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Quaternary site data, till composition and ice-flow indicators in the Roseau River area, southeastern Manitoba (parts of NTS 62H2, 7)

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Quaternary site data, till composition and ice-flow indicators in the Roseau River area, southeastern Manitoba (parts of NTS 62H2, 7)

by M.S. Gauthier and T.J. Hodder
Manitoba Geological Survey
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Front cover photos:

This section along the Roseau River (top photo), just around the corner from the swinging bridge, exposes glaciofluvial gravels (bottom left photo) over 2.5 m metres of nonglacial beige horizontally bedded fine sand, and 2.5+ metres of massive to laminated brown to black to blue-grey silt (bottom right photo).

Abstract

The Roseau River area in southeastern Manitoba preserves an exceptional stratigraphic record of multiple Quaternary glacial-interglacial cycles. We examined 6 sections on the Roseau River, 4 gravel pits and 22 surface sites to document the surficial sediments and till composition. Released herein are the stratigraphic columns, till fabrics, till-clast lithology and till-matrix geochemical data.

Résumé

La région de la rivière Roseau, dans le sud-est du Manitoba, a préservé un profil stratigraphique exceptionnel de plusieurs cycles glaciaires-interglaciaires du Quaternaire. Nous avons examiné six coupes sur la rivière Roseau, quatre carrières de gravier et 22 sites de surface afin d'obtenir des données sur les sédiments de surface et la composition du till. Publié dans la présente sont les colonnes stratigraphiques, les textures du till, l'analyse pétrologique des clastes du till et les données géochimiques sur la matrice du till.

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Introduction

The Roseau River area, in southeastern Manitoba (Figure 1), Canada, preserves a remarkable Quaternary stratigraphic record that encompasses multiple glacial-interglacial cycles (Fenton, 1974). Sections exposed along the Roseau River were targeted for fieldwork in 2021 and 2022 to assess whether near-surface nonglacial sediments (Vita Formation) were deposited during the marine isotope stage 3 interstadial or an earlier ice-free period (interpretation I vs. II of Fenton, 1974). The purpose of this report is to publish till data from 2021 and 2022 in the Roseau River area, combined with digitized data from nearby till samples (Fenton, 1974; Thorleifson and Matile, 1993). The longer-term objective is to apply more quantitative tools, along with geochronology, to confirm the initial stratigraphic work.

Quaternary geology

Most of the study area is mapped as till covered by a thin veneer of glaciolacustrine and/or glaciofluvial sediments, or as

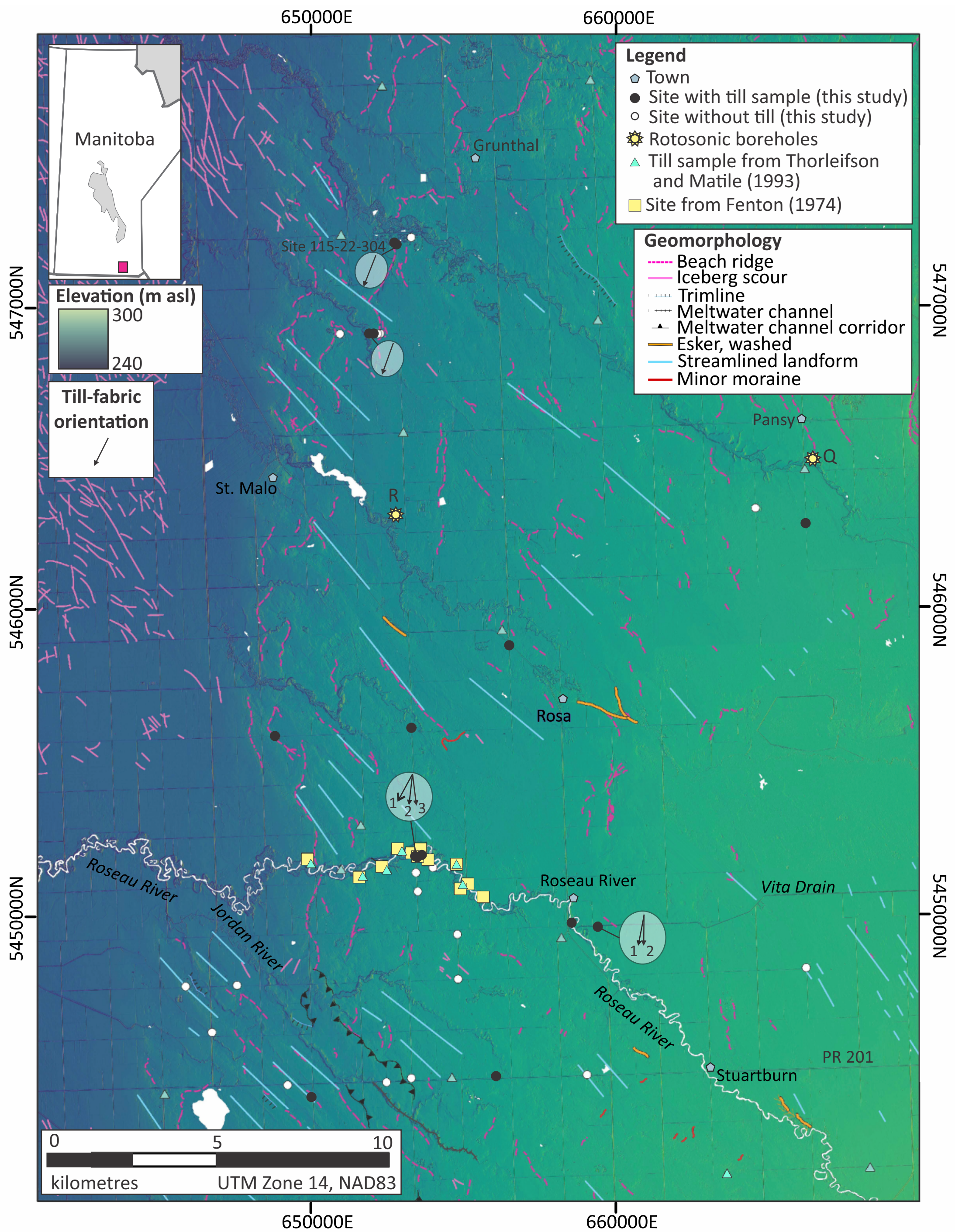

Figure 1: *Study area in southeastern Manitoba (pink on upper left inset map), showing field sites from 2021 and 2022 (this study), 1993 (Thorleifson and Matile) and 1974 (Fenton). The rotosonic boreholes are also from Thorleifson and Matile (1993), with stratigraphy published in Matile et al. (2023a). Till-fabric orientations are from this study, and numbered according to relative age. Geomorphology is mapped using the background hillshade derived from LiDAR imagery (Government of Manitoba, 2020). Abbreviation: PR, provincial road.*

fine to medium sand deposited in moderate to shallow levels of glacial Lake Agassiz (Mihychuk, 1997; Matile, 2004). The study area lies between ~240 and 300 m above sea level, and is situated just east of the main Lake Agassiz clay plain in south-central Manitoba (Figure 2). The eastward rise in topography from the main Agassiz basin and into the Roseau River area is due more to the thickness of Quaternary sediment (70–90 m) than bedrock topography (Matile and Keller, 2012; Keller and Matile, 2021).

Fenton (1974) was the first to establish a stratigraphic framework for the region. This framework consisted of four laterally discontinuous tills that were identified at surface; initially interpreted to represent one southwest-trending advance of ice from the Quebec–Labrador sector of the Laurentide Ice Sheet (LIS), and three southeast-trending advances and re-advances of ice from the Keewatin sector of the LIS (Fenton, 1974; Teller and Fenton, 1980).

Of particular interest are sparsely-mapped economic gravel deposits, which are attributed to ice-contact glaciofluvial deposition (Matile and Conley, 1979; Matile, 1994; Mihychuk, 1997). The northwestward retreat of the Red River lobe late in deglaciation may have deposited some of these gravel deposits (kame-deltas of Fenton, 1974). Interestingly though, pit exposures near Grunthal expose thin till at surface (0–3 m) that is underlain by fossiliferous gravels and sands (0–30 m thick), fossiliferous sandy silt (~2 m thick; averaging 14 m depth), and ≥32 m of additional sediment (Harington et al., 2007). The fossiliferous sediments, extracted from below the water table in several pits, contain mammal fossils and spruce wood. In particular, steppe bison, mammoth, musk ox and giant beaver fossils were donated to, and are held by, the Manitoba Museum (G. Young, pers. comm., 2021). At a second gravel pit near Rosa, the stratigraphy is composed of 1 m of till that is underlain by 4 m of sand and gravel, 0.5 m diamict and 1+ m of sand (G.L.D. Matile, unpublished field notes, 1978). The lower diamicton contains wood that provided a radiocarbon age of >50 000 ^{14}C years BP (BGS-596; Morlan et al., 2000), suggesting that deposit is also more complex than an esker (as per Mihychuk, 1997). As such, much work is needed to clarify the age and depositional environment of gravel deposits in the study area. Only then can mapping be updated and new deposits accurately identified.

Bedrock geology

A scarcity of outcrop means that the regional bedrock mapping is based predominately on geophysical interpretation and drillcores (Manitoba Energy and Mines, 1990). The study area is underlain by red argillaceous dolomitic siltstone and evaporites of the Jurassic–Triassic Amaranth Formation (Figure 3). The area to the west is predominantly underlain by Mesozoic shale and siltstone, with minor sand, silt, bentonite, lignite, limestone and sandstone. Paleozoic carbonate, dominated by dolomite and limestone, are situated north and south of the study area. Paleozoic Winnipeg Formation quartzose sandstone and shale outcrop along the eastern boundary of the Paleozoic carbonate. Precambrian shield granitoids, gneiss and greenstones outcrop to the east and northeast.

Regional drilling notes that gypsum is at ~67.8 m depth at borehole R and limestone is at 69.2 m depth at borehole Q (Figure 1; Thorleifson and Matile, 1993). Sandstone was encountered at 95 m depth, 31 km to the northeast (07RS-3; Matile et al., 2023b).

Methods

Field data collection

Field work was conducted in the Roseau River area for one week each in 2021 and 2022, and consisted of examining geologic sections and making test holes with a hand auger or shovel. The section locations were chosen based on previous studies and

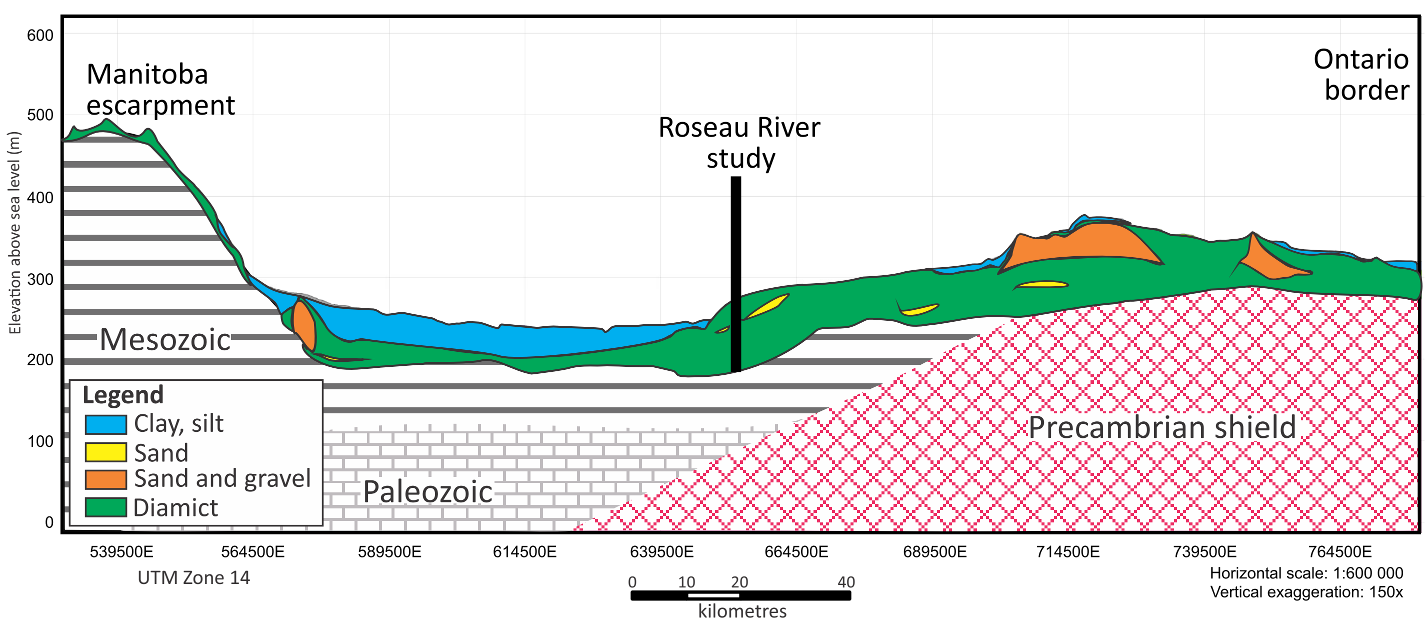

Figure 2: *Cross-section of the regional topography, simplified Quaternary geology and drift thickness, modified from Matile and Keller (2012).*

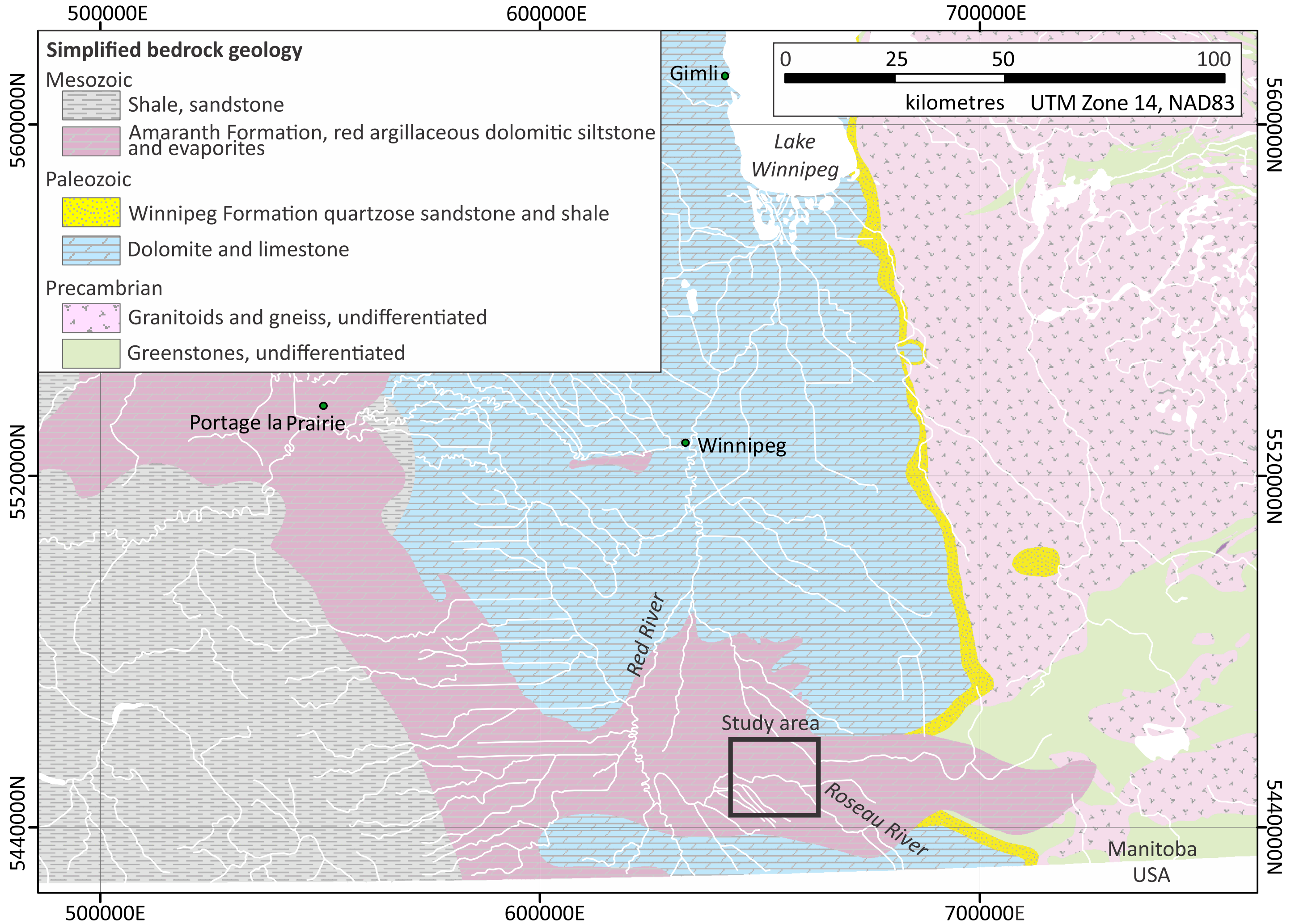

Figure 3: *Regional bedrock geology surrounding the study area, modified from Manitoba Geological Survey (2022).*

ease of access (Figure 1). For example, site 115-21-002 is near or at the 'Circus Section', which is a type section used by Fenton (1974) for three different formations. Surficial mapping sites were chosen based on the desire to find additional surface till samples with which to compare to till studied in sections. From these sections and surficial sites, 20 samples of till and 4 samples of gravel were collected. The site and sample information is included in Appendix 1. Stratigraphic columns and field photographs are included in Appendix 2.

Ice-flow data

To obtain ice-flow data for till exposed in sections, measurement of the long-axes orientation, or fabric, of clasts are used to interpret the ice-flow orientation. Certain shapes of clasts, defined as a particular arrangement of the a-axis (longest), b-axis (middle) and c-axis (shortest), are statistically proven to often deposit parallel to the direction of shear (Holmes, 1941).

Clast-fabric measurements were conducted at nine selected depths within seven sections in the study area (Appendix 3). Clast-fabric locations were chosen based on uniformity of diamict, where no sand lenses or discontinuous bedding was present. At each location, a horizontal step was excavated at least 20 cm into the section face. Clasts were then carefully excavated and measured from within a 'box' consisting of three vertical faces of different orientations, over a max distance of 30 x 30 x 30 cm. Measurements consisted of the length of all axes, and the a-axis trend and plunge. At each site, the orientation of 30–31 clasts were measured. Owing to the clast-poor nature of the diamict, all clasts with an a-axis length between 0.5 and 6.0 cm were included. The average length was 1.7 cm, the median length was 1.5 cm, and the standard deviation was 0.9 cm. Accepted clasts included in these analyses met the following criteria:

- clast was free to rotate in the matrix (not clast-supported or close to much larger clasts)
- rod, tabular-rectangle or wedge-shaped
- ratio of the a:b axis was 1.5 or greater
- plunge of the a-axis was less than 60° (average 17° and standard deviation 11°)
- plunge of the b-axis was less than 60° (cf. Holmes, 1941)

Assuming there is not a bimodal distribution, fabric data can be analyzed using three mutually orthogonal eigenvectors

(V_1, V_2, V_3), and their normalized magnitudes (eigenvalues S_1, S_2, S_3; (Mark, 1973, 1974; Benn, 1994). Bimodal or multimodal fabric patterns cannot be described solely using these procedures and must be interpreted qualitatively using stereonet and rose diagrams (Ramsden, 1970; Mark, 1973). V_1 parallels the axis of maximum clustering of the a-axes while V_3 represents the axis of minimum clustering and is orthogonal to the preferred plane of the fabric. Elongation ($E = 1 – (S_2/S_1)$) and isotropy ($I = S_3/S_1$) are also used to define the clast-fabric shape (Benn, 1994). The elongation index measures the preferred orientation in the V_1/V_2 plane, where E = 1 is defined as a very strong fabric in perfect alignment. The isotropy index measures the similarity to a uniform distribution, where I = 0 is defined as a very strong fabric in perfect alignment. In an ideal case for ice-flow interpretation, the fabric would be perfectly elongated (all of the clasts had exactly the same orientation) and S_1 would equal 1, while S_2 and S_3 would equal 0 (Benn, 1994). In the opposite case, with an isotropic fabric (perfectly random yet equal orientation of clasts), S_1, S_2 and S_3 would each equal 0.333. Thus, as S_1 approaches a value of 1, the fabric pattern becomes more strongly oriented. Fabrics between these two extremes will have intermediate eigenvalues, and intermediate stereonet patterns. Only fabrics considered to be of moderate to very strong strength were used to interpret ice-flow orientation. The remaining clast fabrics are valid, but cannot be confidently used to interpret ice-flow orientation due to a combination of bimodality or multimodality fabric, low elongation and/or high isotropy.

Laboratory and analytical procedures

Collected till samples were analyzed for color, clast lithology, grain size (<2 mm size-fraction) and till-matrix geochemistry analysis. Till samples were split to retain an archive at the Manitoba Geological Survey Midland Sample and Core Library (Winnipeg, Manitoba), and assigned a moist-matrix color (Munsell Color-X-Rite Incorporated, 2015). Lab splits were sent to the Saskatchewan Research Council Geoanalytical Laboratories (SRC; Saskatoon, Saskatchewan). Approximately 1 kg of each till sample was air-dried and dry-sieved, using stainless steel mesh screens to obtain the <2 mm fraction for texture and <63 µm fraction for geochemical analyses and carbonate content determination. Very dense/hard samples were wet-sieved and oven-dried before sieving.

Grain-size distribution

The matrix texture results were calculated as weight percent (wt. %) sand, silt and clay of the <2 mm fraction and are presented in Appendix 1.

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

Clast lithology

The clast lithology of the till and gravel samples was determined to help identify major directions of dispersal and hence provenance. Clasts larger than 2 mm were sieved from a portion of each sample collected and further separated into size-fractions of 2–4 mm and 4–8 mm. The granules or pebbles within each clast–size-fraction were then separated according to lithology into 16 lithological classes using an optical microscope. An average of 433 clasts were counted for each sample, averaging 300 and 139 clasts for the 2–4 mm and 4–8 mm size-fractions, respectively. In Appendix 4, the lithological class results are expressed as counts of clasts in a separate table for each size-fraction. The separate size-fraction counts were then summed (2–8 mm) and expressed as a count percent (ct. %) in Table 11. Photos of each sorted 2–4 mm and 4–8 mm size-fraction are presented in Appendix 5. Previously published clast-lithology data, from the 4–16 mm size-fraction of till samples expressed as weight percent, also provided for nearby samples in Table 12 (Thorleifson and Matile, 1993).

The 16 lithological classes were then grouped into four simplified classes: granitoid, undifferentiated greenstones and greywackes, Paleozoic and other (Table 1). This was completed to ease interpretation of the till composition, identify regional-scale dispersal patterns and to reduce lithological identification errors.

Ca/Mg method for carbonate content

The results for till carbonate content, expressed as weight percent, are provided in Appendix 6. An aliquot of the till matrix (<63 µm size-fraction) was digested using HCl and analyzed for Ca and Mg by inductively coupled plasma–optical emission spectrometry (ICP-OES). The proportion of calcite and dolomite was then calculated (wt. %).

Partial digestion till-matrix geochemistry

In 2021, an aliquot of the <63 µm size-fraction was digested in a aqua regia (1:3 HNO_3:HCl) mixture. Following digestion, samples were analyzed by inductively coupled plasma–mass spectrometry (ICP-MS) and ICP-OES techniques for 63 elements at Activation Laboratories Ltd. (Actlabs; Ancaster, Ontario). 2022 till samples were analyzed using the same methodology at SRC. The analytical results are in Appendix 7, together with data for control reference standards, analytical and field duplicates, and blanks.

Table 1: Simplified and detailed lithological classes for till and gravel clasts.

Simplified class	Granitoid	Undifferentiated greenstones and greywackes	Paleozoic	Other
Detailed classes	Granitoid	Undifferentiated greenstone	Grey, tan, white limestone/dolostone	Quartz
	Gneiss	Metavolcanic rocks		Ironstone
	Intermediate intrusive	Metasedimentary rocks	Pink limestone	
	Amphibolite	Quartzite	Chert	
	Gabbro		Sandstone	
			Quartz arenite	

Fusion digestion till-matrix geochemistry

An aliquot of the <63 µm size-fraction was digested by lithium metaborate/tetraborate fusion (5% HNO_3). Following digestion, samples were analyzed by ICP-MS and ICP-OES techniques for 58 elements at Actlabs in 2021 and SRC in 2022. The analytical results are presented in Appendix 8, together with analytical data for control reference standards, analytical and field duplicates, and blanks.

Data compilation

Till samples were collected from roadcuts, boreholes and river exposures across southeastern-central Manitoba during a Ph.D. thesis by Fenton (1974) and between 1991 and 1992 as part of the National Geoscience Mapping Program (Matile et al., 1999). All till samples were analyzed for grain size and total carbonate (<63 µm size-fraction), and published with minimal (Fenton, 1974) to no stratigraphic data (Thorleifson and Matile, 1993). Simplified clast lithology (crystalline vs. carbonate) of the 1–2 mm size-fraction was denoted in the earlier work, and more complex clast lithology of the 4–16 mm size-fraction in the later work. M. Budge digitized the 1974 data for sites along the Roseau River, during her B.Sc. thesis (Budge, 2022).

For this report, H. Thorleifson has graciously supplied simplified stratigraphic data for seven sections along the Roseau River, and detailed stratigraphic data for two 70 m deep rotosonic drill-cores near St. Malo and Pansy, Manitoba (Figure 1; Appendices 1, 2). The rotosonic drill recovered a continous, intact, 8 cm thick core; stratigraphic data for an additional 21 boreholes from Thorleifson and Matile (1993) are now published within Matile et al. (2023a).

Results

Stratigraphy

Stratigraphic data is obtained from sections along the Roseau River, new road and gravel pit exposures, two rotosonic boreholes and historical boreholes with limited descriptions (Fenton, 1974; Thorleifson and Matile, 1993). Sections along the Roseau River expose ~3–16 m of Quaternary sediment (Figure 4). This sediment contains up to three diamict packages, interpreted as tills, which are also separated by proglacial or nonglacial lacustrine, pond or fluvial sediments (Fenton, 1974). To the north, a gravel pit documented in 2022 exposed 1.25 m of laminated diamict, interpreted as a till, that overlies 9.0+ m of clast- to matrix-supported gravel that continues below the water table (section 115-22-303/304; Appendix 2). The rotosonic boreholes in the study area encountered 68–70 m of Quaternary sediments overlying bedrock (R is 8.7 km south of the pit, Q is 13 km southeast; details within Appendix 2). These boreholes drilled into ~four different diamict packages, interpreted as tills, separated by proglacial or nonglacial lacustrine, pond or fluvial sediments. Thus, while detailed stratigraphy is beyond the scope of this Open File, it is clear that the study area has a depositional record that spans multiple glacial-interglacial cycles.

Tills

Given the complex stratigraphy of the study area, it is desirable to see if tills can be differentiated using their quantitative characteristics, in addition to their stratigraphic relationships. This Open File compiles existing data, upon which this hypothesis can eventually be tested. Currently, the till-composition dataset is limited to 20 till samples from this study and 65 till samples from Thorleifson and Matile (1993). An additional 44 till samples from Fenton (1974) are limited to grain size (Appendix 1) and matrix carbonate data (Appendix 6). This is an insufficient number of observations to investigate the composition of tills statistically; however, at this time we can use the till sedimentology, till-fabric and stratigraphy observations to begin to understand when the region was glaciated and in which direction ice was flowing.

Clast fabric

Clast-fabric measurements in the study area are interpreted to have formed by south, south-southwest, southwest and possibly west-northwest flowing ice (169–219°, ~287°; Figures 1, 4; Appendix 3). Significantly more clast fabrics in tills are needed to better understand the regional history.

Matrix grain size

There is a large spread in the textural composition of the tills in the study area (Figure 5; Appendix 1). The samples con-

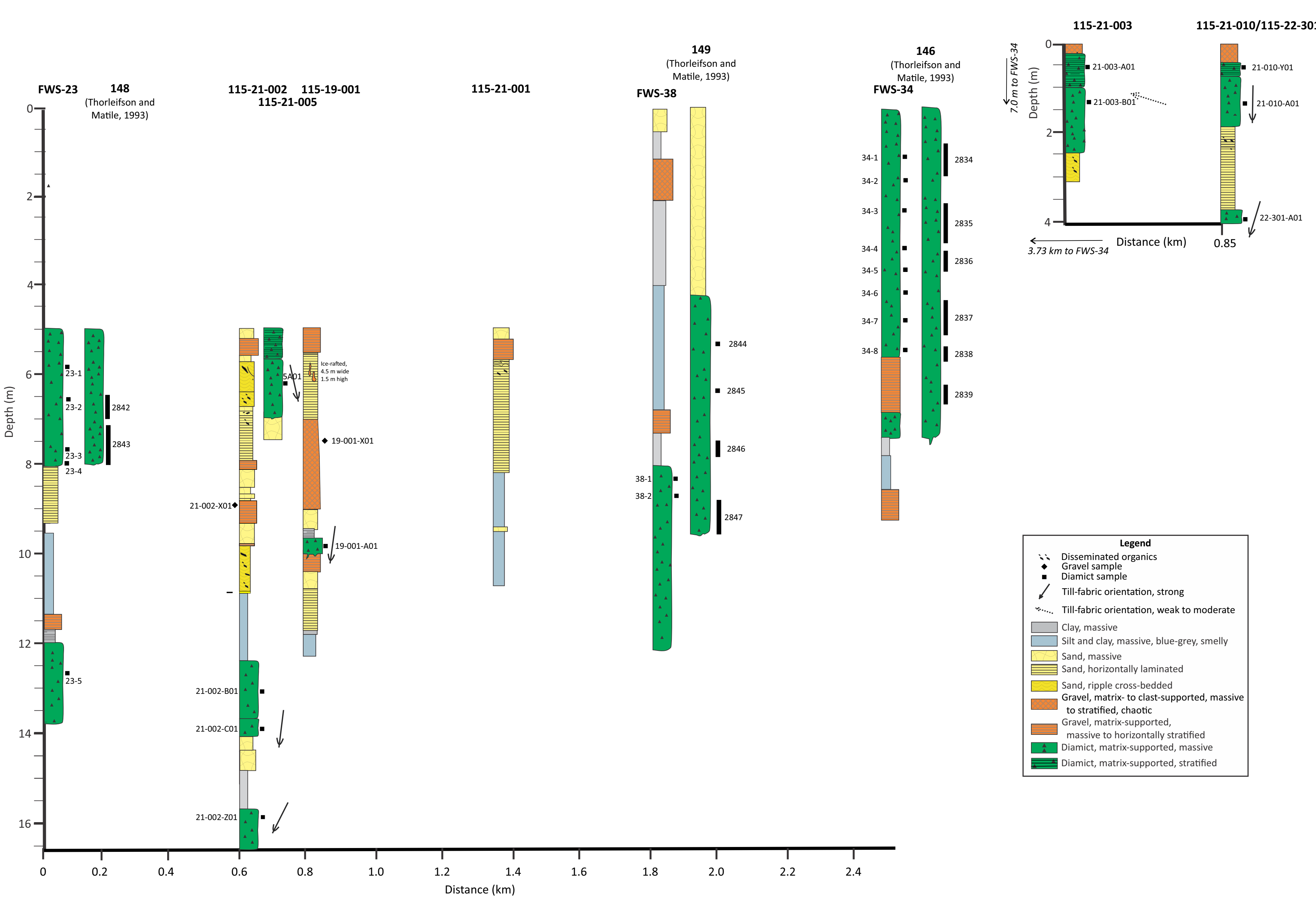

Figure 4: *Stratigraphic sections along the Roseau River and nearby ditch section, studied in 2021–2022 (115-xx-xxx), 1993 (148, 149, 146; Thorleifson and Matile) and 1974 (FWS-xx; Fenton). Diamict samples are also labelled; from herein (xx-xxx-xxx), 1993 (xxxx; Thorleifson and Matile) and 1974 (xx-x; Fenton).*

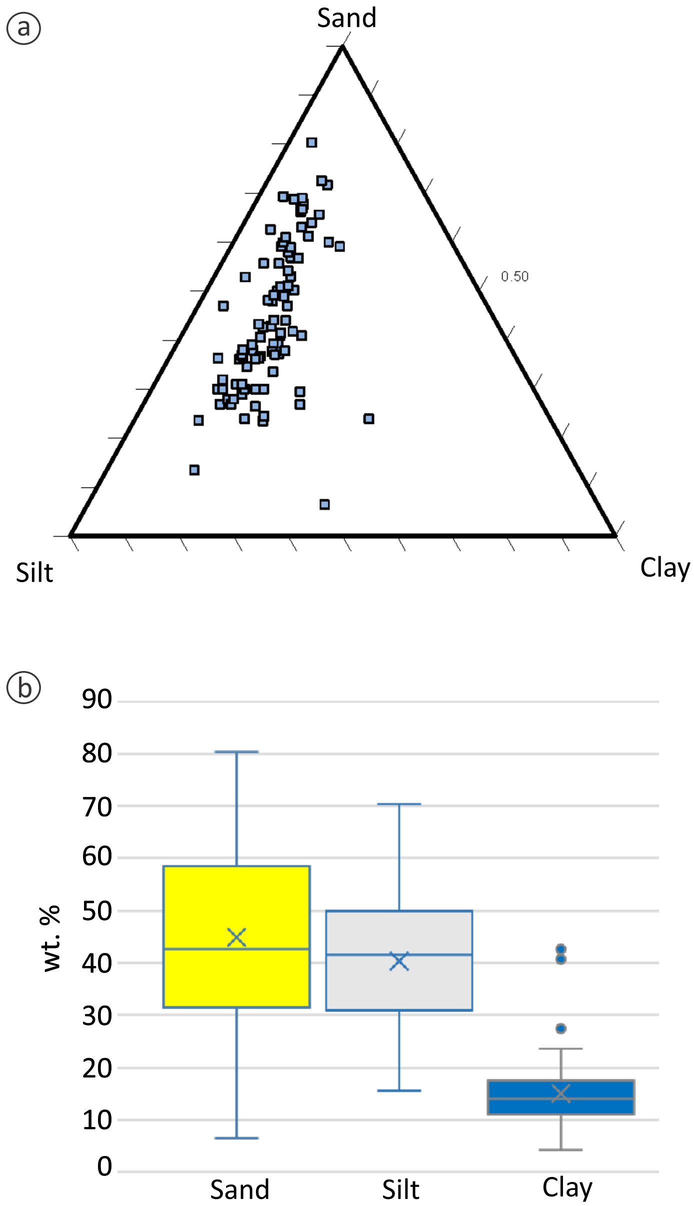

*Figure 5: Texture of tills in the study area, displayed on a ternary diagram **(a)** and box plots **(b)**. The 113 samples are from this study, Thorleifson and Matile (1993) and Fenton (1974).*

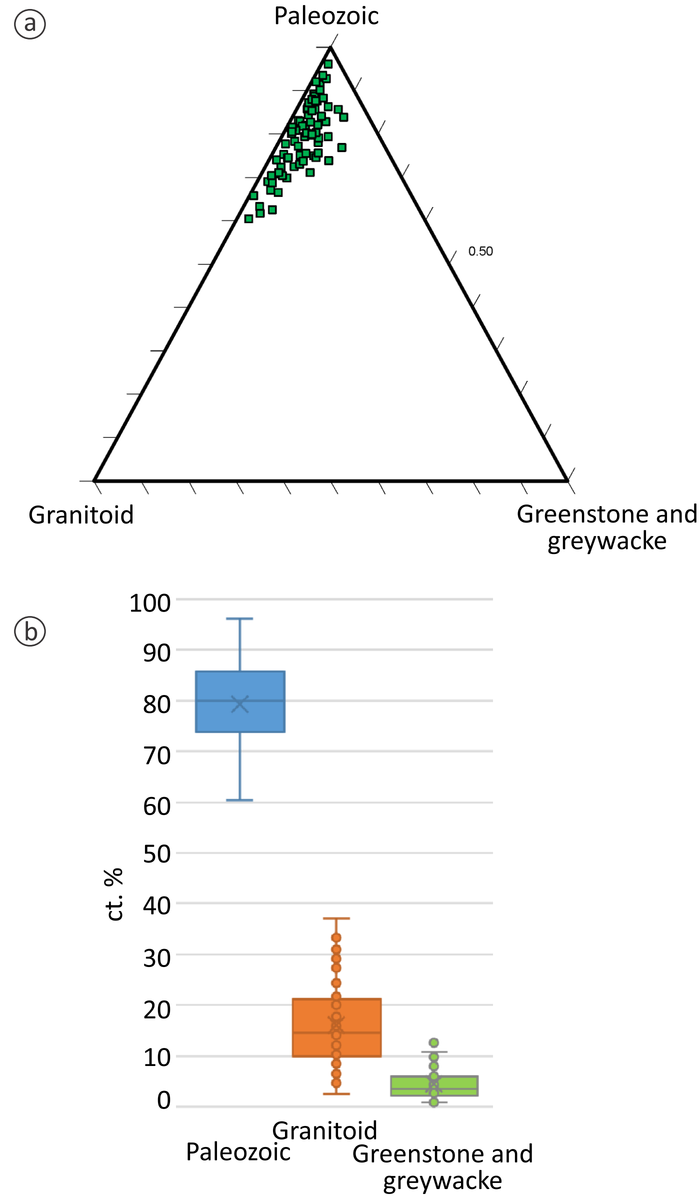

*Figure 6: Simplified till clast-lithology for till samples in the study area, as a ternary diagram **(a)** and box plots **(b)**. The 85 samples are from this study and Thorleifson and Matile (1993).*

tain 6.50–80.30 wt. % sand (mean of 44.83 wt. %), 15.60–70.40 wt. % silt (mean of 40.27 wt. %) and 4.20–43.50 wt. % clay (mean of 14.92 wt. %).

Clast lithology

The majority of till clasts are Paleozoic, derived from bedrock in central Manitoba (Figure 3), though concentrations range significantly from 60.41–96.16 ct. % (mean of 79.36 ct. %; Figures 6, 7).

There is a difference in the morphology of calcareous clasts observed. Some till samples contain angular to subangular clasts (Figure 8a) lithologically similar to the Ordovician upper Red River Formation or lower Stony Mountain Formation that outcrop north to north-northeast of the study area (Manitoba Energy and Mines, 1990). Contrastingly, some calcareous clasts are subangular to rounded (Figure 8b) and lithologically similar to the Interlake group, which outcrops northwest of the study area (Manitoba Energy and Mines, 1990).

Granitoid, metavolcanic and metasedimentary clasts in till are most likely derived from the Precambrian shield to the east (Figure 3). Granitoid concentrations range significantly (2.41–44.25 ct. %, mean of 16.6 ct. %), as do undifferentiated greenstone and greywacke clasts (0.86–13.9 ct. %, mean of 4.45 ct. %).

Trace Mesozoic shale clasts (>0.1 ct. %) were found in just three till samples from the borehole Q (Appendix 4).

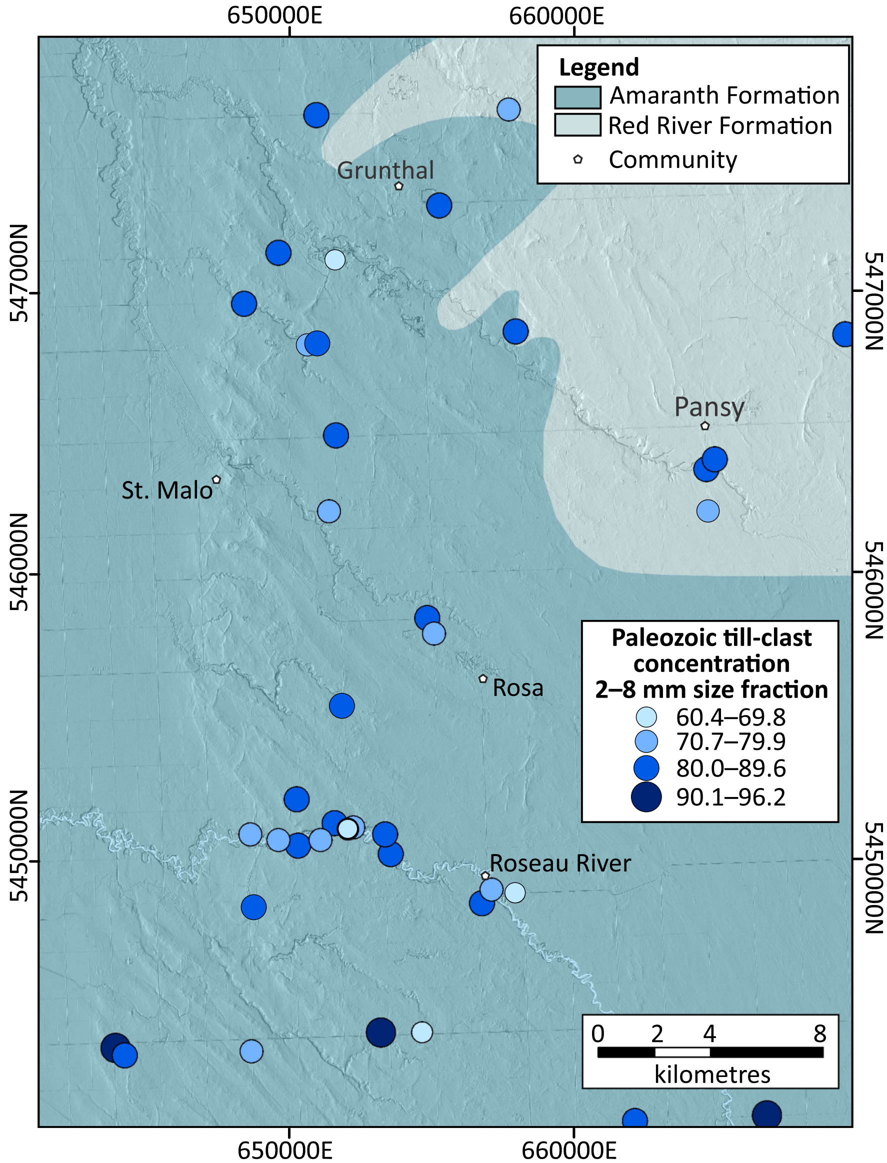

Figure 7: *Spatial distribution of Paleozoic till-clast concentration (ct. %), for surface till samples.*

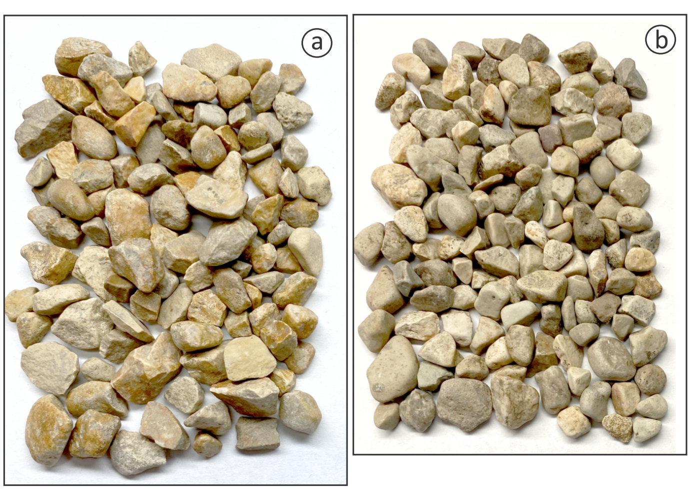

Figure 8: *Clast lithology (4–8 mm size-fraction) from two different till samples:* ***a)*** *angular to subangular Ordovician upper Red River Formation or lower Stony Mountain Formation and* ***b)*** *subangular to rounded, possibly sourced from the Interlake group.*

Matrix carbonate

The concentration of carbonate in local tills is derived from comminution of Paleozoic bedrock and Paleozoic clasts within the tills. There is a large spread in the total carbonate within the till matrix (<63 µm size-fraction) in the study area (32.94–68.85 wt. %, average 51.23 wt. %; Appendix 6).

Regional gravel

Preliminary work suggests there are two different gravels at surface; a Paleozoic-rich pebble gravel (Figure 9a, b) and more Precambrian-rich pebble–cobble gravel with boulders (Figure 9c, d). At site 115-22-307, 0.65 m of a Paleozoic-rich pebble gravel (74.0 ct. % Paleozoic, 24.1 ct. % granitoid, 1.8% undifferentiated greenstone and greywacke) overlies till with a similar clast composition (81.6 ct. % Paleozoic, 17.3 ct. % granitoid, 1.1% undifferentiated greenstone and greywacke). Given the similar clast concentrations, it's likely that the gravel has the same source or

Figure 9:** Preliminary work, conducted at only a few field sites, suggests there are two different gravels at surface:* ***a, b) *a Paleozoic-rich pebble gravel and* ***c, d)*** *a relatively more Precambrian-rich pebble–cobble gravel with boulders.*

that the gravel is derived directly from the underlying till; possibly from reworking within a glaciolacustrine environment (Lake Agassiz). Conversely, at site 115-22-303/304 (Appendix 2), 1.25 m of till overlies 7.00+ m of sand or gravel and the composition of the till is different than the gravel directly underlying the till. The till contains 67.1 ct. % Palezoic and 29.2 ct. % granitoid clasts, whereas the gravel contains 50.6 ct. % Paleozoic and 44.2 ct. % granitoid clasts. The elevated Precambrian shield clast-concentration in the buried gravel suggests the source of this gravel was situated to the east or northeast. The clast-supported, poorly-sorted, subangular–subrounded, imbricated, horizontally- to chaotically-bedded nature of the gravel (sites 115-22-303, -305) together with the mixed-clast lithologies, requires a glacial source for the gravel. While these near-surface sub-till gravels have variably been attributed as esker sediments (Harington et al., 2007) or kame-delta sediments (Fenton, 1974), we suggest the gravel was likely deposited as proglacial or interglacial outwash during ice-margin retreat in an earlier interstadial period.

Future work

Surficial mapping studies that incorporate new field observations, legacy datasets and high resolution LiDAR elevation models are needed in order to sort out the type, age, genesis and relative age of surface and near-surface sediments. This will be essential for new aggregate exploration in the area.

Acknowledgments

We thank C. Epp and P. Benger for help sorting samples at the Midland Sample and Core Library, and J. Marchand for letting us collect samples from her property. M Budge is thanked for digital compilation of Fenton's data and for identifying and counting till-sample clasts.

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