN, IRSL, till) for glacial lakes, erosion, and deglaciation studies and ice-flow indicator measurements (e.g., striae, grooves). The study area is divided (yellow line) into four distinct landsystems (cf. Brouard et al., 2024): The Dubawnt Lake Ice Stream landsystem, characterized by a single set of large, well-defined landforms, is found in the northeast; the palimpsest landsystem, marked by superimposed and cross-cutting ice-flow indicators, occupies the central and northwest regions; the preserved warm-based glacial remnant landsystem, with low-erosion features, defines the southeast; and the warm-based deglacial landsystem, featuring rogen moraines and drumlinoid landforms, characterizes the southwest of the area. Insets display preliminary relative ice-flow chronology and identified ice-flow sets from oldest to youngest (A to E) as reported in the 2023 report (Brouard et al., 2024).

Methods

Logistics

The scientific team comprised two Geological Survey of Canada (GSC) research scientists (Etienne Brouard and Pierre-Marc Godbout), a professor from Université du Québec à Montréal (UQAM) (Martin Roy), and a MSc student at UQAM (Noé-Malcolm Renaud). The crew was supported by a wildlife monitor from Baker Lake (Barney Aaruaq), a helicopter pilot, and two staff members at the lodge. Helicopter-based field operations were conducted between August 3rd and August 14th from the Tukto Lodge base camp on Mosquito Lake, Northwest Territories (62.492 °N, 103.283 °W), with a single fuel cache to facilitate long-distance flights.

Geospatial Data Acquisition

At each site, ground observations were recorded in the GSC Field Application (Version 2.4.1; https://github.com/NRCan/GSC-Field-Application) installed on a Juniper Systems Mesa 3 rugged tablet running the Windows 10 Operating System. The GSC Field

Application uses the tablet built-in GPS to locate (position and elevation) individual stations linked to the Surficial Data Model (v2.5.1; Deblonde et al., 2024) 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 (.gpkg) and geodatabase (.gdb) resulting from the 2024 fieldwork are provided with this report (**suppl. material 1**).

Photographs were taken at both remote and ground observation sites using either a Canon Powershot D30 or the built-in camera of an iPad Pro (3rd generation; iOS 17.6). Custom maps (.tif format) were uploaded to the Avenza Maps application (https://www.avenza.com/avenza-maps/) on both the iPad Pro and iPhones for navigation. A hand-held Garmin GPS was used to track the helicopter's position.

Measurements and sampling

Measurement of ice-flow indicators

Palaeo ice-flow indicators such as small landforms (e.g., roches moutonnées) and small-scale erosional features (e.g., striations, grooves, etc.) were measured on bedrock outcrops to document the direction(s) and sense(s) (when possible) of ice flows and their relative chronology where applicable (**fig. 4**). The azimuth of each feature was measured with a 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, relative position, and number of indicators for each landform/feature were recorded in the GSC Field Application. The relative chronology was also recorded where more than one set (direction) of indicators was observed at a single 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 and Roy, 1995; McMartin and Paulen, 2009).

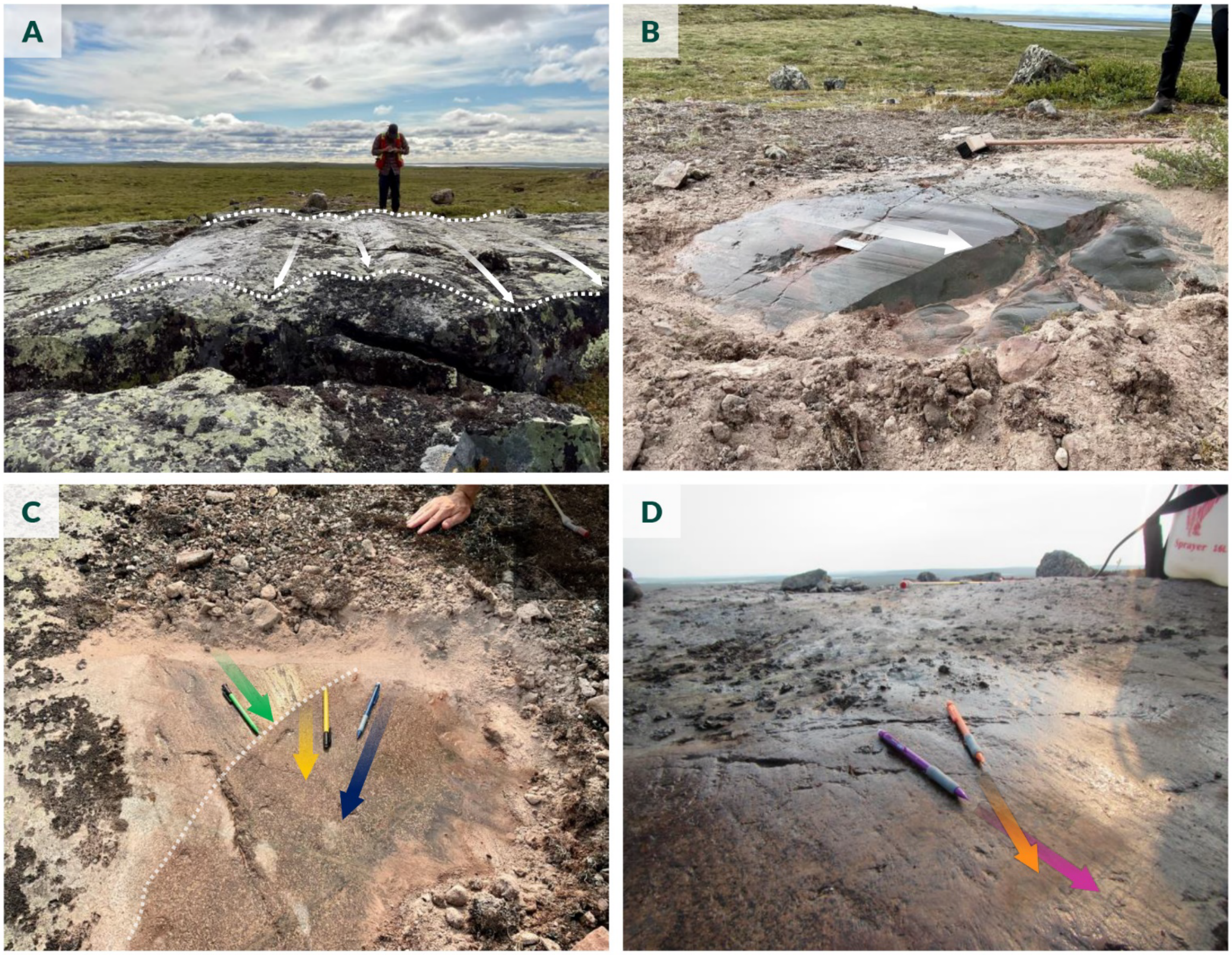

Figure 4 | Examples of ice-flow indicators observed in the field. **A.** Grooves delineated by the white arrows (ice-flow direction), on top of a roche moutonnée in the Dubawnt Lake Ice Stream (Station 24BVB0012; NRCan photo 2023-705). **B.** Small grooves and striations on top of glacially polished outcrop at the same station as in A (NRCan photo 2023-706). The white arrow shows the orientation of the ice flow. **C.** Faceted surface with the edge (dashed white line) delimiting the different sets of striae at station 24BVB0053 (NRCan photo 2023-707). The youngest set is shown on top in green while the yellow and blue arrows show the direction of the two oldest ice-flow sets found on the lower protected surface. **D.** Cross-cutting fine striations at station 24BVB0072 (NRCan photo 2023-704). Pen and arrows are used here to show the direction of striations on outcrop. The striations marked by the orange pencil cross-cut (i.e., younger than) those marked by the purple pencil.

Till Sampling

Potential till sampling sites were identified prior to fieldwork using high-resolution ESRI World Imagery, ensuring comprehensive geographic coverage that complemented the 2023 sampling campaign. Targeted sites were mostly located on gently rolling till plains situated on higher grounds with well-developed frost boils (e.g., **fig. 5a**). The samples were recovered from hand-dug pits in active frost boils (**fig. 5a-d**) following the established till-sampling protocols at the GSC (McClenaghan et al., 2023).

At each site, two samples were collected from the C-Cy soil horizon: a small sample (~3–5 kg) and a large sample (~10–15 kg), both in plastic bags. These samples are intended for sedimentological and geochemical analyses of the till-matrix fine fraction (small sample), as well as for characterizing the heavy mineral and clast lithological content of coarser fractions (large sample; **fig. 5c**). Field duplicates were also collected at two sites, approximately 5–10 m from the primary sampling hole, to assess site variability. All the holes dug were filled back after the sediment sampling was completed (**fig. 5d**).

Data for each sample, including sample number, type, purpose, quality, depth, and other relevant information, was recorded in the GSC Field Application. The small (~3–5 kg) till samples will undergo initial processing at the GSC Sedimentology Laboratory in Ottawa before being shipped to an external laboratory for geochemical analysis. Analyses at the GSC Sedimentolgy Laboratory will include textural analysis of particles, dry Munsell colour evaluation, total carbon content, calcite/dolomite content, and preparation of the silt+clay (<63 µm) fraction for geochemical analysis in a commercial laboratory. The large till samples will be shipped to an external laboratory for indicator mineral analyses. Pebble fractions (8–30 mm) for lithology counts will also be recovered during the processing of the large samples.

Figure 5 | Examples of till sampling sites. **A.** Frost boils (pointed by white arrows) in till as seen from the helicopter (NRCan photo 2023-708). Till plain dissected by a subglacial meltwater corridor, delimited here by the dashed lines**. B.** Fresh (active) frost boil prior to sampling at the station 24BVB0060 (NRCan photo 2023-703). **C.** Dug hole (~45 cm depth) in a fresh frost boil at station 24BVB0020 (NRCan photo 2023-700). **D.** Refilled sample hole after sampling at station 24BVB0020 (NRCan photo 2023-701).

Sampling for Terrestrial Cosmogenic Nuclide (TCN) Dating

Sampling for TCN dating focused on boulders (>1 m) and bedrock outcrops with granitic or quartz-rich lithologies that were suitable for exposure dating (i.e., flat-top surfaces with visible quartz grains). Sampling sites were selected using satellite imagery and based on the location of 2023 TCN samples as a reference for filling in data gaps.

At each site, grids approximately 2–3 cm deep were cut into the rock surface using a battery-powered portable rock saw (DeWalt 60V MAX Brushless Cordless 9″ Cut-Off Saw) equipped with a water-cooled diamond blade. The rock material within the grid was then separated using a chisel and hammer and collected in plastic bags for transport (**figs. 6 a-d**).

Topographic shielding values will be calculated from digital elevation model analyses (Li, 2018) using the 2-m ArcticDEM (Porter et al., 2018). Details on each sample, including sample number, type, purpose, quality, depth, and other relevant information, were recorded in the GSC Field Application.

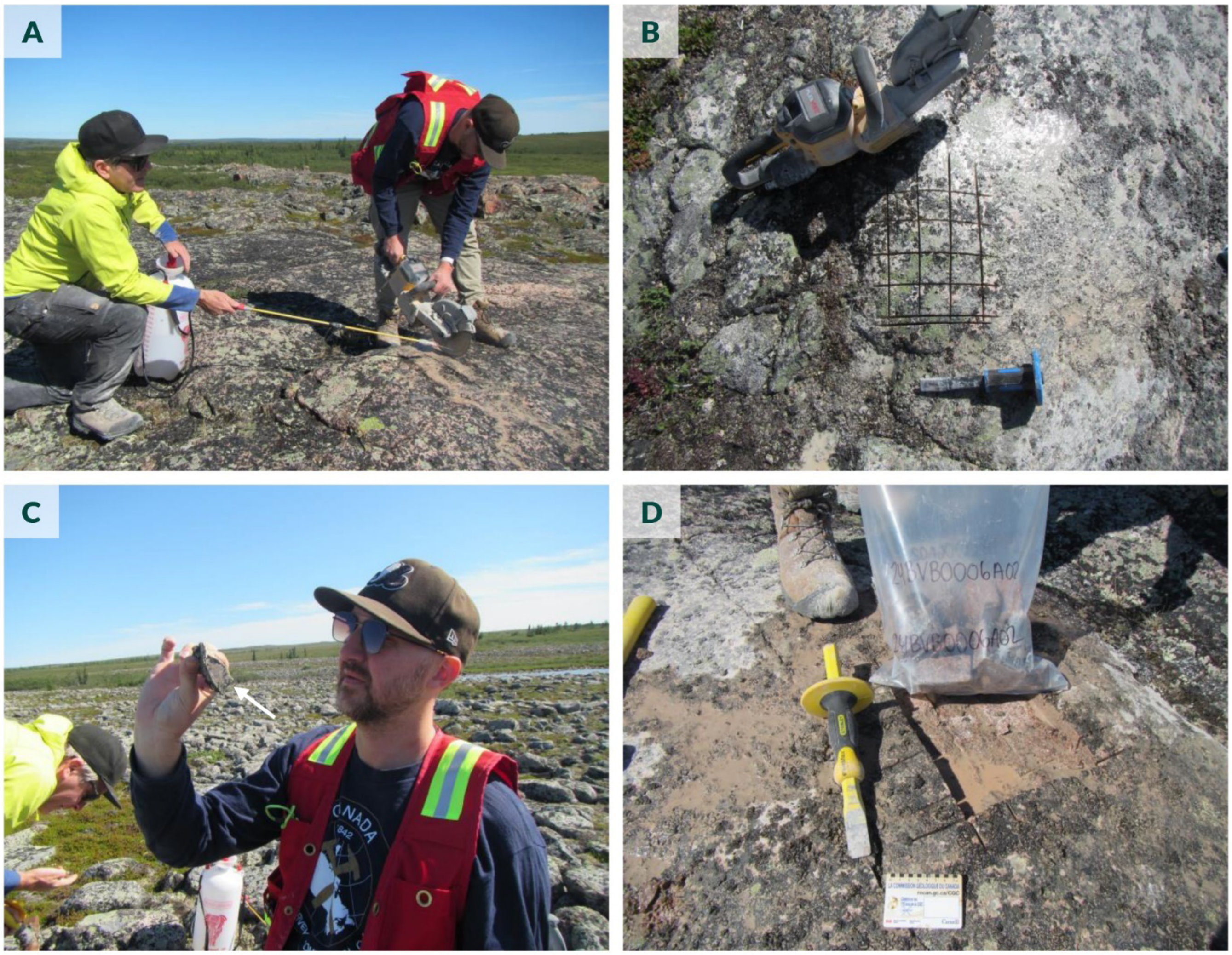

Figure 6 | TCN sampling sites. **A.** TCN sampling using the portable rocksaw at station 24BVB0006, (NRCan photo 2023-696). **B.** Resulting sampling grid at station 24BVB0033, (NRCan photo 2023-702). **C.** Typical rock chip (1.5-2 cm, white arrow) separated from the surface using a chisel and a hammer, photo 24BVB0005P011 (NRCan photo 2023-695). **D.** Sampling surface and bagged sample after TCN sampling at station 24BVB0006, (NRCan photo 2023-696).

Sampling for hand-size bedrock samples and lithogeochemical analysis

Hand-size samples (~0.5 kg) and fresh (unweathered) rock chips were collected, from an erratic boulder of distinct lithology (sedimentary), as representative samples for visual pebble lithological counts and whole-rock geochemical analysis to determine the geochemical signature of distinct lithologies.

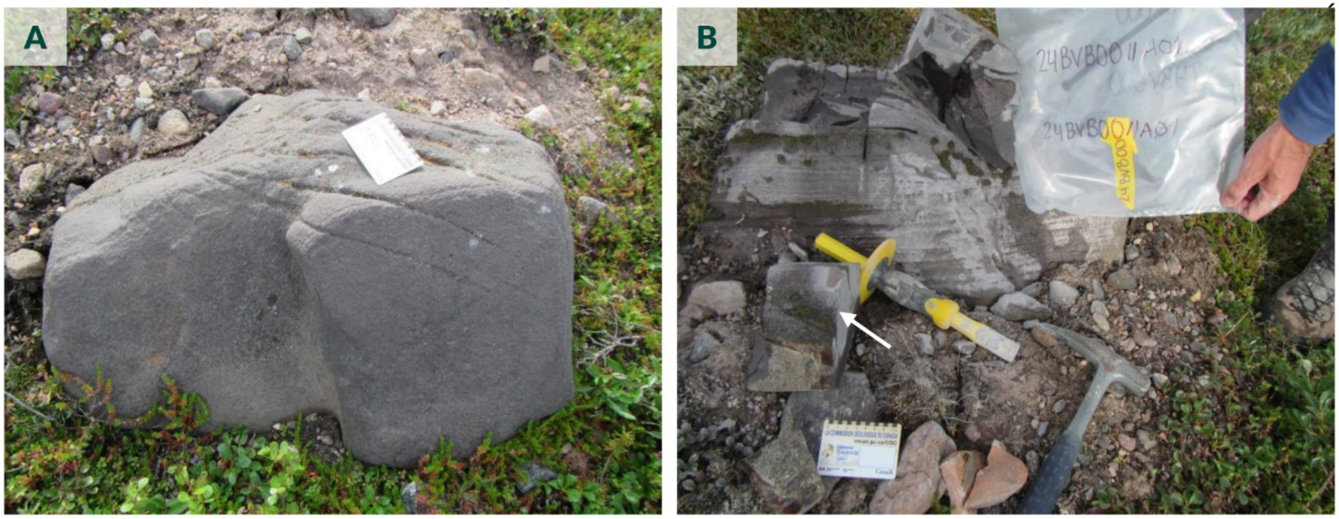

Figure 7 | **A.** Glacial erratic boulder sampled for lithogeochemical and provenance analyses, photo 24BVB0011P007 (NRCan photo 2023-698). **B.** The same boulder after sampling, photo 24BVB0011P010 (NRCan photo 2023-696). The hand sample collected (24BVB0011A01) is indicated by the arrow.

Results

Field database, stations, and photographs

Fieldwork in 2024 consisted of different ground observations at 88 distinct locations (stations) spread across ~14,000 km^2 (**fig. 8**). These stations fall into the following categories: 35 dugholes, 35 ice-flow indicator sites, one natural exposure, and 17 geochronology sites. The geographical distribution of these stations included various landforms: twenty-three on hills, fourteen on bedrock uplands, eight on crag-and-tail features, eight on islands, seven on till plains, six on bedrock shorelines, four in meltwater channels, four on streamlined drift, three on deltas, three on undifferentiated moraines, two on Rogen moraines, one on an esker, one on a drumlin, and one on a kame. A total of 726 photographs were taken at and around these locations and are included in the database to provide visual support.

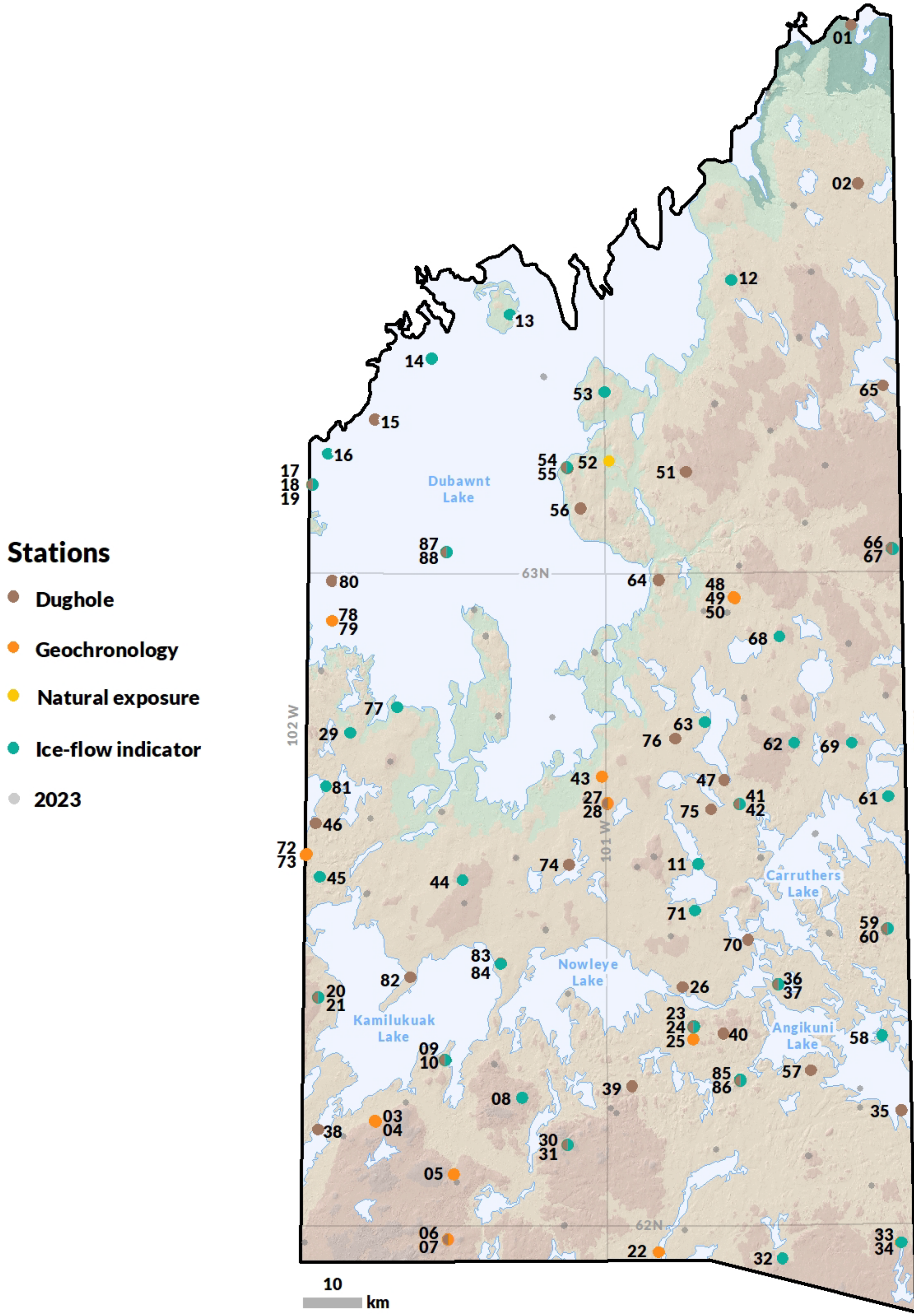

Figure 8 | Location of the 2024 field observations (stations). Note that multiple types of observations (dugholes, geochemistry and ice-flow indicators) were taken at some sites. 2023 sites shown in grey for reference, and overall distribution of sites visited.

Ice-Flow Measurements

A total of 75 ice-flow measurements and small-scale erosional indicators were collected from 37 individual stations (**fig. 9**). Emphasis was placed in the northern and eastern parts of Dubawnt Lake and in the southeastern part of the study area, filling in gaps left after the 2023 field season. These measurements comprised 64 striations, 6 grooves, 4 roches moutonnées, and 1 stoss and lee topography. The sense of the ice flow could be inferred (i.e., "known") for 41 of the 75 measurements (55%). The most complex relative ice-flow chronology at a single station included three different sets of ice-flow indicators (12 sites).

Till Samples

A total of 38 tills were sampled at 36 field stations (2 stations with field duplicates) for geochemical analysis (~3 kg) and indicator mineral analysis (>10 kg; "geochemistry&HM" in GSC Field Application; **fig. 10**). Till sampling was distributed throughout the study area, filling most gaps left after the 2023 field season. Field estimations indicated that the majority of the surface till samples (71%) contained a moderately compact fine silty-sand or sandy-silt matrix, with 66% showing a brown colouration. Interestingly, 68% of the tills exhibited secondary colours such as red or pink. The clast content of the tills was estimated to range between 5% and 30% of the total volume.

Boulder Samples

Twenty-one boulders were sampled at 13 stations for TCN exposure dating, and at one station (78A01) an erratic boulder was sampled for provenance (**fig. 11a**). Boulder samples were predominantly collected in the western part of the study area, which was not investigated during the 2023 field season but showed numerous glaciolacustrine landforms. Sixteen of these boulder samples were collected to investigate the timing of glacial lake development, one to characterize the degree of subglacial erosion, and three to provide minimum deglacial ages to constrain ice margin retreat. The boulder sample collected to assess subglacial erosion was paired with bedrock samples, which were also collected for TCN dating (see subsequent section). The boulders sampled in relation to glacial lakes were either resting on glaciolacustrine delta pads (n = 7), wave-washed surfaces near the upper limit of glacial lakes (n = 4), or within meltwater channels feeding glaciolacustrine deltas (n = 5).

Bedrock Samples

Ten bedrock surfaces were sampled at six individual stations for TCN exposure dating (**fig. 11b**), generally close to where boulders were sampled for TCN. Six bedrock samples were collected to study the development of glacial lakes, and 4 samples were taken to assess the degree of erosion of glacial landscapes. The bedrock samples collected near glacial lakes were taken from wave-washed surfaces near the upper limit of glacial lakes or at the bottom of a channel feeding a glaciolacustrine delta (station 06).

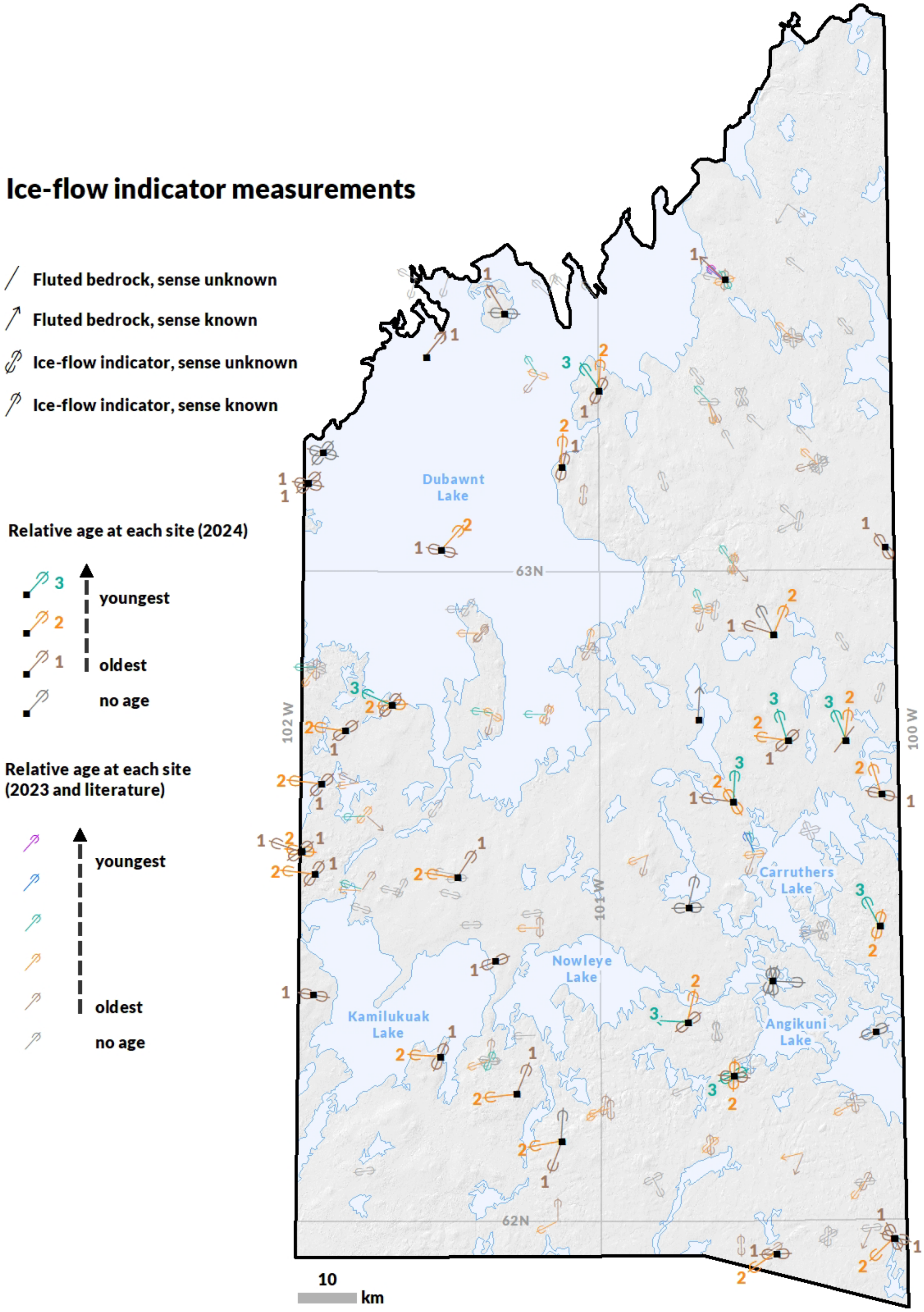

Figure 9 | Distribution of ice-flow measurements.

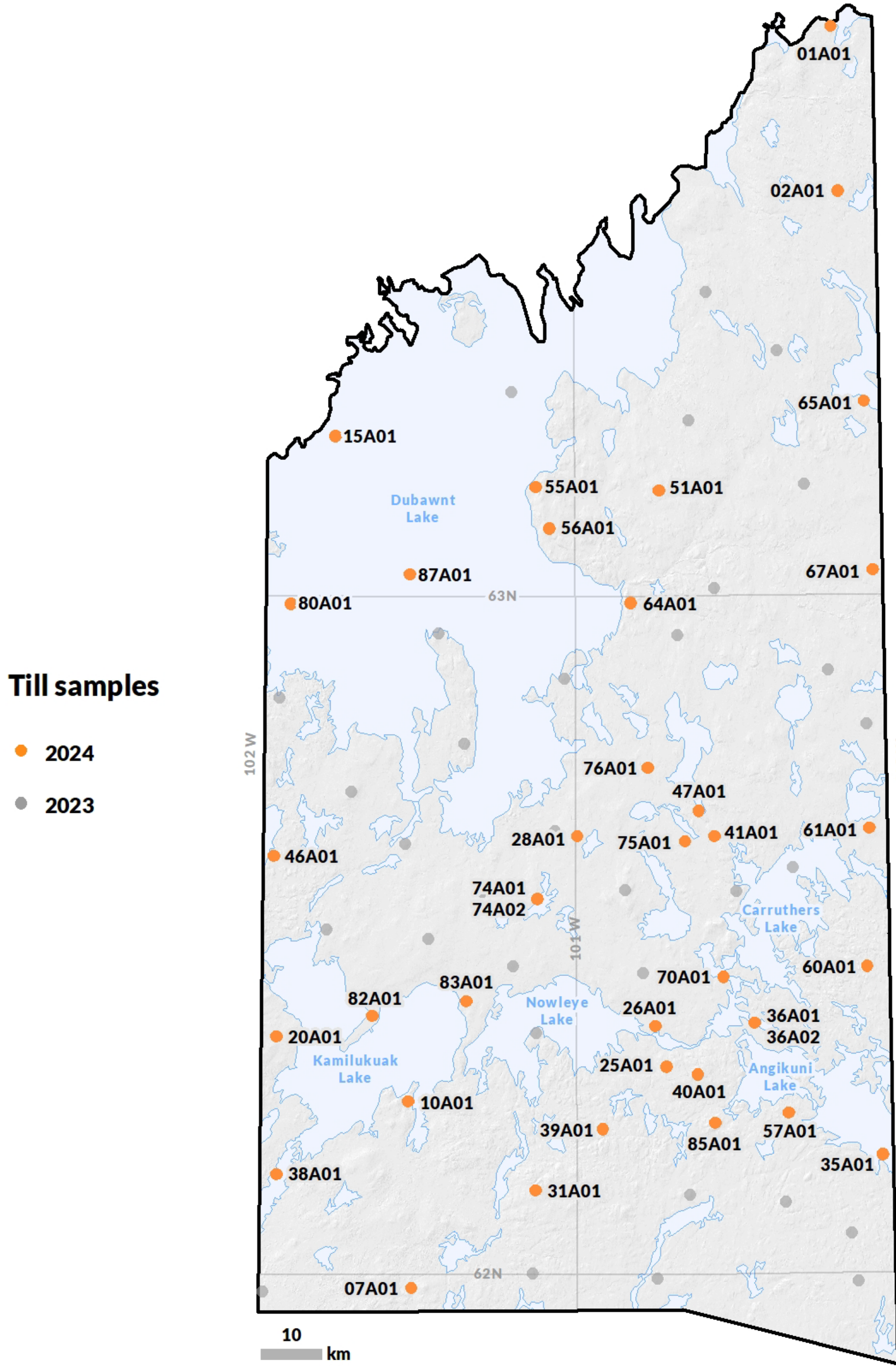

Figure 10 | Distribution of till sample sites.

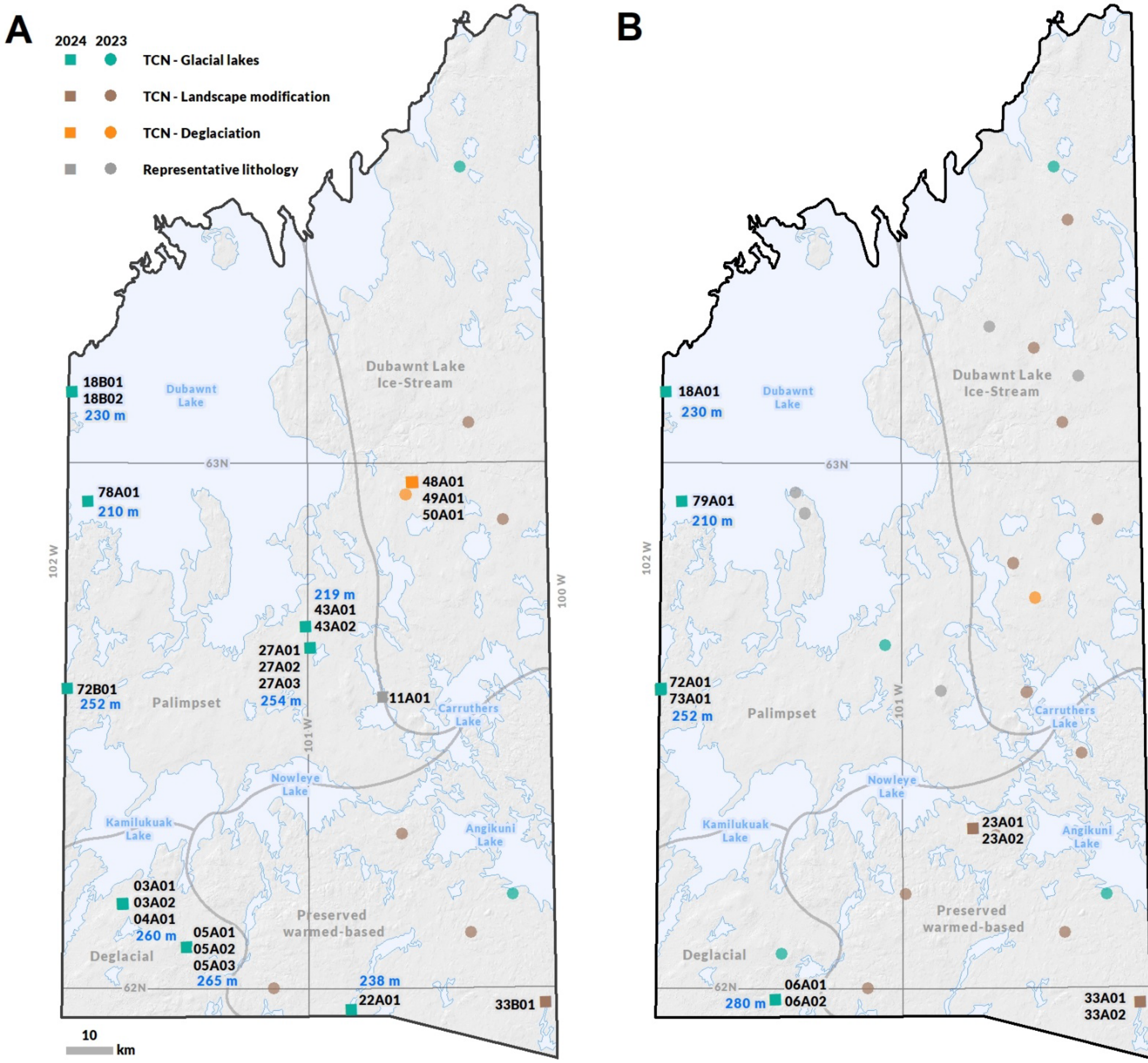

Figure 11 | **A**. Distribution of boulder samples by purpose. Where samples were collected for studying glacial lakes, the elevation of the site is labelled in blue. **B**. Distribution of bedrock samples by purpose. Where samples were collected for studying glacial lakes, the elevation of the site is labelled in blue.

Discussion

Ice Flows

Ice-flow indicators measured during both the 2023 and 2024 field seasons are largely consistent with regional ice-flow sets (i.e., McMartin and Henderson, 2004) and landforms on published surficial maps (Prest et al., 1968; Geological Survey of Canada, 2017a, b, 2019). Evidence of an older SW ice flow (cf. Flow A of McMartin and Henderson, 2004; **fig. 12**—flowset B) was measured almost across the whole study area. These features likely correspond to pre-LGM or earlier glacial flows observed in adjacent regions (Boulton and Clark, 1990; Kleman et al., 2002; McMartin and Henderson, 2004; Kleman et al., 2010; Dalton et al., 2022).

In the eastern portion of the study area, we observed striae indicating an E flow (**fig. 12**—flowset C). These eastward indicators are superimposed by younger striae oriented to the north and southwest. This pattern could align well with previously hypothesized early E ice flows toward Hudson Bay (cf. Flow C of McMartin and Henderson, 2004). However, their relationship with SW-oriented striae from flowset B remains elusive, mostly because flowset B is oriented in the same direction as younger, late deglacial flowsets. Hence, flowset C could also be older than flowset B and could align with other E flows documented in neighbouring areas which are older than flowset B (Dredge et al., 1986; Campbell, 2002; Hardy et al., 2005).

We also measured NNE-oriented striae (**fig. 12**—light-grey arrows) that are younger than flowsets B and C but older than flowset E. These features are consistent in age and orientation with the Chantrey Ice Stream (Ozyer, 2011; Hodder et al., 2016; McMartin et al., 2021), suggesting these indicators could represent the southwestern extent of that system. Diverging westward-oriented striae (cf. Flow F of McMartin and Henderson, 2004; **fig. 12**—flowset D) were also measured, as were indicators associated with the converging Dubawnt Lake Ice Stream flow (Stokes and Clark, 2003; **fig. 12**—flowset E). In addition, we identified relatively young (or of unknown relative age) striae, oriented either sub-parallel to deglacial features such as eskers (**fig. 12**—dark blue flowset) or perpendicular to deglacial isochrones. These indicators are interpreted to have been formed during the local late-glacial retreat phase.

Several sets of ice-flow indicators remain ambiguous in terms of age and their position in the relative ice-flow chronology and as such complicate spatial correlations, and the delineation of robust flow sets. For example, the N-oriented striae in the southern part of the study area, previously attributed to a N-NE flow (Flow A*), could potentially predate any other known flows in the region (**fig. 12**; Brouard et al., 2024). However, flowset A* lacks a clear relation to flowset B, which makes it difficult to place in the regional chronology. Similarly, NE-trending striae identified in the northwestern part of the study area on an island in Dubawnt Lake (**fig 12**; dark grey arrow) lack a clear association with known ice-flow patterns.

Future data compilation in the field study area, including high-resolution remote mapping and integration of all datasets (e.g., till geochemistry, indicator minerals, and clast lithology), will provide a better regional context for these newly observed ice-flow indicators. The 2023 and 2024 datasets will also be integrated with regional ice-flow indicators from the larger remote-mapping project area (Brouard et al., 2022) and regional till geochemistry datasets (Godbout et al., 2023, 2024) and then investigated using GIS-based algorithms.

Glacial Landscape Evolution

In 2024, we collected one boulder and four bedrock surface samples for TCN analysis in the “preserved warm-based” landsystem to deepen our understanding of glacial landscape evolution (**fig. 11**). While it is currently classified as “warm-based preserved” (warm-based landforms preserved under cold-based conditions), we anticipated a greater diversity of features resembling cold-based conditions, similar to the different preserved landsystems in adjacent areas (Campbell et al., 2019; McMartin et al., 2021). Most of the outcrops in the “warm-based” zone are characterized glacially polished surfaces with minimal weathering. The only outcrop showing limited weathering was in the southeasternmost part of the study area and was sampled for TCN analyses (33A01; **fig. 11**). These observations raise important questions about erosion dynamics and preservation in the study area. The limited cold-based features suggest significant subglacial erosion related to shifts in ice-flow directions, which is corroborated by our ice-flow indicator record. Future analyses integrating field datasets, high-resolution remote mapping of landforms, GIS-based algorithms, and cosmogenic ^{10}Be and ^{26}Al exposure (burial) dating will refine our understanding of how basal thermal regimes and ice dynamics influenced erosion processes, ultimately providing a more complete picture of glacial landscape evolution.

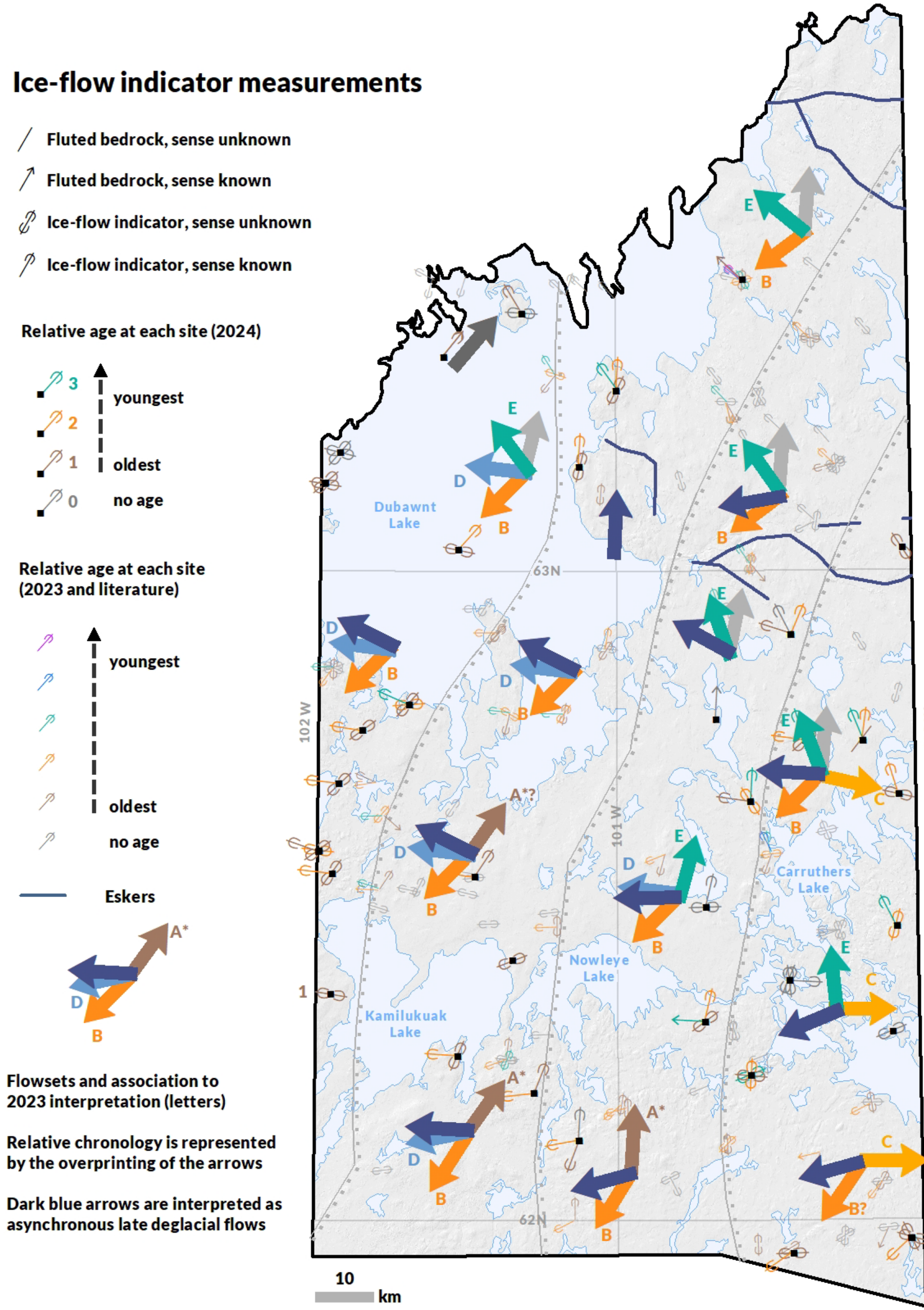

Figure 12 | Generalized ice flow sets for the study area and associated ice flow measurements from the two field seasons and from previous work. The grey (continuous and hashed) lines show the ice margin geometry during ice retreat (Dalton et al., 2023).

Glaciolacustrine Landforms

The 2024 fieldwork expanded our sampling efforts toward the centre and northwest of the study area, achieving our goal of gathering TCN samples from diverse glaciolacustrine landforms. This sampling included boulders resting on deltas, within alluvial bars in spillways (linked to distinct lake levels), and wave-washed bedrock surfaces in trimlines. This diversity in sampling environments, alongside those from the 2023 season—such as sampling from the bottoms (bedrock) of spillways feeding glaciolacustrine deltas and collecting sand from raised beaches—aims to create a less biased chronological framework for understanding the development and drainage of the meltwater bodies. The increased number of lake levels sampled for TCN between 171 and 280 m asl (**fig. 11**) in 2024 will provide a more comprehensive understanding of glacial lake morphology and chronology. By targeting glacial lake limits and features associated with the highest water levels in the area, we anticipate that the wide range in elevation of samples dated using ^{10}Be exposure or IRSL dating will reflect distinct water levels (rather than glacio-isostatic adjustment), from various small water bodies formed during different stages of glacial retreat, rather than a single large lake basin (i.e., Glacial Lake Dubawnt).

To improve our understanding of the formation of the glaciolacustrine landforms and their paleoglaciological context, future work involving remote mapping, especially regarding tilts due to glacial isostatic adjustment, will be essential. Integrating geomorphological and chronological data will therefore enhance our understanding of the pattern of ice margin retreat. These findings will contribute to understanding their potential impact of glacial lakes on ice retreat geometry, dynamics, drift dispersal, and on meltwater routing and drainage events.

Conclusions

The 2024 fieldwork campaign was conducted in a remote western region of mainland Nunavut as part of the GEM-GeoNorth's West-central Keewatin Glacial Dynamics project. The 2024 fieldwork, combined with data from previous work, is pivotal in documenting and refining our understanding of the regional glacial history. A total of 88 stations were visited in August 2024, leading to the collection of 75 ice-flow indicator measurements, 38 till samples for geochemical, mineral indicators, and clast lithology analyses, and 30 samples for geochronology.

Preliminary interpretations of the ice-flow measurements, in conjunction with ongoing remote mapping of the glacial geomorphology, suggest that the study area has undergone a complex succession of distinct glacial events, as evidenced by various ice-flow sets, diverse landsystems and numerous indicators of glacial lake levels.

The next steps in this project will involve the compilation and interpretation of glacial transport patterns and geochronological results, which will provide critical constraints for our field observations and remote mapping efforts. The forthcoming compositional data from the till samples will also establish a regional framework for drift prospecting and environmental applications. By integrating these new datasets with remote geomorphological mapping, we aim to enhance our understanding of the regional glacial history, thereby improving the framework for mineral exploration in this northern Canadian region.

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References

Batchelor, C.L., Margold, M., Krapp, M., Murton, D.K., Dalton, A.S., Gibbard, P.L., Stokes, C.R., Murton, J.B., Manica, A. 2019. The configuration of Northern Hemisphere ice sheets through the Quaternary. Nature Communications 10(1), 1-10, https://doi.org/10.1038/s41467-019-11601-2.

Boulton, G.S., Clark, C.D. 1990. A highly mobile Laurentide ice sheet revealed by satellite images of glacial lineations. Nature 346(6287), 813-817, https://doi.org/10.1038/346813a0.

Brouard, E., Campbell, J.E., McMartin, I., Godbout, P.M. 2022. Compilation of surficial geology field data for the West-central Keewatin Sector of the Laurentide Ice Sheet (Northwest Territories and Nunavut). Geological Survey of Canada, Open File Report 8915, 1-9, https://doi.org/10.4095/330559.

Brouard, E., Campbell, J.E., Godbout, P.M., Renaud, N.M., McMartin, I., Roy, M., Kelley, S.E., 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 Report 9159, 1-34, https://doi.org/10.4095/332531.

Campbell, J.E. 2002. Phelps Lake Project: Highlights of the Quaternary Investigations in the Keseechewun Lake Area (NTS 64M-9, -10, -15, and -16). In, Summary of Investigations 2002. Miscellaneous Report 2002-4.2, Paper A-2, Saskatchewan Geological Survey, 1-16, https://publications.saskatchewan.ca/api/v1/products/4821/formats/88721/download.

Campbell, J.E., McMartin, I., Normandeau, P.X., Godbout, P.M. 2019. Report of 2018 activities for the GEM-2 Rae glacial history activity in the eastern Northwest Territories and the Kitikmeot and Kivalliq regions, Nunavut. Geological Survey of Canada, Open File Report 8586, 1-16, https://doi.org/10.4095/314741.

Dalton, A.S., Stokes, C.R., Batchelor, C.L. 2022. Evolution of the Laurentide and Innuitian ice sheets prior to the Last Glacial Maximum (115 ka to 25 ka). Earth-Science Reviews 224, 103875, https://doi.org/10.1016/j.earscirev.2021.103875.

Dalton, A.S., Dulfer, H.E., Margold, M., Heyman, J., Clague, J.J., Froese, D.G., Gauthier, M.S., Hughes, A.L.C., Jennings, C.E., Norris, S.L., Stoker, B.J. 2023. Deglaciation of the north American ice sheet complex in calendar years based on a comprehensive database of chronological data: NADI-1. Quaternary Science Reviews 321, 108345, https://doi.org/10.1016/j.quascirev.2023.108345.

Deblonde, C., Campbell, J.E., Chow, W., Cocking, R.B., Huntley, D.H., Parent, M.P., Rice, J.M., Robertson, L., Smith, I.R., Weatherston, A.J., Zawadzka, K. 2024. Surficial Data Model: the science language of the integrated Geological Survey of Canada data model for surficial geology maps. version 2.5.1. Geological Survey of Canada, Open File Report 8236, 1-9, https://doi.org/10.4095/332530.

Dredge, L.A., Nixon, F.M., Richardson, R.J. 1986. Quaternary geology and geomorphology of northwestern Manitoba. Geological Survey of Canada, Memoir 418, 1-38, https://doi.org/10.4095/121045.

Dyke, A.S., Prest, V.K. 1987. Paleogeography of northern North America, 18 000 - 5 000 years ago. Geological Survey of Canada, "A" Series Map 1703A, 11 maps, 1:5,000,000, https://doi.org/10.4095/133927.

Geological Survey of Canada. 2017a. Reconnaissance surficial geology, Kamilukuak Lake, Nunavut, NTS 65-K (ed. Prelim., surficial data model v.2.2 conversion). Geological Survey of Canada, Canadian Geoscience Map 221, 1:125,000, https://doi.org/10.4095/297331.

Geological Survey of Canada. 2017b. Reconnaissance surficial geology, Ennadai, Nunavut, NTS 65-F. Geological Survey of Canada, Canadian Geoscience Map 224, 1:125,000, https://doi.org/10.4095/299727.

Geological Survey of Canada. 2019. Reconnaissance surficial geology, Dubawnt Lake, Nunavut, NTS 65-N (ed. surficial data model v.2.3.14 conversion). Geological Survey of Canada, Canadian Geoscience Map 368, 1:125,000, https://doi.org/10.4095/308431.

Godbout, P.-M., McMartin, I., Brouard, E., Campbell, J., Gauthier, M.S., Tremblay, T. 2023. The regional relict component of the Dubawnt glacial transport in the Keewatin Sector of the Laurentide Ice Sheet. In: Gervais, S.D. (Ed.), Northwest Territories Geological Survey, YKGSF Abstracts Volume 2023, 51st Annual Yellowknife Geoscience Forum, Yellowknife, Northwest Territories, Canada, 54-55, https://doi.org/10.13140/RG.2.2.27595.81441.

Godbout, P.M., McMartin, I., Brouard, E. 2024. The regional relict components of Dubawnt glacial transport in the Keewatin sector of the Laurentide Ice Sheet In, Canadian Quaternary Association and Canadian Geomorphology Research Group Biennial Meeting 2024, Regina, Saskatchewan, Canada, 1-1.

Hardy, F., Delgaty, J., Martel, E. 2005. Drift exploration surveys in the Snowbird Lake area, NWT: Kimberlite indicator minerals – gold – heavy minerals geochemistry – till geochemistry. Northwest Territories Geoscience Office, Open File 2005-07, 1-89, https://doi.org/10.46887/2005-07.

Hodder, T.J., Ross, M., Menzies, J. 2016. Sedimentary record of ice divide migration and ice streams in the Keewatin core region of the Laurentide Ice Sheet. Sedimentary Geology 338, 97-114, https://doi.org/10.1016/j.sedgeo.2016.01.001.

Kleman, J., Fastook, J., Stroeven, A.P. 2002. Geologically and geomorphologically constrained numerical model of Laurentide Ice Sheet inception and build-up. Quaternary International 95-96, 87-98, https://doi.org/10.1016/S1040-6182(02)00030-7.

Kleman, J., Jansson, K.N., De Angelis, H., Stroeven, A.P., Hättestrand, C., Alm, G., Glasser, N.F. 2010. North American Ice Sheet build-up during the last glacial cycle, 115–21kyr. Quaternary Science Reviews 29(17-18), 2036-2051, https://doi.org/10.1016/j.quascirev.2010.04.021.

Li, Y.-k. 2018. Determining topographic shielding from digital elevation models for cosmogenic nuclide analysis: a GIS model for discrete sample sites. Journal of Mountain Science 15(5), 939-947, https://doi.org/10.1007/s11629-018-4895-4.

Margold, M., Stokes, C.R., Clark, C.D., Kleman, J. 2014. Ice streams in the Laurentide Ice Sheet: a new mapping inventory. Journal of Maps 11(3), 380-395, https://doi.org/10.1080/17445647.2014.912036.

McClenaghan, M.B., Paulen, R.C., Smith, I.R., Rice, J.M., Plouffe, A., McMartin, I., Campbell, J.E., Lehtonen, M., Parsasadr, M., Beckett-Brown, C.E. 2023. Review of till geochemistry and indicator mineral methods for mineral exploration in glaciated terrain. Geochemistry: Exploration, Environment, Analysis 0(ja), geochem2023-2013, https://doi.org/10.1144/geochem2023-013.

McMartin, I., Henderson, P. 2004. Evidence from Keewatin (Central Nunavut) for Paleo-Ice Divide Migration. Géographie physique et Quaternaire 58(2-3), 163-186, https://doi.org/10.7202/013137ar.

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

McMartin, I., Tremblay, T., Godbout, P.M. 2017. Report of 2017 field activities for the GEM-2 Rae glacial history activity in the Kivalliq region, Nunavut. Geological Survey of Canada, Open File Report 8320, 1-14, https://doi.org/10.4095/306006.

McMartin, I., Godbout, P.-M., Campbell, J.E., Tremblay, T., Behnia, P. 2021. A new map of glacigenic features and glacial landsystems in central mainland Nunavut, Canada. Boreas 50(1), 51-75, https://doi.org/10.1111/bor.12479.

Ozyer, C. 2011. Ice-movement history and kimberlite indicator mineral dispersal study, Pelly Bay, lower Boothia Peninsula, and Wager Plateau areas, Nunavut, Canada. PhD. University of Western Ontario, London, Ontario, Canada. 1-180. https://ir.lib.uwo.ca/etd/226

Porter, C., Morin, P.J., Howat, I., Noh, M.-J., Bates, B., Peterman, K., Keesey, S., Schlenk, M., Gardiner, J., Tomko, K., Willis, M., Kelleher, C., Cloutier, M., Husby, E., Foga, S., Nakamura, H., Platson, M., Wethington Jr, M., Williamson, C., Bauer, G., Enos, J., Arnold, G., Kramer, W., Becker, P., Doshi, A., D'Souza, C., Cummens, P., Laurier, F., Bojesen, M. 2018. ArcticDEM, Version 3. Harvard Dataverse, https://doi.org/10.7910/DVN/OHHUKH.

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

Stokes, C.R., Clark, C.D. 2003. The Dubawnt Lake palaeo-ice stream: evidence for dynamic ice sheet behaviour on the Canadian Shield and insights regarding the controls on ice-stream location and vigour. Boreas 32(1), 263-279, https://doi.org/10.1080/03009480310001155.

Veillette, J.J., Roy, M. 1995. The spectacular cross-striated outcrops of James Bay, Quebec. In, Canadian Shield. Geological Survey of Canada, Current Research 1995-C, Natural Resources Canada, 243-248, https://doi.org/10.4095/202923.