GS2024-25

Quaternary site data, till composition and ice-flow indicators between the North Knife River and the Seal River, and in the Gross Lake area, far northeastern Manitoba (parts of NTS 54L10–15, 54M5, 6, 12)

by M.S. Gauthier and S. Bergen[1]

In Brief:

- Surficial mapping west and northwest of Churchill
- Collection of till samples to determine provenance and till-exploration potential, including for diamonds, gold, lithium and other critical minerals
- Collection of ice-flow data to reconstruct the glacial history and aid till exploration
- Update of the relative sea level history

Citation:

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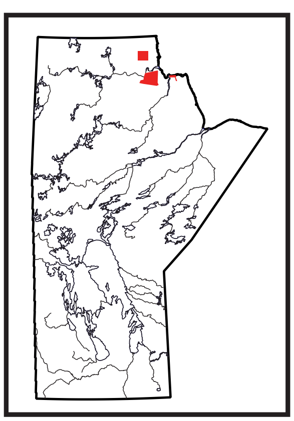

Summary

Quaternary geology fieldwork, including till sampling and ice-flow–indicator mapping, was conducted in a 2700 km^2 area between the North Knife River and the Seal River, and in a 865 km^2 area around Gross Lake, far northeastern Manitoba (parts of NTS 54L10–15, 54M5, 6, 12) to infill gaps within existing mapping. A total of 66 two kilogram till samples were collected for grain-size, geochemical (<63 µm size fraction) and clast-lithology (2–8 mm size fraction) analyses. At 55 of these 66 sample sites, an additional 14–16 kg was collected for indicator-mineral analysis. In addition, eight marine shell samples were collected for radiocarbon dating, to update the postglacial rebound (isostatic uplift) history.

Introduction

This report presents a summary of activities related to three weeks of fieldwork undertaken west and northwest of Churchill, Manitoba, in the summer of 2024. Quaternary geology investigations included site characterization (sedimentology, geomorphology, type and thickness of glacial sediments) and collection of representative till samples for compositional analysis. Ice-flow indicators were mapped to augment the current understanding of the regional ice-flow history. Geological observations, sampling of till and/or measurements of ice-flow indicators were recorded at 185 stations, which includes 10 sections along the North Knife and South Knife rivers and 12 road-accessible sites near Churchill. The objectives of this study are to

- conduct 1:50 000 scale surficial geology mapping;
- collect till samples to assess the composition and provenance of the till;
- map paleo–ice-flow indicators to assist reconstructions of the glacial history; and
- collect organic material (shell or wood) for radiocarbon dating in order to update the postglacial rebound (isostatic uplift) history.

Bedrock geology

The study area is underlain by Paleozoic limestone and dolostone of the Hudson Bay Basin in the east and Proterozoic and Archean metasedimentary, metavolcanic and plutonic rocks of the Precambrian shield in the west (Figure GS2024-25-1; Anderson et al., 2010; Manitoba Geological Survey, 2022). Within the Gross Lake area, there is one mineral occurrence of rare earth elements (REE) ~5.4 km southeast of Gross Lake (Böhm et al., 2020; Rinne, 2024). There are no reported mineral occurrences within the North Knife River to Seal River area; however, drilling immediately to the north has identified multiple mineral occurrences within the Archean gabbro and mafic volcanics that outcrop along the Seal River (Rinne, 2024).

Quaternary history

The study area was previously mapped in the late 1980s (1:250 000 scale, Dredge and Nixon, 1981, 1982). More recent detailed mapped has been conducted to the west of the study area (1:50 000 scale, Trommelen and Campbell, 2012b; Trommelen, 2014c; Gauthier, 2016b). Most of the North Knife River to Seal River area is poorly drained, with variable organic cover underlain by permafrost. The study area was glaciated multiple times by ice flowing from multiple migratory domes of the Laurentide Ice Sheet (Dredge and Nixon, 1992; Gauthier et al., 2019). The glaciers left behind a palimpsest landscape (Figure GS2024-25-2) dominated by ice-transverse crevasse ridges and ribbed

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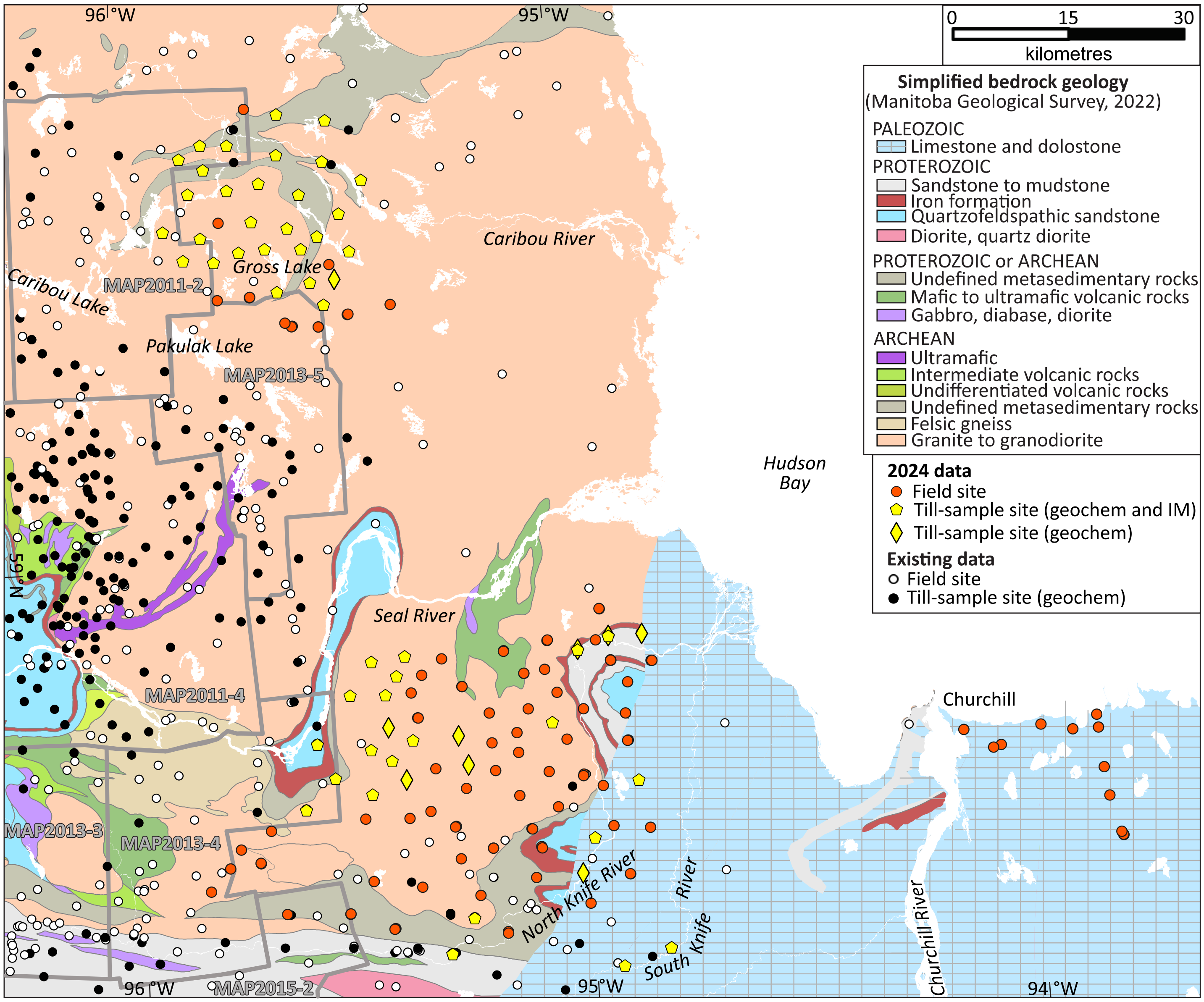

Figure GS2024-25-1: *Field sites and till sample sites overlying the bedrock geology of far northeastern Manitoba (Manitoba Geological Survey, 2022). Grey outlined polygons and MAPxxxx-x refers to the Manitoba Geological Survey map and publication number, respectively (Trommelen and Campbell, 2012a, b; Trommelen, 2014a–c; Gauthier, 2016b). Datum is NAD83. Abbreviations: geochem, geochemical analysis; IM, indicator-mineral analysis.*

moraine ridges (Trommelen et al., 2014) and ice-parallel streamlined landforms, eskers and meltwater channels (Trommelen et al., 2012). During and post deglaciation, the area was covered by the Tyrrell Sea to ~175 m above sea level (asl) along the Caribou River, ~150 m asl along the North Knife River and 140–150 m asl along the Churchill River (Dredge and Nixon, 1992; Gauthier et al., 2020; McMartin et al., 2022). As the sea regressed, it formed numerous small beach ridges (Figure GS2024-25-2).

Methods

Truck- and helicopter-supported fieldwork was undertaken over 21 days in July–August, 2024, based out of the town of Churchill. A total of 185 field sites were visited to ground-truth the surficial geology mapping, collect till samples and map ice-flow indicators (Figure GS2024-25-1). The surficial material at each field station was investigated by means of a hand-dug shovel hole, a Dutch auger (1.2 m long) hole and/or a natural sediment exposure.

The 66 collected till samples will be split for archiving at the Manitoba Geological Survey Midland Sample and Core Library (Winnipeg, Manitoba), and then analyzed for grain size, matrix geochemistry (<63 µm size fraction) and clast lithology. An additional 14–16 kg till sample was collected for indicator-mineral analysis at 55 sample sites. These samples were submitted to Overburden Drilling Management Limited (Ottawa, Ontario) in collaboration with the Geological Survey of Canada. They will

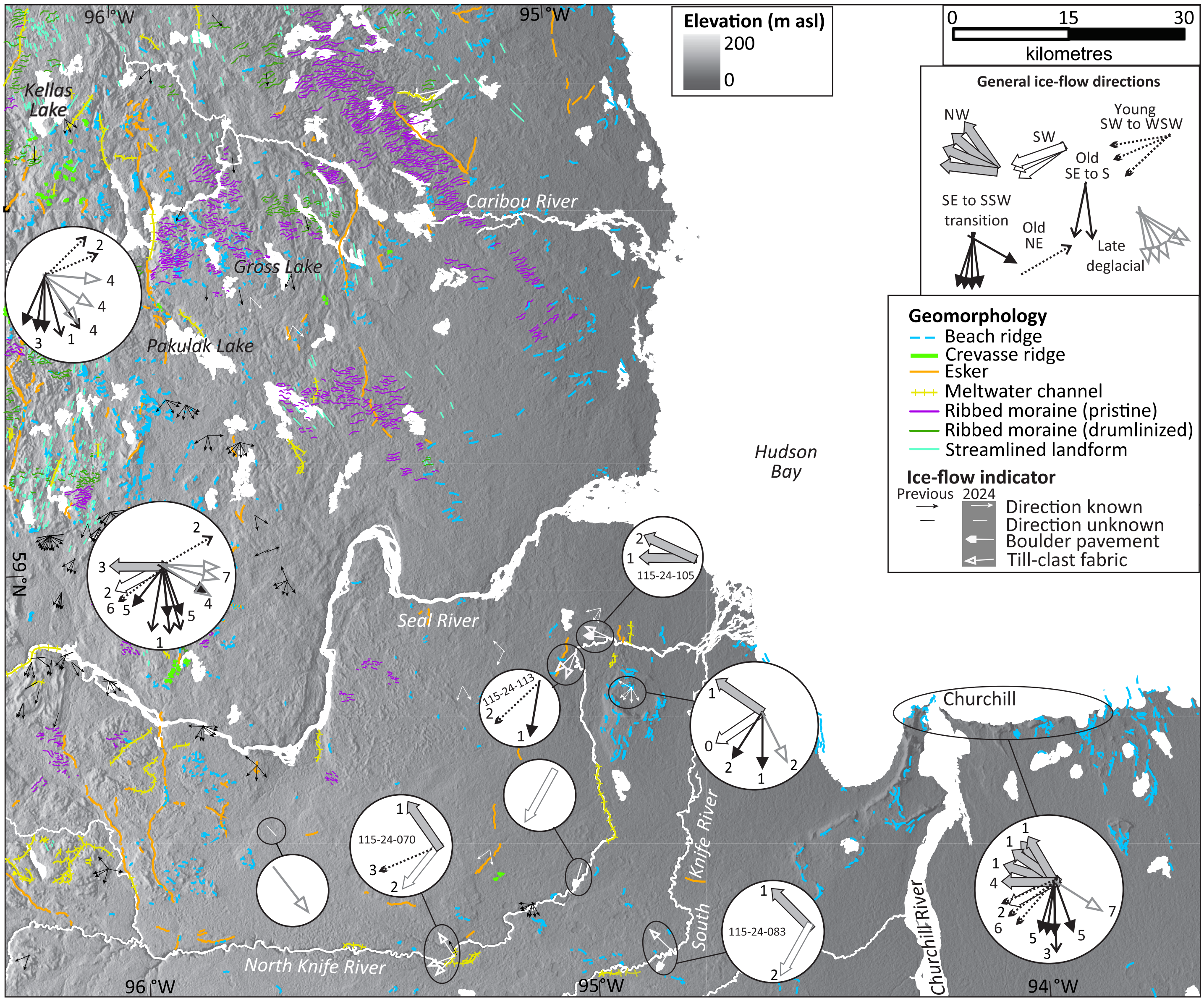

Figure GS2024-25-2: *Geomorphology and ice-flow indicators mapped in the far northeast of Manitoba, from this study and previous work (Trommelen and Ross, 2011; Trommelen, 2015; Gauthier, 2019, 2022). Indicators are denoted by relative age when observed either upsection (till fabrics) or by crosscutting relationships (erosional field-based ice-flow indicators). Locations of till-fabric analyses indicated (site 115-24-XX). Background hillshade is generated from a Shuttle Radar Topography Mission digital elevation model (U.S. Geological Survey, 2014). Datum is NAD83.*

be analyzed for metamorphosed massive-sulphide–indicator minerals (MMSIMs®), kimberlite-indicator minerals (KIM), lithium-indicator minerals (LIM) and visible gold.

Ice-flow data were obtained from erosional ice-flow indicators observed in the field, or by measuring the long-axes orientation, or fabric, of clasts within till. The long-axis orientation of elongated clasts were measured, as such clasts tend to rotate within the fine-grained till matrix and orient parallel to the overlying glacier's shear stress direction (Holmes, 1941). Elongated clasts are defined as having a minimum ratio of 1.5:1.0 of lengths of their longest axis to their second-longest axis. The orientations (trend and plunge) of a minimum sampled population of 25 elongated clasts were measured in situ for a statistically valid result. Lodged boulders in till, with parallel striae on their polished upper surface, were also measured when present.

Preliminary surficial geology

Bedrock

Bedrock is near surface in most of the study area. Problematically, the bedrock often exists as boulder fields (Figure GS2024-25-3a) or frost-shattered broken rock draped by variable organics or modern lake sediments (felsenmeer, Figure GS2024-25-3b, c). Intact bedrock is rare and is actively shattering or being heaved by frost (Figure GS2024-25-3d, e). These rubble areas are identified as bedrock based on the angular to

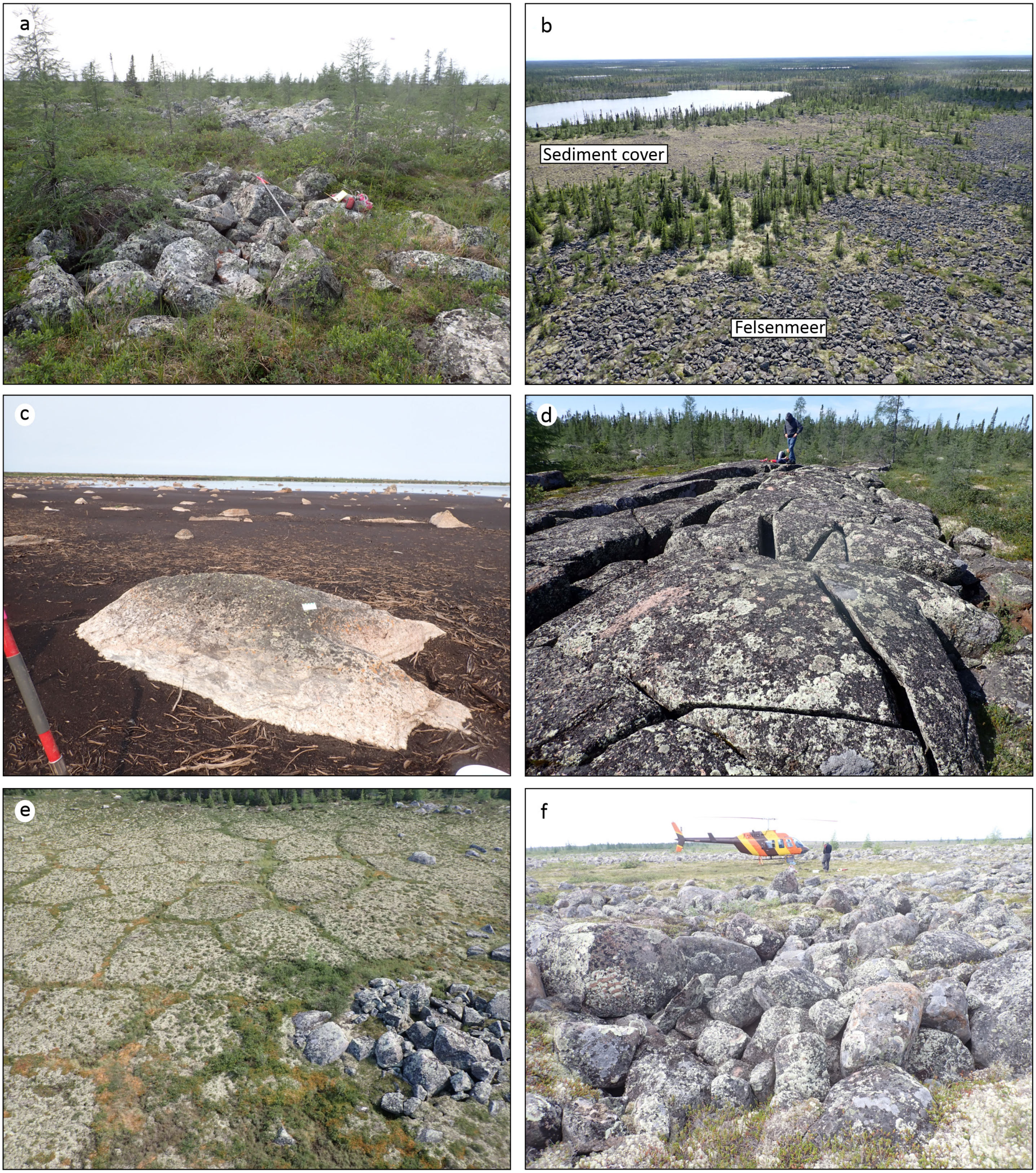

Figure GS2024-25-3: *Bedrock in the study area often outcrops as monolithic boulder fields* ***(a)*** *or angular blocks termed felsenmeer* ***(b)*** *that may be covered by organics* ***(c)****. 'Intact' bedrock outcrops are actively shattering or being heaved by frost* ***(d, e)****. Due to the same frost action, till-derived boulder fields look similar to rubble bedrock but contain rocks of different lithologies that may be more rounded* ***(f)****.*

subangular boulder edges and their monolithic nature (Dredge and Nixon, 1992). Careful attention in the field is needed to separate rubble bedrock from till-derived boulder fields, which contain rocks of different lithologies with angular to subrounded edges (Figure GS2024-25-3f).

Glaciomarine and marine

Glaciers depress the surface of the Earth, and how the Earth responds to this loading and subsequent unloading (deglaciation) is a process called glacial isostatic adjustment. Glacial ice was present in the Churchill area as late as 8000 cal. years BP, meaning that there were complex interactions between the ice and the Tyrrell Sea waters on its eastern side (Dredge and Nixon, 1992; Gauthier et al., 2020; McMartin et al., 2022). The land was still depressed once the glaciers melted, and marine sediments were deposited far inland; up to ~150 m above modern sea level along the North Knife River and ~175 m asl west of the Gross Lake area (McMartin et al., 2022). The North Knife River–Seal River and Gross Lake study areas are between 20–135 m asl and 70–150 m asl, respectively, meaning that most of the landscape was beneath the Tyrrell Sea for a long time. To assess how long the land took to rebound, eight marine shell samples were collected from ~21–87 m asl. Twigs were collected near the base of fluvial sands, within a peat bed overlying marine sediment at 48 m asl, to date the minimum age of marine regression at that site along the North Knife River. Three samples near Churchill were collected to provide more accurate dates than the current 1960 and 1970s conventional dates on bulk samples (Craig, 1969; McNeely and Brennan, 2005; Gauthier, 2023a). Combining this new data with other radiocarbon dates in the area will provide a better assessment of the relative sea level history for the region (Gauthier, 2016a; Simon et al., 2016; Lambeck et al., 2017).

Glaciomarine to marine sediments include completely reworked and redistributed till turned into gravelly sand (Figure GS2024-25-4a), sand or gravel beach ridges (Figure GS2024-25-4b), littoral sand, intertidal silt and clast-poor diamict (Figure GS2024-25-4c–f). The glaciomarine to marine diamict, also termed stony pelite (Dredge and Nixon, 1992), is a massive, matrix-supported, very poorly sorted, silty-clayey diamict with 3–25% clasts that are granule- to small cobble-sized. The clasts may be randomly distributed throughout, or only near the surface due to permafrost action. Dredge and Nixon (1992) note that the stony pelite has an uncertain origin and can be interpreted as permafrost-mixed marine sediments and till, glaciomarine sediments, and/or deepwater marine sea-ice detritus, like that observed on the sea floor in modern Hudson Bay. Regardless of origin, these sites must be avoided during till prospecting, as the sediments are unrelated to the underlying bedrock. Several previously sampled ‘tills’ are actually marine diamicts and will be removed from existing till-data compilations (Gauthier, 2019, 2024, samples AN356713, AN360213, AN361513).

Tills

The study area is draped by a massive, matrix-supported, overconsolidated, generally olive-brown diamict with a sandy-silt or silty-sand matrix (Figure GS2024-25-5a, d). An older highly overconsolidated diamict(s) with blocky structure and oxidation staining along the joints was studied at section 115-24-070 along the North Knife River (Figure GS2024-25-2). There is a pre-existing till sample from this section (Gauthier, 2019, AN345913; Gauthier and Godbout, 2023), though the new work shows there are actually three tills within the 5.4 m of exposed diamict—interpreted to have been deposited by ice with very different flow directions (Figure GS2024-25-2).

Washed tills

Till prospecting programs must be careful to sample unmodified till whenever possible. Till in the study area was washed by the glacial to postglacial Tyrrell Sea waves, which may have caused removal of the fine-textured size fraction, or remobilization and partial sorting of the surface sediments (Figure GS2024-25-5). Wave washing can leach the water-soluble elements from the sediments and hence lead to a decreased elemental concentration than might have been there originally (Randour, 2018). Alternatively, if sampling the sand-size fraction for heavy minerals, then the concentration of these heavier minerals within a sample volume may be increased.

It is still possible to find ‘good till’ that hasn’t been modified within the wave-washed terrain. Till prospecting programs must look for active or inactive mud boils (frost boils) that are bringing / have brought unmodified (typically siltier) sediment up from below. Mud boils are rare (Figure GS2024-25-6a, b), but can be spotted from the air. If mud boils are not found, its often possible to dig down amongst the boulders and wave-washed surface sediments to find unoxidized siltier C-horizon diamict at depth (Figure GS2024-25-6c).

Ice-flow history

Erosional field-based ice-flow indicators

New erosional ice-flow measurements were obtained from striations, grooves, chattermarks, crescentic gouges and fractures at eight field sites in 2024. More bedrock outcrops were visited, but all surfaces were weathered and/or frost shattered. The new data confirms the existing complex ice-flow history summarized in Figure GS2024-25-2 and discussed in detail within Gauthier et al. (2019).

Till-clast fabric analyses

Previous stratigraphic studies along the North Knife and South Knife rivers did not measure till fabrics nor investigate the tills in detail (Dredge and Nixon, 1992; Trommelen, 2015; Gauthier, 2019). New till-based stratigraphies in northeastern Manitoba have shown the importance of this data, especially where

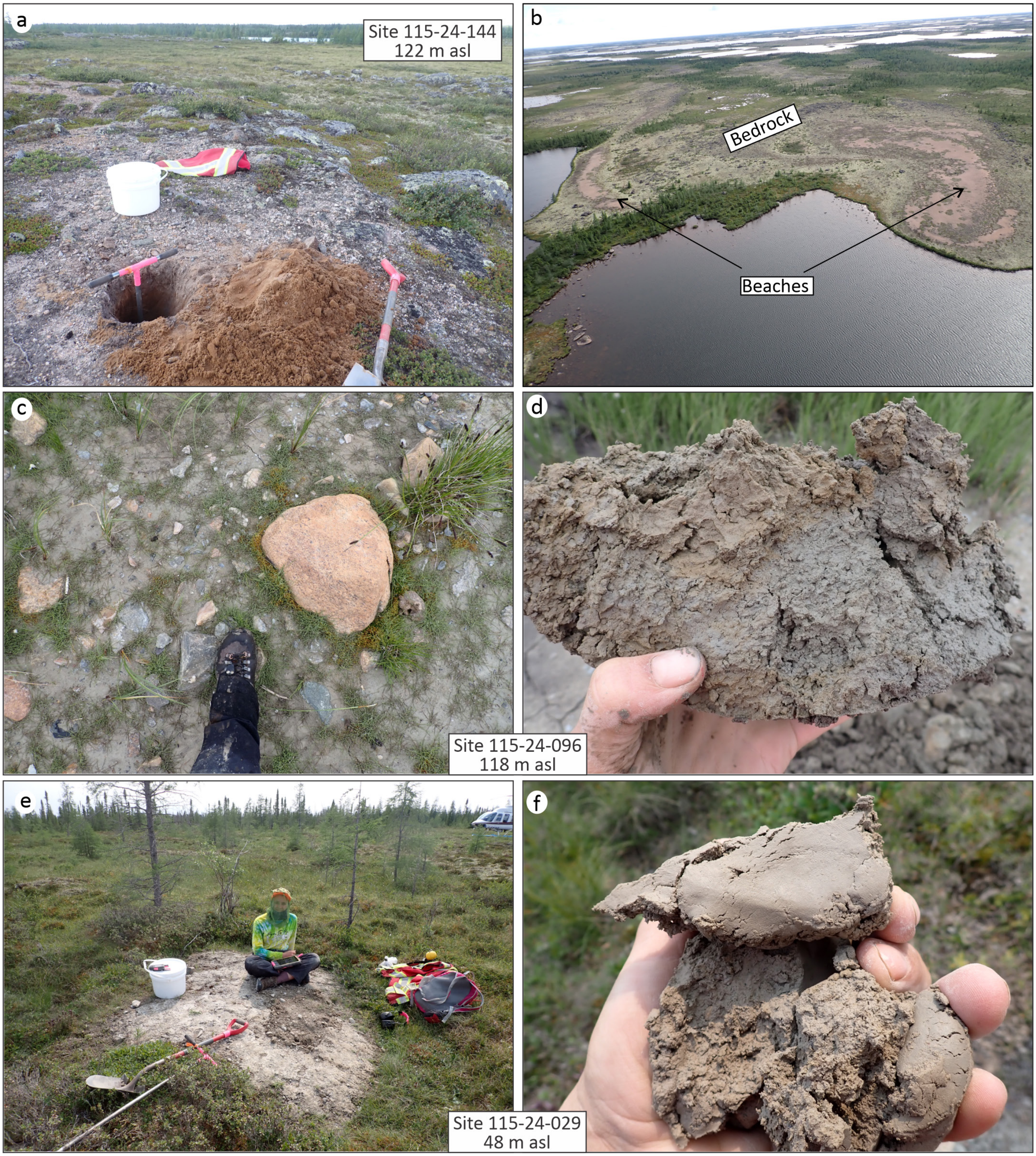

Figure GS2024-25-4: *Glaciomarine to marine sedimentation in the study area includes reworked and redistributed till turned into gravelly sand with no remaining fines **(a)**, sand to gravel beach ridges **(b)** and silt to silty clay diamict **(c–f)**.*

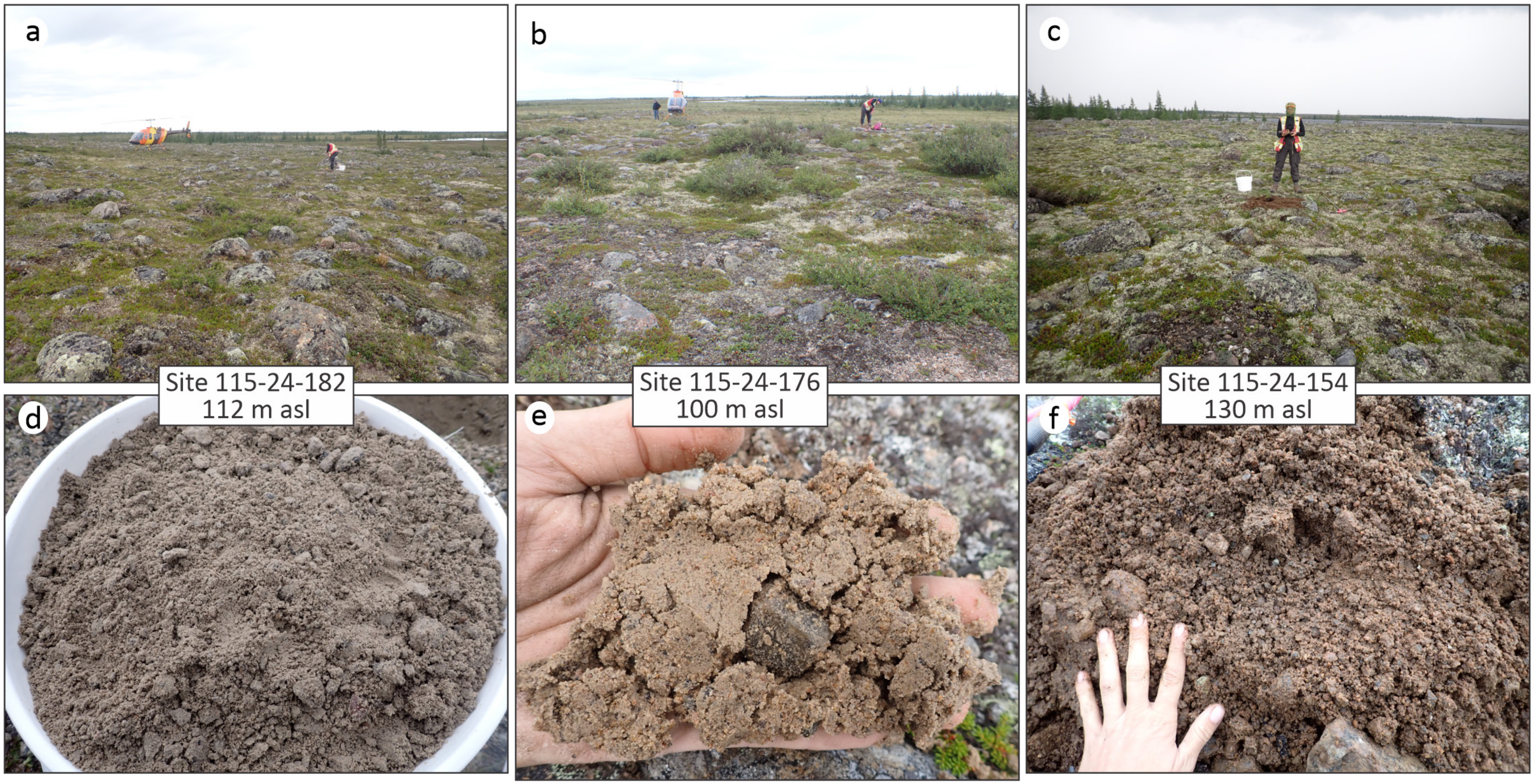

Figure GS2024-25-5: *The intensity of Tyrrell Sea wave washing was variable throughout the study area, and not controlled by elevation. Wave washing may have removed fines from the till, leaving behind just sand and clean clasts* ***(b, e)*** *compared to unmodified diamict* ***(a, d)****, or may have redistributed the surface sediments resulting in the formation of gravelly sand to sandy gravel* ***(c, f)****. Site 115-24-182 has ~60% boulders at surface and unwashed till. Site 115-24-176 has ~80% boulders at surface and sand with 10–15% clasts. Site 115-24-154 has ~60% boulders at surface, with 0.5 m of sand that has 40–60% clasts over ≥0.2 m of sand that has 0–5% clasts.*

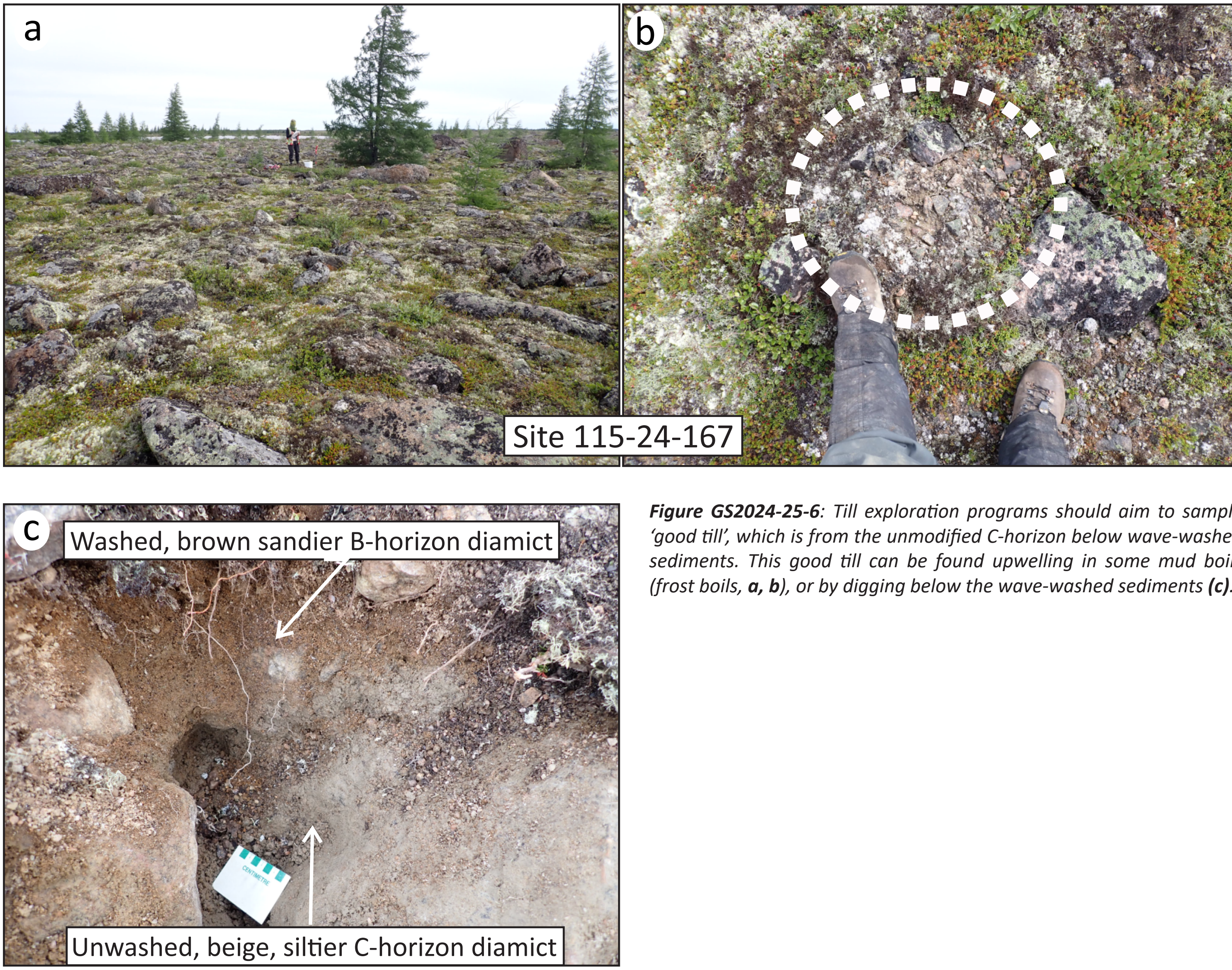

***Figure GS2024-25-6**: Till exploration programs should aim to sample 'good till', which is from the unmodified C-horizon below wave-washed sediments. This good till can be found upwelling in some mud boils (frost boils, **a, b**), or by digging below the wave-washed sediments **(c)**.*

tills appear qualitatively similar (Gauthier et al., 2024; Hodder et al., 2024). As such, five sections were studied using the new methodology and till-clast fabrics were measured at four of the sections (Figure GS2024-25-2). These sections expose ~8–14 m of glacial and postglacial sediments.

An ice-flow event can be erosional, depositional or both. As such, determining which specific ice-flow directions were responsible for till provenance is ongoing. Calcareous detritus was glacially dispersed for distances up to ~40 km west-northwest of the Paleozoic carbonate bedrock, roughly as far as the Seal River (Figure GS2024-25-1). The North Knife River to Seal River study area is within this dispersal pattern, and previously sampled tills contained 5–15% total carbonate in the <63 um size fraction (Gauthier, 2023b). The Gross Lake study area tills may contain trace reworked (inherited) carbonate—to be confirmed by this study. The carbonate dispersal pattern bears little relationship to deglacial ice-flow orientations (Gauthier et al., 2022), requiring most of the detritus to have been transported during earlier west- and northwest-trending ice-flow phases (Trommelen et al., 2013; McMartin et al., 2016; Gauthier et al., 2019). A study just to the west showed that tills contain a complex mix of local- (<15 km) and continental-scale (350–600 km) detritus, with palimpsest dispersal patterns (Trommelen et al., 2013).

Future work

Ongoing surficial geology analyses will focus on 1:50 000 scale surficial mapping, as well as tracing lithological indicators from known bedrock source areas. The latter will be conducted by clast-lithology counts, indicator-mineral counts and geochemical analysis of the collected till samples. Radiocarbon dating results will be added to existing data, to determine updated relative sea level histories for the area.

Economic considerations

Manitoba's far northeast is a remote and largely unexplored frontier, with a variable thickness of sediment covering much of the bedrock. Results from this study will contribute to an improved understanding of the Quaternary surface sediments, subsurface stratigraphy, glacial history and till provenance in the areas west and northwest of Churchill. This is necessary to support habitat mapping, carbon estimates, land-use planning, infrastructure development, aggregate-resource identification and mineral exploration.

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