Invest Manitoba
Open for Business

Open File OF2023-1

Indicator mineral and gold grain data from till sampled in the Churchill to Little Churchill rivers area, northeastern Manitoba

Manitoba

Open File OF2023-1

Indicator mineral and gold grain data from till sampled in the Churchill to Little Churchill rivers area, northeastern Manitoba

by T.J. Hodder and M.S. Gauthier
Manitoba Geological Survey
Winnipeg, 2023

When using information from this publication in other publications or presentations, due acknowledgment should be given to the Manitoba Geological Survey. The following reference format is recommended:

Hodder, T.J. and Gauthier, M.S. 2023: Indicator mineral and gold grain data from till sampled in the Churchill to Little Churchill rivers area, northeastern Manitoba; Manitoba Economic Development, Investment and Trade, Manitoba Geological Survey, Open File OF2023-1, 19 p. plus 4 appendices.

NTS grid: 54E

Published by:

Manitoba Economic Development, Investment and Trade
Manitoba Geological Survey
360–1395 Ellice Avenue
Winnipeg, Manitoba
R3G 3P2 Canada

Telephone: 1-800-223-5215 (General Enquiry)
204-945-6569 (Publication Sales)
Fax: 204-945-8427
Email: minesinfo@gov.mb.ca
Website: manitoba.ca/minerals

ISBN: 978-0-7711-1645-2

This publication is available to download free of charge at manitoba.ca/minerals.
This publication is available in alternate formats upon request.

Front cover photo:

View of section 112-21-823 that is situated on a tributary to the Little Churchill River. The stratigraphy exposed here consists of a light olive brown till overlying a black till.

Abstract

The Manitoba Geological Survey conducted a till indicator mineral and gold grain count survey in the Churchill to Little Churchill rivers area. This is a previously unexplored area with thick sediment cover. The rivers have incised through this thick cover and sections expose up to 65 m of Quaternary sediments. This allows for detailed investigation of the Quaternary stratigraphy of the region and sampling of multiple beds that were deposited by different ice-flow directions. In addition, a limited number of surficial till samples were collected. This survey recovered a total of 67 gold grains from till samples: 49 rounded grains, 14 modified grains and 4 pristine grains. A total of 47 kimberlite-indicator mineral grains were recovered, averaging 0.5 KIM recovered per 10 kg of till processed. The magmatic or metamorphic massive-sulphide–indicator minerals recovered included chalcopyrite (n = 52), molybdenite (n = 12) and scheelite (n = 4), among other indicators within this analysis suite. Within the region there is no obvious spatial pattern nor clear relationship to interpreted ice-flow orientations. Current work is focused on detailed analysis of the till composition, characterization of intertill sorted sediment units and creation of a stratigraphic framework for the area, which will help facilitate drift prospecting efforts in this thick drift region of northeastern Manitoba.

Résumé

La Direction des services géologiques du Manitoba a réalisé un levé pour compter les grains d'or et les minéraux indicateurs présents dans le till dans la zone comprise entre les rivières Churchill et Little Churchill. Cette zone jusqu'ici inexplorée a une couche sédimentaire épaisse, que les rivières ont entaillé, exposant jusqu'à 65 m de sédiments quaternaires. Cela permet d'enquêter de manière détaillée sur la stratigraphie du Quaternaire dans la région et d'échantillonner plusieurs lits déposés par différentes directions d'écoulement glaciaire. De plus, un nombre limité d'échantillons de till de surface ont été prélevés. Ce levé a permis de collecter, à partir des échantillons de till, un total de 67 grains d'or : 49 grains ronds, 14 grains modifiés et 4 grains purs. Au total, 47 grains de minéraux indicateurs de kimberlite ont été récupérés, avec une concentration moyenne de minéraux indicateurs de kimberlite de 0,5 par tranche de 10 kg de till traité. Les minéraux indicateurs de sulfures massifs magmatiques ou métamorphiques récupérés comprenaient de la chalcopyrite (n = 52), de la molybdénite (n = 12) et de la scheelite (n = 4), entre autres indicateurs inclus à cette série d'analyses. On ne relève dans la région aucune configuration spatiale évidente ni aucun lien clair avec les directions d'écoulement glaciaire interprétées. Les travaux sont actuellement centrés sur des analyses détaillées de la composition du till, la caractérisation des unités sédimentaires triées selon l'intertill et la création pour la zone en question d'un cadre stratigraphique, ce qui facilitera la tenue des activités de prospection glacio-sédimentaire dans cette région du Nord-Est du Manitoba aux épais dépôts glaciaires.

TABLE OF CONTENTS

TABLES

FIGURES

SUPPLEMENTAL FIGURES

DIGITAL DATA

Introduction

The Manitoba Geological Survey (MGS) conducted a till indicator mineral and gold grain count survey in the Churchill to Little Churchill rivers area in 2021 (Figure 1). This is a previously unexplored area with thick sediment cover; 20–65 and 5–17 m of sediment, respectively. These thick exposures of Quaternary sediments allowed for the sampling of multiple stratigraphic beds that were deposited by different ice-flow events over time. A small number of surface-till samples were also taken. This report releases the visible gold grain and indicator mineral (magmatic or metamorphosed massive-sulphide–indicator minerals [MMSIM®]) and kimberlite-indicator minerals (KIM) count data. Identified KIM grains were microprobed to further characterize their chemical composition. This report provides a preliminary interpretation of the ice-flow direction(s) that deposited the sampled tills. These results are being released before the comprehensive data report, to provide the mineral exploration industry timely updates on new geological knowledge.

Exploration in the thick drift of northeastern Manitoba

Large segments of geologically-prospective rocks in northeastern Manitoba are buried by thick sequences of glacial sediments (Hodder and Gauthier, 2021b), which, coupled with sparse baseline geological data, present significant obstacles to under-

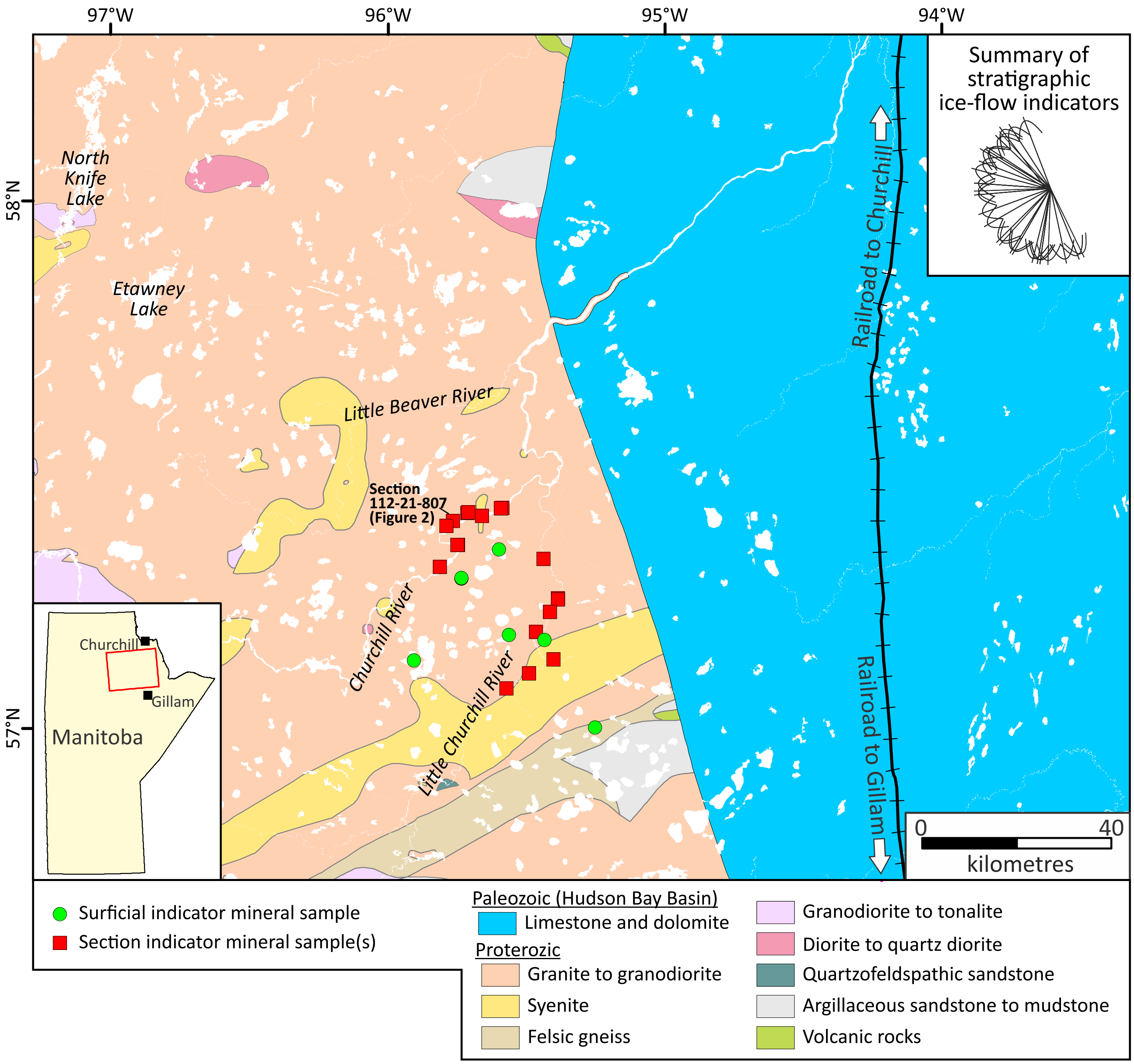


Figure 1: *Bedrock geology (1:250 000 scale) and location of the study area in northeastern Manitoba. Bedrock geology is from Manitoba Geological Survey (2022) and Nicolas and Armstrong (2017).*

standing the mineral potential. This project aims to provide new Quaternary baseline data, while also analyzing for indicators of economic interest (gold, KIM, MMSIM®) in the till.

Regionally, thick Quaternary sediments were deposited over multiple glacial–interglacial cycles, and preserved as fragmented patches (over space and time) on the landscape (Gauthier et al., 2019). The Manitoba Geological Survey, together with the Geological Survey of Canada, is working towards establishing a new stratigraphic framework that will eventually advance knowledge of drift exploration vectors and glacial dispersal models in the thick multi-till stratigraphy of the Manitoba Hudson Bay Lowland (HBL). A major part of this work involves studying the relationship between ice-flow direction and till composition over time. This relationship is complex in the HBL, due to spatiotemporal variability in both the strength of different ice domes at an ice-sheet scale and the subglacial processes at a very local ice-bed interface scale. This means that, over at least two different glacial cycles, ice advanced into northeastern Manitoba from ice centered to the east (Quebec), followed by a switch in ice-flow direction indicating flow from the Keewatin ice centre to the northwest and north (Gauthier et al., 2019). As the ice-flow direction changed, subglacial sediments of different provenance were deposited and subsequently preserved, or partially re-entrained and mixed in places, and/or covered or replaced by newly-produced sediments elsewhere.

One of the main questions of this specific study is whether the majority of the glacial sediments are from the north (~Keewatin), the east (~Quebec) or a mixture of both sources areas. Is the source region consistent throughout multiple glacial cycles, or are tills closest to bedrock from different source areas than higher in the section? The answer to these questions will greatly impact how drift prospecting programs should proceed in the study area. Complex dispersal patterns are expected, and any indicators of economic interest may not have a provenance that is simply 'up-ice' of the ice-flow indicator at the sample location.

Methods

Sample collection

Till samples were collected from multiple stratigraphic beds along the Churchill and Little Churchill rivers, in addition to surface hand-dug pits or mudboils. Mudboils were the preferred surface sampling sites, as these permafrost features bring unweathered (C horizon) till to the surface (McMartin and McClenaghan, 2001). At six surface sites, an 11.4 L sample of till was collected for analysis, weighing on average 21.7 kg (17.5–27.2 kg range). Sediment exposures along river cuts were cleared of slumped detritus, exposing a continuous vertical section with no gap, and then described in detail. A total of 59 11.4 L samples from 14 exposures were collected, weighing on average 15.5 kg (12.5–21.2 kg range).

Ice-flow data

Ice-flow data was obtained from studied sections by measuring the long-axes orientation, or fabric, of clasts within till. Elongate clasts, defined by a minimum 1.5:1.0 ratio of the a-axis (longest) to the b-axis (middle), will rotate within the till matrix and orient parallel to the direction of stress that the overriding glacier exerts on the till (Holmes, 1941). Clast-fabric locations on the cleaned section face were chosen based on uniformity of till, 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 maximum distance of 30 x 30 x 30 cm. A minimum of 30 elongated clasts were measured at each till-fabric site. Owing to the clasts-poor nature of the till, all clasts with an a-axis length between 0.4 and 13 cm were included. The average length was 2.0 cm, the median length was 1.6 cm, and the standard deviation was 1.3 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
- plunge of the a-axis was less than 60°
- plunge of the b-axis less than 60°

For the purpose of this report, the ice-flow directions were interpreted from stereonet plots of till-fabric data based on the fabric modality, principal eigenvector (V_1) and eigenvalue (S_1) (Mark, 1973, 1974; Hicock et al., 1996).

Parallel striations on flat-topped cobbles and boulders in till are considered a good indicator of paleo-ice flow direction (McMartin and Paulen, 2009). They may reflect basal ice sliding on stiff till if the logged clasts are found at the contact between two till sheets, but it can also develop locally, within a till sheet, on a lodged clast while till is being deposited elsewhere around. In any case, they both provide useful information which can be carefully analyzed and interpreted to reconstruct paleo-ice flow of stratigraphic units.

Indicator mineral and gold grain data

Till samples were processed at Overburden Drilling Management Limited (ODM; Ottawa, Ontario) using standard Geological Survey of Canada protocols (Plouffe et al., 2013). Till samples were disaggregated and sieved at 2 mm. The 2–4, 4–8 and 8+ mm size-fractions were returned to the MGS for clast counts after an oxalic acid bath. The <2 mm size-fraction was passed across a shaker table to pre-concentrate the heavy mineral fraction. The pre-concentrate was then micropanned to recover fine-grained gold, sulphide and other indicator minerals. The 0.25–2.0 mm concentrate was then processed using a heavy liquid separation to a specific gravity of 3.2 to produce a heavy mineral concentrate (HMC). Ferromagnetic minerals were removed from the HMC fraction using a magnet. The non-ferromagentic HMC were then sieved into 0.25–0.5, 0.5–1.0 and 1.0–2.0 mm size-fractions.

The 0.25–0.5 HMC was then refined with a paramagnetic separation to assist counting of this fine fraction. These size-fractions were then visually picked for MMSIM® and KIM. A select number of MMSIM® and KIM grains were then verified using a SEM and these grains are noted in the remarks column for each table.

This study incorporated four samples blanks for QA/QC purposes. Two samples were the Linton till blank and two samples were the Bathhurst blank (Plouffe et al., 2013). The sample processing order was predetermined and these blanks were inserted ~every 20 samples and the order of samples presented in Appendix 1 is the order in which they were processed.

The chemical composition of visually identified KIM grains and all crustal ilmenites was further characterized using electron microprobe analysis. This analysis was completed at the Electron Microprobe Laboratory at the University of Alberta (Edmonton, Alberta). The KIM grains were then initially classified using electron microprobe results, following the methodology outlined in the Manitoba KIM database (Keller, 2019). The chemistry of certain KIM grain types was then further investigated with bivariate plots.

Results

Preliminary till fabric interpretations

Clasts within till typically dip up-ice as the particles orient themselves to pose the least resistance to ice flow (Kjaer and Kruger, 1998; Hooyer and Iverson, 2000). Hence, with a unimodal cluster or spread unimodal fabric modality (Hicock et al., 1996), the principal eigenvector (V_1) plus 180° is usually assumed to be the ice-flow orientation (e.g., Hopkins et al., 2016). However, the plunge direction of the principal eigenvector is not reliable enough to conclusively determine the up-ice direction (Gauthier et al., 2019). In these cases, other factors such as regional glacial history and/or provenance of clasts within the till may provide an indication of ice-flow direction (Catto, 1998).

Interpretation of till fabrics across northeastern Manitoba is especially difficult because both NW- and SE-trending ice flow is documented in the depositional and erosional ice-flow records (Gauthier et al., 2019). Within this study area, numerous till fabrics have principal eigenvectors (V_1) that are oriented to either the NW or SE within a single section (e.g., Figure 2a). To determine the actual ice-flow direction for these till fabrics, other datasets such as till composition are needed to characterize the provenance of the sediment. For this study, each NW-SE oriented till fabric has been assessed using clast-lithology counts (unpublished dataset) and till-matrix carbonate data (Hodder and Gauthier, 2022b) to determine the direction of ice flow (Figure 2b). For example, section 112-21-807 has two till beds where NW-SE oriented till fabrics were measured (Figure 2a). The lowermost till sampled for indicator minerals (stratigraphic bed E) is interpreted to be deposited by SSE-trending (158°) ice flow based on a relatively high proportion of granitoid clasts (48 ct. %; 2–8 mm size-fraction; Figure 2b) and low matrix carbonate content (21.2 wt. %; Figure 2b). The till bed above the interpreted interglacial sediments (stratigraphic bed C) is interpreted to be deposited by WNW-trending (301–303°) ice flow based on a relatively high proportion of Hudson Bay Basin clasts (75–77 ct. %; 2–8 mm size-fraction; Figure 2b) and relatively elevated matrix carbonate (42.3–47.5 wt. %; Figure 2b). The till fabric interpretation of one till bed was uncertain and the ice-flow direction was left as bidirectional at this site. A breakdown of section till samples by ice-flow direction is presented in Table 1.

Gold grain counts

Raw data for gold grain counts is presented in Appendix 2 and plotted spatially in Supplemental Figures 1–3. A total of 67 gold grains were recovered from till samples: 49 rounded grains, 14 modified grains and 4 pristine grains. The highest total grain counts in a single sample were 10 grains (8 rounded, 2 modified) at a surface till sample site east of the Churchill River near McIntyre Lake (Supplemental Figure 3) and 7 grains (2 pristine, 1 modified, 4 rounded) from the uppermost till sampled at section 21-802 (Supplemental Figure 2). At section 21-802, a till fabric indicates the till sampled was deposited by SSW-trending ice flow. All other till samples recovered 0–4 gold grains. The 4 pristine gold grains recovered were from three till samples deposited by SSW- to SW-trending ice flow in close proximity to each other on the Little Churchill River (Supplemental Figure 2). For comparison of these results with the rest of publically-available gold grain data in Manitoba, please refer to Open File OF2020-6 (Gauthier, 2020).

Magmatic or metamorphosed massive-sulphide–indicator minerals counts

Raw data for the MMSIM® counts is presented in Appendix 3 and picked grains for each till sample are plotted spatially in Supplemental Figures 4–6. This report highlights certain indicators and a thorough analysis of the dataset is encouraged by any interested party.

Chalcopyrite

A total of 52 chalcopyrite grains were covered from till samples. Thirty-eight grains were recovered from till sampled on Churchill River (Supplemental Figure 4), 13 grains from till sampled on the Little Churchill River (Supplemental Figure 5) and 1 from a surficial till sample near Embleton Lake (Supplemental Figure 6). The majority of these grains (n = 29) are associated with till deposited by W- to NW-trending ice flow, but there is a higher recovery rate from till that was deposited by SE-trending ice flow (Table 2). The multiple ice-flow directions associated with till sampled indicates there is likely multiple sources of recovered chalcopyrite grains; alternatively this could be interpreted as evidence for more complex palimpsest dispersal patterns.

Molybdenite

A total of 12 molybdenite grains were recovered from seven till samples at six sections (Supplemental Figure 4, 5). On the

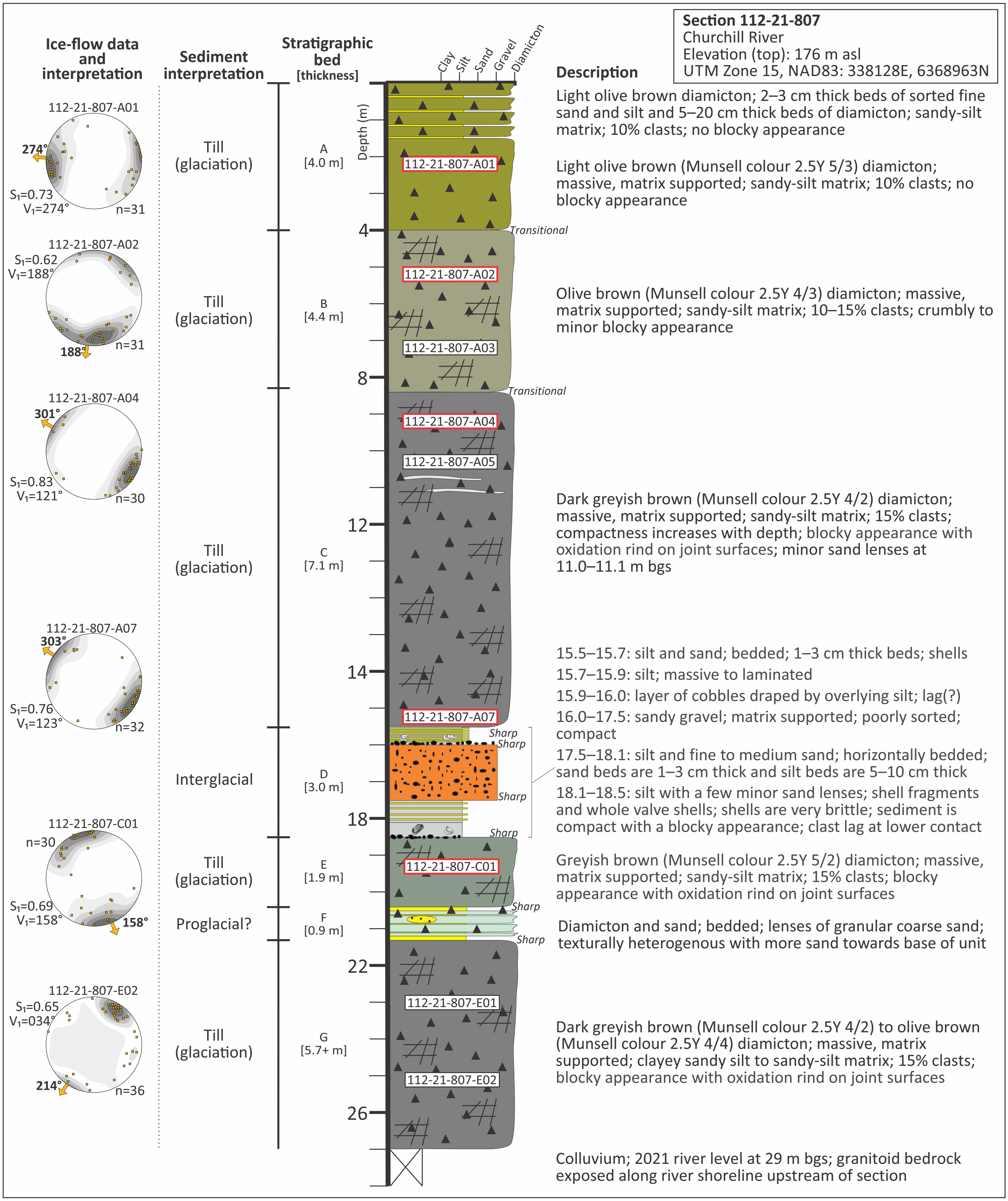


Figure 2a: *Example of a Quaternary sediment exposure described and sampled on the Churchill River (section 112-21-807, see Figure 1 for location) and preliminary till composition: stratigraphic column and description of the sediments exposed at section 112-21-807. Till sample numbers and till-fabric sites are labelled within the white boxes. Till samples that were also analyzed for indicator minerals are highlighted by a red outline box. Till-fabric data is plotted on equal area, lower hemisphere projection stereonets. The value of the principal eigenvalue (S_1) and direction of the principal eigenvector (V_1) are provided and an interpretation of the ice-flow direction is indicated (orange arrow). Diamicton colour from Munsell Color–X-Rite, Incorporated (2015). Abbreviation: bgs, below ground surface.*

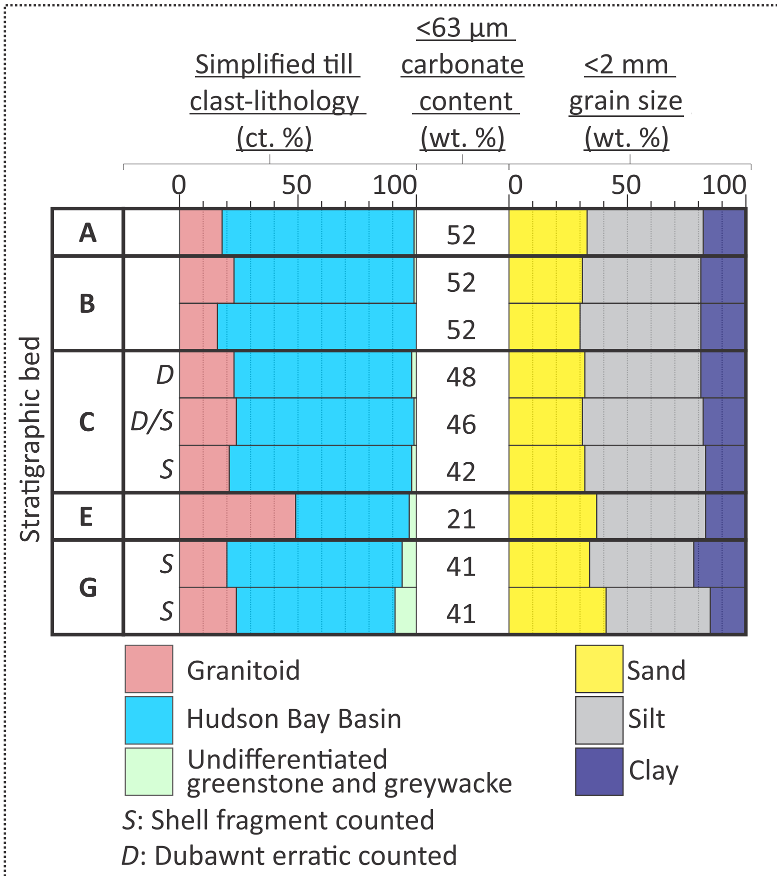


Figure 2b: *Example of a Quaternary sediment exposure described and sampled on the Churchill River (section 112-21-807, see Figure 1 for location) and preliminary till composition: preliminary till composition of section 112-21-807. Please refer to Figure 2a for the corresponding stratigraphic bed and stratigraphy of the section.*

Table 1: Breakdown of till sampled for indicator mineral analysis by interpreted ice-flow direction that deposited the sediment.

	W to NNW (260–328°)	S to SW (174–250°)	SSE (154–168°)	NW-SE bidirectional (132° or 312°)
Churchill River (n = 35)	21	11	2	1
Little Churchill River (n = 24)	8	15	1	0
Total	**29**	**26**	**3**	**1**
Proportion of population	**49.2%**	**44.1%**	**5.1%**	**1.7%**

Table 2: Recovery of chalcopyrite grains classified according to ice-flow direction that deposited the till sampled, and the section location. The number of samples broken down by ice-flow direction is provided in Table 1, which was used to calculate the proportion of the population and average recovery per sample.

Till fabric interpretation	W to NNW (260–328°)	S to SW (174–250°)	SSE (154–168°)	NW-SE bidirectional (132° or 312°)
Proportion of population	49%	44%	5%	2%
Churchill River	24	8	5	1
Little Churchill River	4	7	2	0
Average recovery per sample	1.0	0.6	2.3	1.0

Churchill River, 3 molybdenite grains were deposited by SW-trending ice flow, 3 molybdenite grains were deposited by SSE-trending ice flow and 3 molybdenite grains were deposited by NW-trending ice flow (Supplemental Figure 4). On the Little Churchill River, 2 molybdenite grains were deposited by S- to SSW-trending ice flow and 1 molybdenite grain by SE-trending ice flow (Supplemental Figure 5). The multiple ice-flow directions associated with till sampled indicates there are likely multiple sources of recovered molybdenite grains; alternatively this could be interpreted as evidence for more complex palimpsest dispersal patterns.

Scheelite

A total of 4 scheelite grains were recovered from four till samples. On the Churchill River, 2 scheelite grains were recovered from till deposited by SSW-trending ice flow (Supplemental Figure 4). On the Little Churchill River, 1 scheelite grain was recovered from till deposited by SW-trending ice flow (Supplemental Figure 5). One scheelite grain was recovered from a surficial till sample near Embleton Lake (Supplemental Figure 6).

Sphalerite

A single sphalerite grain was recovered from a till sample on the Churchill River. The till fabric at this site indicates deposition by SE-trending ice flow (112-21-807-C01 on Figure 2).

Gahnite

A total of 2 gahnite grains were recovered from two till samples on the Little Churchill River (Supplemental Figure 4). One gahnite grain was recovered from till deposited by NW-trending ice flow and 1 gahnite grain was recovered from till deposited by SSW-trending ice flow.

Galena

A single galena grain was recovered from a till sample on the Churchill River (Supplemental Figure 4). The till fabric at this site indicates deposition by NW-trending ice flow.

Kimberlite-indicator mineral counts

A total of 47 KIM grains were recovered, averaging 0.5 KIM recovered per 10 kg of till processed. Raw data for KIM counts is presented in Appendix 4. The classification of these grains and spatial patterns are discussed herein. For comparison of these results with the rest of publically-available KIM data in Manitoba, please refer to the Manitoba Kimberlite Indicator Mineral database (Keller, 2019). For additional regional context, please refer to recent surveys in the Hudson Bay Lowland (Hodder and Kelley, 2018; Hodder and Gauthier, 2021a, 2022a).

Garnet

A total of 12 kimberlitic garnet grains were picked from nine till samples: six peridotitic garnets and six orange mantle garnets. The garnet grains were classified using their chemical composition according to the criteria described in Grütter et al. (2004). The six periodotitic garnets are classified as G9 garnets (Figure 3). The six orange mantle garnets are classified as five G3 garnets and one G4 garnet (Figure 3).

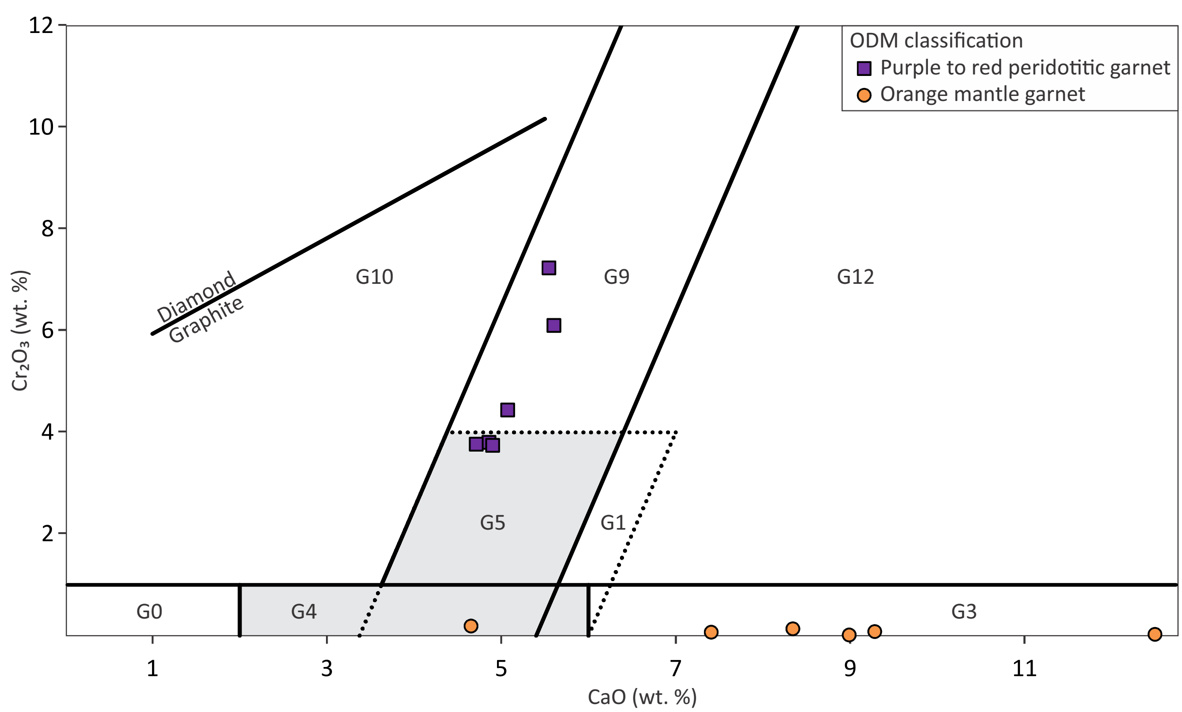


***Figure 3:** Cr_2O_3 versus CaO bivariate plot for garnet grains recovered. Garnet classification fields after Grütter et al. (2004); the G5 and G4 classifications indicated by the light grey fill pattern are distinguished by Mg-number; the stippled outline of the G1 group does not overlap G4, G5, G9 or G12 categories as G1 garnet grains are distinguished by a higher TiO_2 content; G11 garnets are also classified based on a higher TiO_2 content and are differentiated from G1 garnets by a higher Cr_2O_3 content.*

Mg-ilmenite

A total of 16 Mg-ilmenite grains were recovered. The microprobe data for these grains indicate that only one of the grains picked by ODM is not a kimberlitic Mg-ilmenite grain (Figure 4) based on the criteria outlined by Wyatt et al. (2004). In addition, all of the crustal ilmenite grains picked from till samples were microprobed to determine if any of these grains should be classified as a kimberlitic Mg-ilmenite. The chemistry of the crustal ilmenite grains indicated that one of these grains was reclassified as a kimberlitic Mg-ilmenite grain (Figure 4).

Cr-diopside

A single Cr-diopside grain was recovered. The chemical composition of the grain falls within the diamond inclusion and intergrowth field based on the classification criteria of Nimis (2002; Figure 5).

Chromite

A total of 15 chromite grains were picked from till samples. Two of these grains contain <20 wt. % Cr_2O_3 and were removed from the dataset as a KIM. Of the remaining 13 grains, none of the grains reside within the diamond inclusion and intergrowth fields of the discriminant diagrams (Figure 6).

Forsterite

A total of four forsterite grains were picked from till samples. Two of these grains have detectable concentrations of chromium and plot within the diamond inclusion and intergrowth field of Fipke et al. (1995; Figure 7).

KIM spatial patterns

The KIM grains recovered for each till sample are plotted spatially in Supplemental Figures 7–9. There was a limited number of KIM grains recovered from till sampled from sections along the Churchill River (Supplemental Figure 7). The highest count was 1.4 KIM recovered per 10 kg feed at 40.7 m depth at section 21-832 (two Mg-ilmenite) and 9.5 m depth at section 21-826 (one forsterite, one Cr-diopside). More KIM grains were recovered along the Little Churchill River (Supplemental Figure 8), where the highest count (4.6 KIM recovered per 10 kg feed) was from till sampled at 5.0 m depth at section 21-811. The next two highest counts, at 4.2 and 2.9 KIM recovered per 10 kg feed, were from till sampled at surface sites 21-830 and 21-821, respectively (Supplemental Figure 9).

The KIMs recovered from section samples were separated according to the interpreted ice-flow direction that deposited the till (Table 3). There is similar KIM recovery between till deposited by W- to NW-trending and S- to SW-trending ice flow and no KIMs recovered from the small number of till samples deposited by SE-trending ice flow. The recovery of KIM grains associated with multiple ice-flow directions indicates that there are likely multiple sources for grains; alternatively this could be interpreted as evidence for more complex palimpsest dispersal patterns.

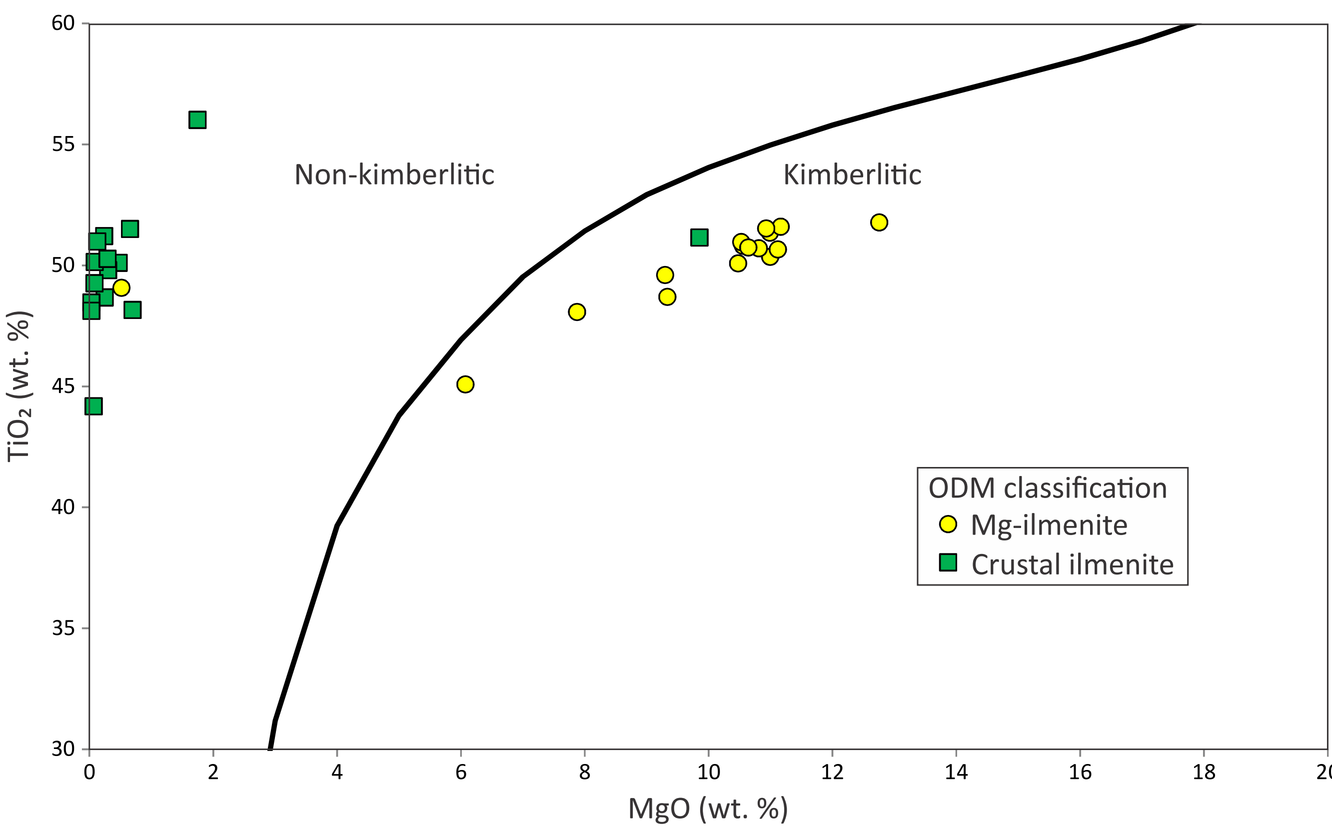


Figure 4: *TiO_2 versus MgO bivariate plot for ilmenite grains recovered. The compositional field for kimberlitic Mg-ilmenite is after Wyatt et al. (2004).*

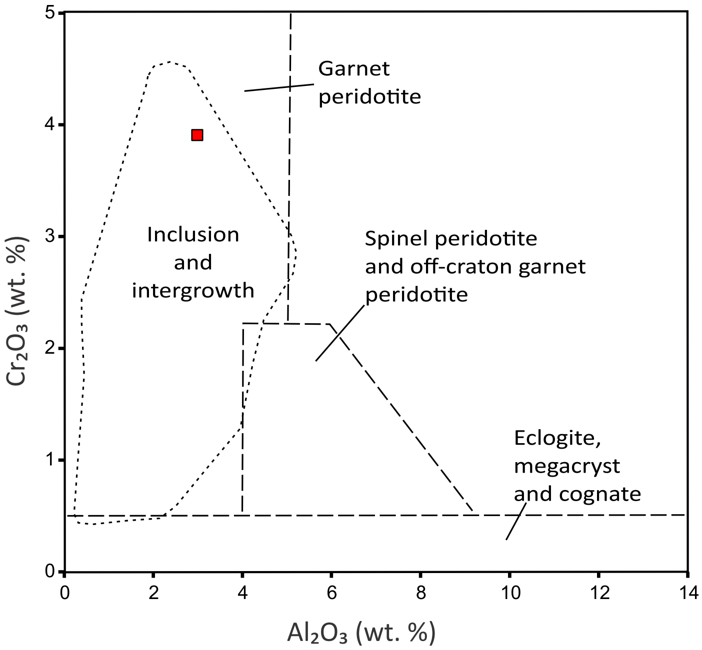


Figure 5: *Cr_2O_3 versus Al_2O_3 bivariate plot for Cr-diopside grains. The compositional field for diamond inclusion and intergrowth is from Nimis (2002); other compositional fields are from Ramsay and Tompkins (1994).*

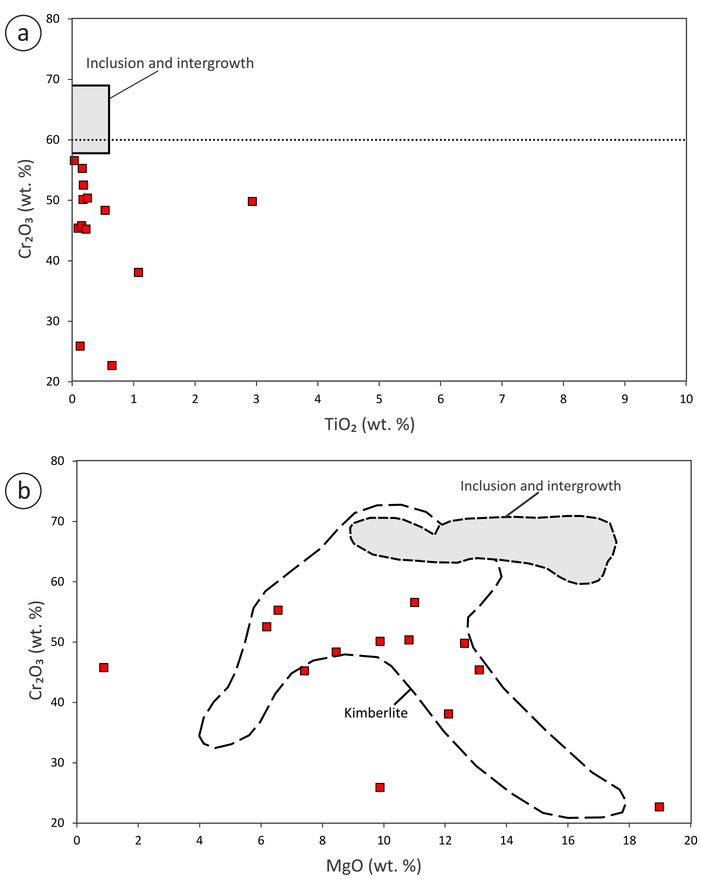


Figure 6: *Bivariate plots of chromite grain compositional data:* ***a)*** *Cr_2O_3 versus TiO_2 for chromite and Cr-spinel grains; diamond inclusion and intergrowth field modified after Fipke et al. (1995); a dashed line representing 60 wt. % Cr_2O_3 is shown for visual reference;* ***b)*** *Cr_2O_3 versus MgO for chromite and Cr-spinel grains; compositional field for diamond inclusion and intergrowth after Fipke et al. (1995); compositional field for kimberlite from Nowicki et al. (2007).*

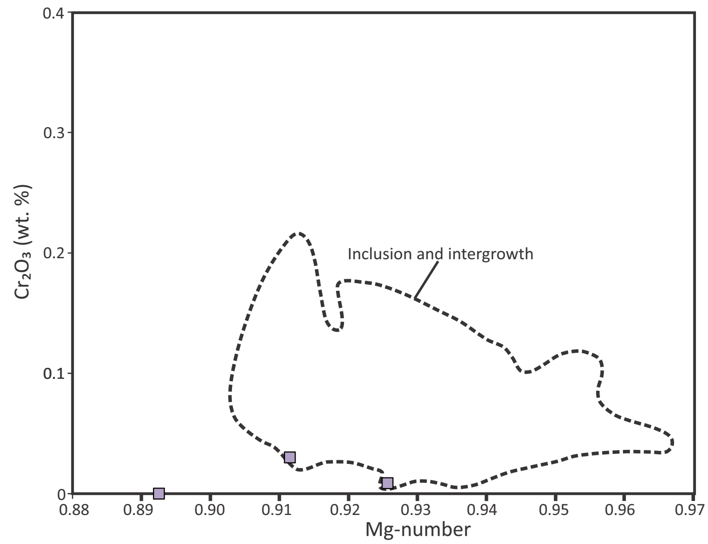


Figure 7: *Bivariate plot of Cr_2O_3 versus Mg-number for forsterite grains; compositional field for diamond inclusion and intergrowth is from Fipke et al. (1995). Note, one sample does not appear within this bivariate plot.*

Ongoing till provenance and stratigraphic work

The recovery of indicator mineral grains in this study are associated with multiple ice-flow directions. For all indicators, there are either multiple sources for grains or complex palimpsest dispersal patterns from a few sources. Preliminary analysis of the till fabric data and till composition indicates a high proportion of the till was deposited by ice flowing towards the west to northwest or south to southwest (Table 1). Further analysis of these datasets will then be evaluated using multivariate statistical methods to understand their relationship to the field-based stratigraphy interpretations. The nonglacial beds are being further evaluated for paleobotonical indicators and geochronology (Gauthier et al., 2021). These further studies will help to construct a regional stratigraphic framework for the Churchill to Little Churchill rivers area, which will help provide a context for any indicators of economic interest within this remote region of northeastern Manitoba. Until this analysis is completed, additional stratigraphic data can be supplied upon request for mineral exploration purposes.

Acknowledgments

M. Rinne is thanked for providing enthusiastic field participation. Pilot K. Dunthorne and Prairie Helicopters Inc. are thanked for providing excellent air support during this project. The field component and till-composition analysis of this study is funded by the Manitoba Geological Survey. The gold and indicator mineral analyses of till samples is funded by Geological Survey of Canada's Geo-mapping for Energy and Minerals, GeoNorth program (GEM-GeoNorth).

Table 3: Recovery of KIM grains classified according to ice-flow direction that deposited the till sampled. The number of samples broken down by ice-flow direction is provided in Table 1, which was used to calculate the proportion of the population.

Till fabric interpretation	W to NNW (260–328°)	S to SW (174–250°)	SSE (154–168°)	NW-SE bidirectional (132° or 312°)
Proportion of population	49%	44%	5%	2%
G3	3	1		
G9	2	2		
Mg-Ilmenite	3	2		2
Fortserite	1	3		
Cr-diopside		1		
Chromite	5	2		

References

Catto, N.R. 1998: Comparative study of striations and basal till clast fabrics, Malpeque—Bedeque region, Prince Edward Island, Canada; Boreas, v. 27, p. 259–274.

Fipke, C.E., Gurney, J.J. and Moore, R.O. 1995: Diamond exploration techniques emphasising indicator mineral geochemistry and Canadian examples; Geological Survey of Canada, Bulletin 423, 96 p.

Gauthier, M.S. 2020: Manitoba till-matrix geochemistry compilation 4: visible gold grains in the heavy mineral (<2 mm; –10 mesh) size-fraction; Manitoba Agriculture and Resource Development, Manitoba Geological Survey, Open File OF2020-6, 3 p., URL <https://manitoba.ca/iem/info/libmin/OF2020-6.zip> [May 2023].

Gauthier, M.S., Hodder, T.J., Lian, O.B., Finkelstein, S.A., Dalton, A.S. and Paulen, R.C. 2021: Stratigraphic, paleoenvironmental and geochronological investigations of intertill nonglacial deposits in northeastern Manitoba (parts of NTS 54B–F, K, L, 64A, H, I); *in* Report of Activities 2021, Manitoba Agriculture and Resource Development, Manitoba Geological Survey, p. 71–76, URL <https://manitoba.ca/iem/geo/field/roa21pdfs/GS2021-8.pdf> [May 2023].

Gauthier, M.S., Hodder, T.J., Ross, M., Kelley, S.E., Rochester, A. and McCausland, P. 2019: The subglacial mosaic of the Laurentide Ice Sheet; a study of the interior region of southwestern Hudson Bay; Quaternary Science Reviews, v. 214, p. 1–27.

Gauthier, M.S., Santucci, A. and Keller, G.R. 2022: Digital compilation of surficial point and line features for Manitoba, including ice-flow data; Manitoba Natural Resources and Northern Development, Manitoba Geological Survey, GeoFile 1-2022, 5 p., URL <https://manitoba.ca/iem/info/libmin/geofile1.zip> [May 2023].

Grütter, H.S., Gurney, J.J., Menzies, A.H. and Winter, F. 2004: An updated classification scheme for mantle-derived garnet, for use by diamond explorers; Lithos, v. 77, p. 841–857.

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

Hodder, T.J. and Gauthier, M.S. 2021a: Kimberlite-indicator-mineral results from till sampled in the Machichi–Kettle rivers area, far northeastern Manitoba (parts of NTS 54A–C); *in* Report of Activities 2021, Manitoba Agriculture and Resource Development, Manitoba Geological Survey, p. 77–83, URL <https://manitoba.ca/iem/geo/field/roa21pdfs/GS2021-9.pdf> [May 2023].

Hodder, T.J. and Gauthier, M.S. 2021b: Quaternary stratigraphic and depth to bedrock data compilation for northeastern Manitoba; *in* Report of Activities 2021, Manitoba Agriculture and Resource Development, Manitoba Geological Survey, p. 66–70, URL <https://manitoba.ca/iem/geo/field/roa21pdfs/GS2021-7.pdf> [May 2023].

Hodder, T.J. and Gauthier, M.S. 2022a: Quaternary stratigraphic investigations near the confluence of the Hayes and Gods rivers, northeastern Manitoba (part of NTS 54C7); *in* Report of Activities 2022, Manitoba Natural Resources and Northern Development, Manitoba Geological Survey, p. 110–120, URL <https://manitoba.ca/iem/geo/field/roa22pdfs/GS2022-12.pdf> [May 2023].

Hodder, T.J. and Gauthier, M.S. 2022b: Till-matrix geochemistry data from the Churchill–Little Churchill rivers area, northeastern Manitoba (part of NTS 54E); Manitoba Natural Resources and Northern Development, Manitoba Geological Survey, Data Repository Item DRI2022005, Microsoft® Excel® file, URL <https://manitoba.ca/iem/info/libmin/DRI2022005.xlsx> [May 2023].

Hodder, T.J. and Kelley, S.E. 2018: Kimberlite-indicator minerals and clast-lithology composition of till, Kaskattama highland region, northeastern Manitoba (parts of NTS 53N, O, 54B, C); *in* Report of Activities 2018, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 150–165, URL <https://manitoba.ca/iem/geo/field/roa18pdfs/GS2018-13.pdf> [May 2023].

Holmes, C.D. 1941: Till fabric; Geological Society of America Bulletin, v. 52, no. 9, p. 1299–1354.

Hooyer, T.S. and Iverson, N.R. 2000: Clast-fabric development in a shearing granular material: implications for subglacial till and fault gouge; Geological Society of America Bulletin, v. 112, no. 5, p. 683–692.

Hopkins, N.R., Evenson, E.B., Kodama, K.P. and Kozlowski, A. 2016: An anisotropy of magnetic susceptibility (AMS) investigation of the till fabric of drumlins: support for an accretionary origin; Boreas, v. 45, p. 100–108.

Keller, G.R. 2019: Manitoba Kimberlite Indicator Mineral Database (version 3.2); Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, zipped Microsoft® Access® 2016 database, URL <https://manitoba.ca/iem/geo/diamonds/MBKIMDB_32.zip> [May 2023].

Kjaer, K.H. and Kruger, J. 1998: Does clast size influence fabric strength?; Journal of Sedimentary Research, v. 68, p. 746–749.

Manitoba Geological Survey 2022: New edition of the 1:250 000 scale Precambrian bedrock geology compilation map of Manitoba; Manitoba Natural Resources and Northern Development, Manitoba Geological Survey, GeoFile 3-2022, URL <https://manitoba.ca/iem/info/libmin/geofile3-2022.zip> [May 2023].

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

Mark, D.M. 1974: On the interpretation of till fabrics; Geology, v. 2, no. 2, p. 101–104.

McMartin, I. and McClenaghan, M.B. 2001: Till geochemistry and sampling techniques in glaciated shield terrain: a review; *in* Drift Exploration in Glaciated Terrain, M.B. McClenaghan, P.T. Bobrowsky, G.E.M. Hall and S.J. Cook (ed.), Geological Society of London, Special Publications 185, p. 19–43.

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

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

Nicolas, M.P.B. and Armstrong, D.K. 2017: Update on Paleozoic stratigraphic correlations in the Hudson Bay Lowland, northeastern Manitoba and northern Ontario; *in* Report of Activities 2017, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 133–147, URL <https://manitoba.ca/iem/geo/field/roa17pdfs/GS2017-12.pdf> [May 2023].

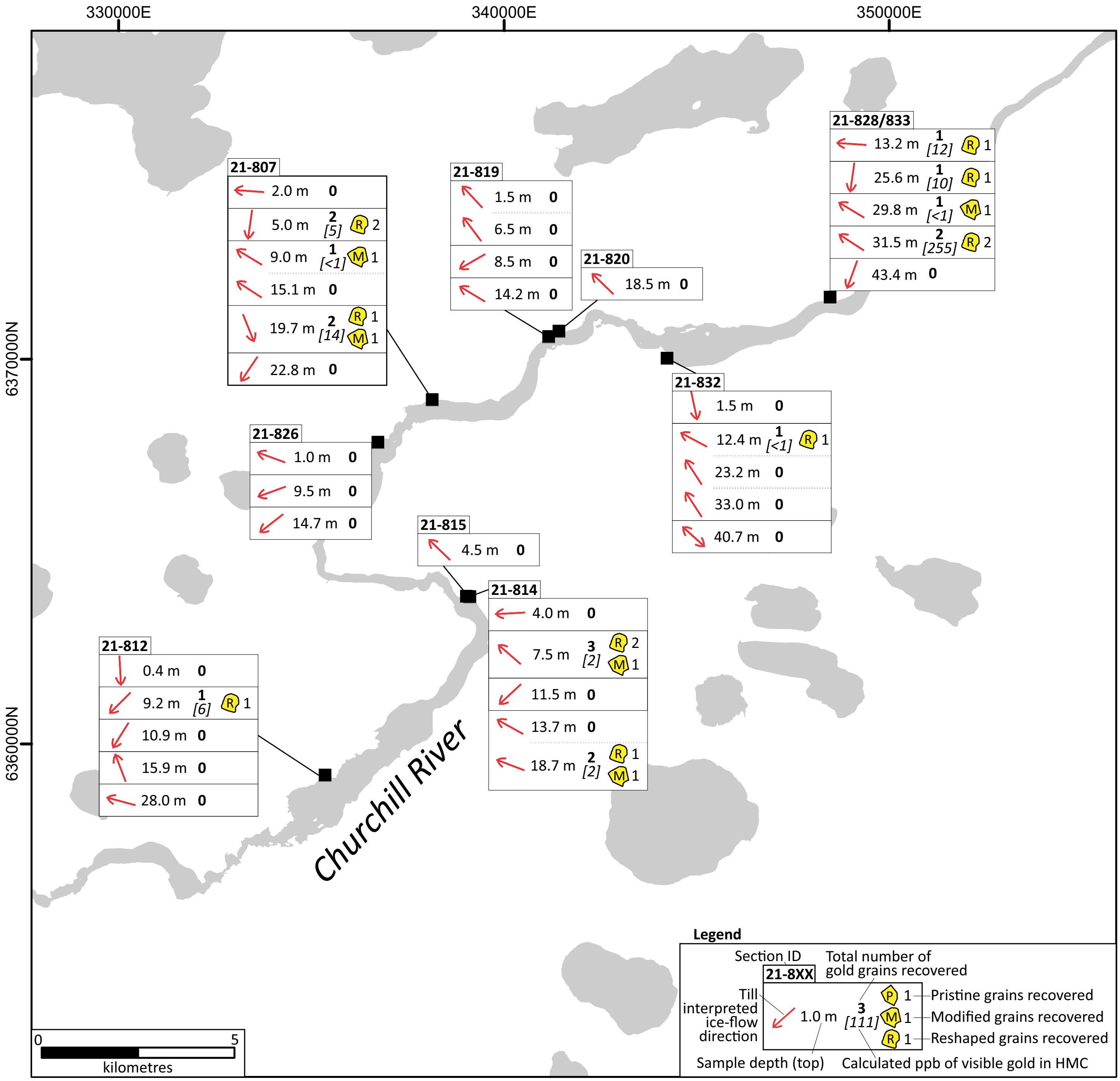
Nimis, P. 2002: The pressures and temperatures of formation of diamond based on thermobarometry of chromian diopside inclusions; The Canadian Mineralogist, v. 40, p. 871–884.

Nowicki, T.E., Moore, R.O., Gurney, J.J. and Baumgartner, M.C. 2007: Diamonds and associated heavy minerals in kimberlite: a review of key concepts and applications; Developments in Sedimentology, v. 58, p. 1235–1267.

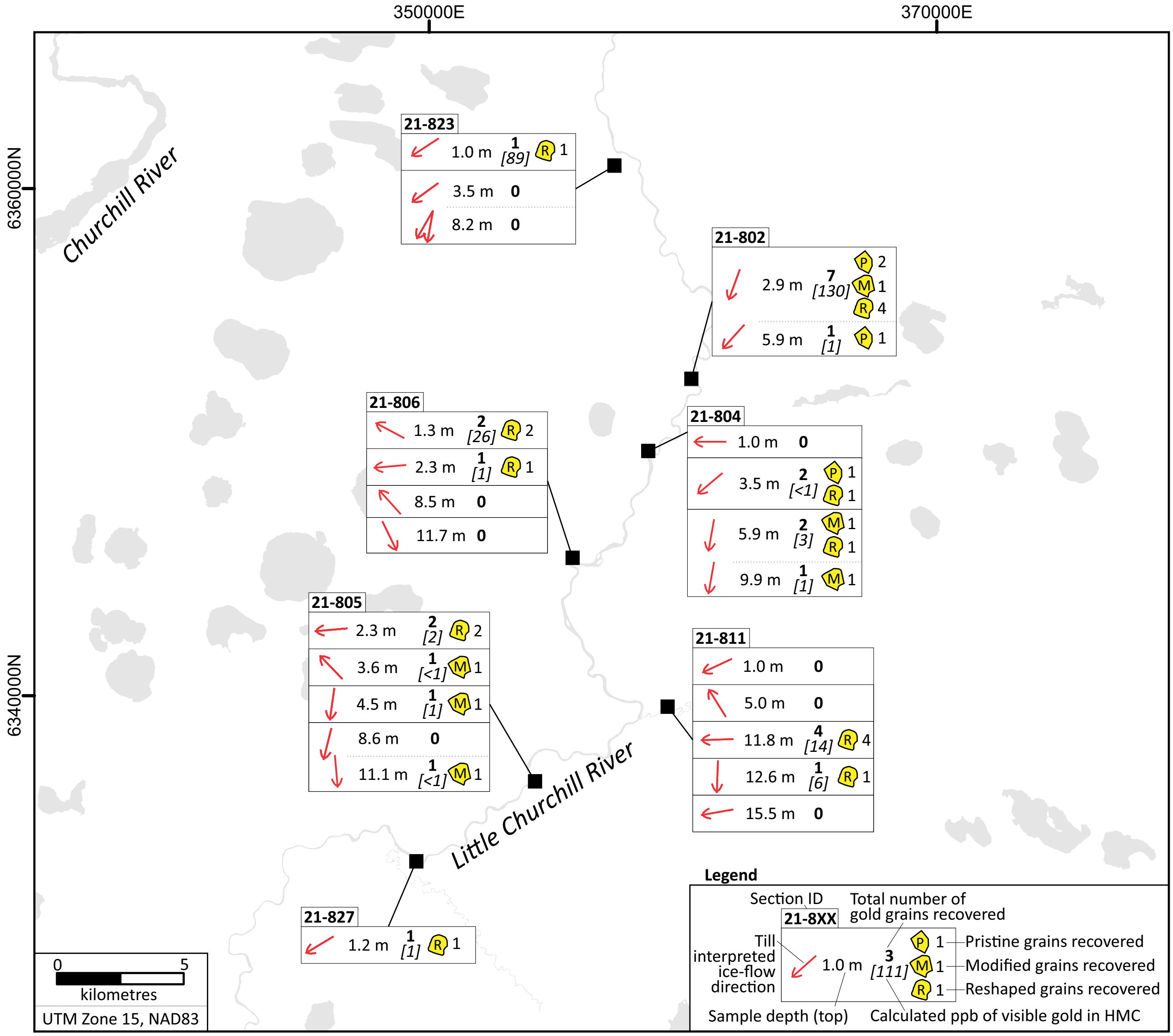
Plouffe, A., McClenaghan, M.B., Paulen, R.C., McMartin, I., Campbell, J.E. and Spirito, W.A. 2013: Processing of glacial sediments for the recovery of indicator minerals: protocols used at the Geological Survey of Canada; Geochemistry: Exploration, Environment, Analysis, v. 13, p. 303–316.

Ramsay, R.R. and Tompkins, L.A. 1994: The geology, heavy mineral concentrate mineralogy, and diamond propectivity of the Boa Esperanca and Cana Verde pipes, Corrego D'anta, Minas Gerais, Brasil; *in* Kimberlites, Related Rocks and Mantle Xenoliths, H.O.A. Meyer and O.H. Leonardos (ed.), Proceedings of the Fifth International Kimberlite Conference, Minas Gerais, Brazil, Companhia de Pesquisa de Recursos Minerais (CRPM), Special Publication, v. 2, p. 329–345.

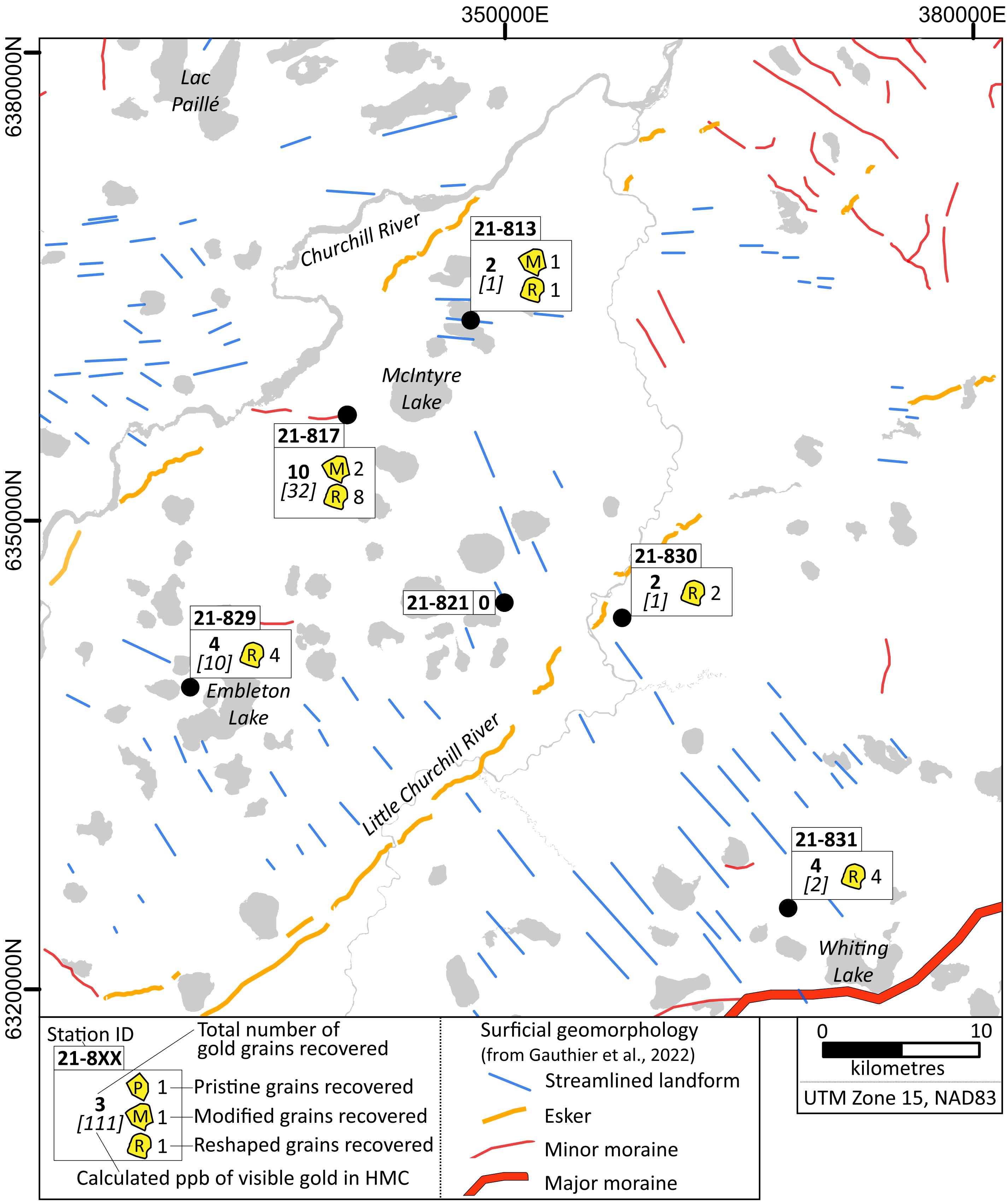
Wyatt, B.A., Baumgartner, M., Anckar, E. and Grütter, H. 2004: Compositional classification of “kimberlitic” and “non-kimberlitic” ilmenite; Lithos, v. 77, p. 819–840.



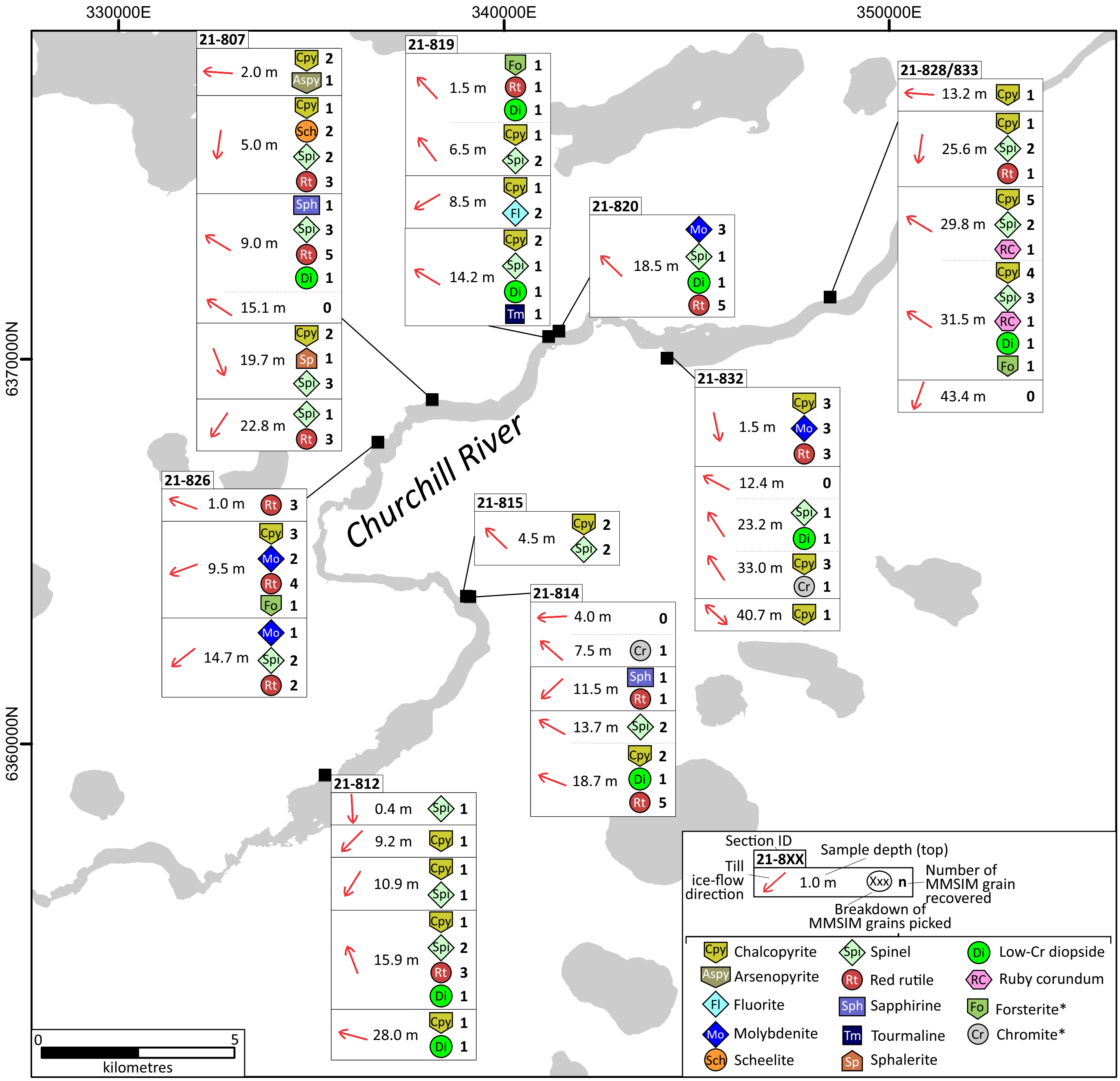
Supplemental Figure 1: *Gold grain counts for till samples: river cut exposures in the Churchill River area. Note, station numbers have been abbreviated (e.g., 112-21-802 to 21-802) relative to those found in the accompanying data appendices.*



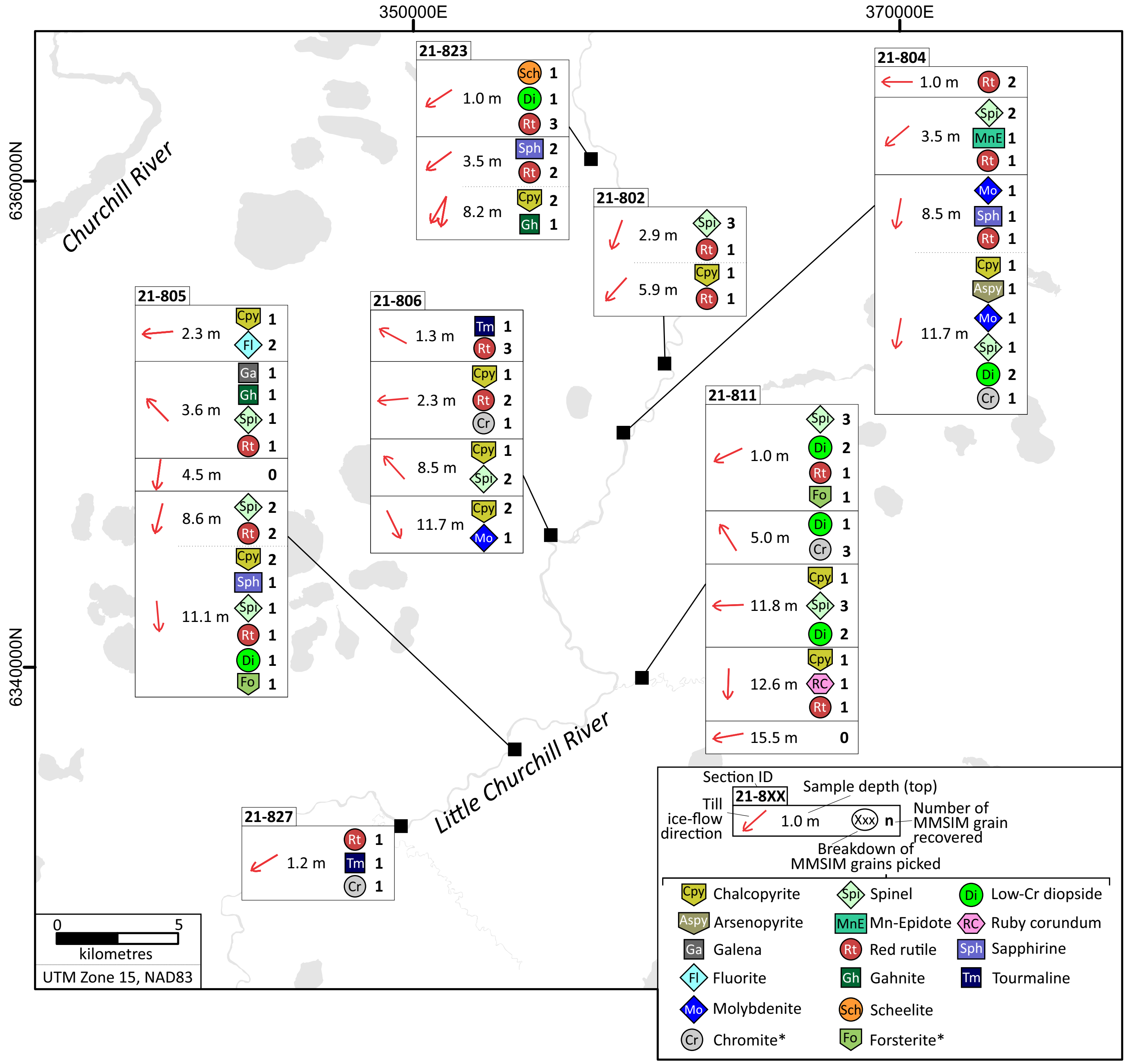
Supplemental Figure 2: *Gold grain counts for till samples: river cut exposures in the Little Churchill River area. Note, station numbers have been abbreviated (e.g., 112-21-802 to 21-802) relative to those found in the accompanying data appendices.*



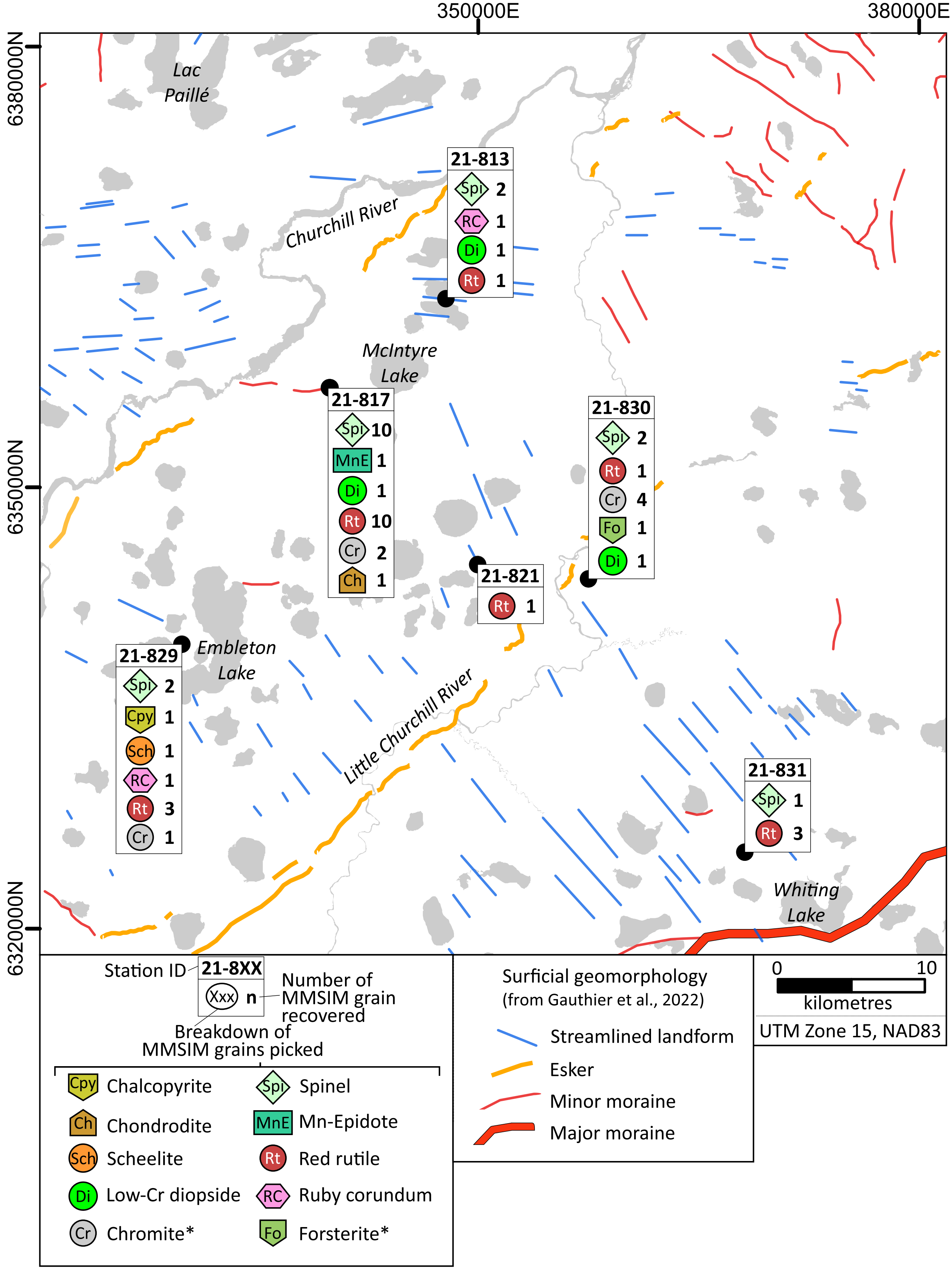
Supplemental Figure 3: *Gold grain counts for till samples: surface sites. Note, station numbers have been abbreviated (e.g., 112-21-802 to 21-802) relative to those found in the accompanying data appendices.*



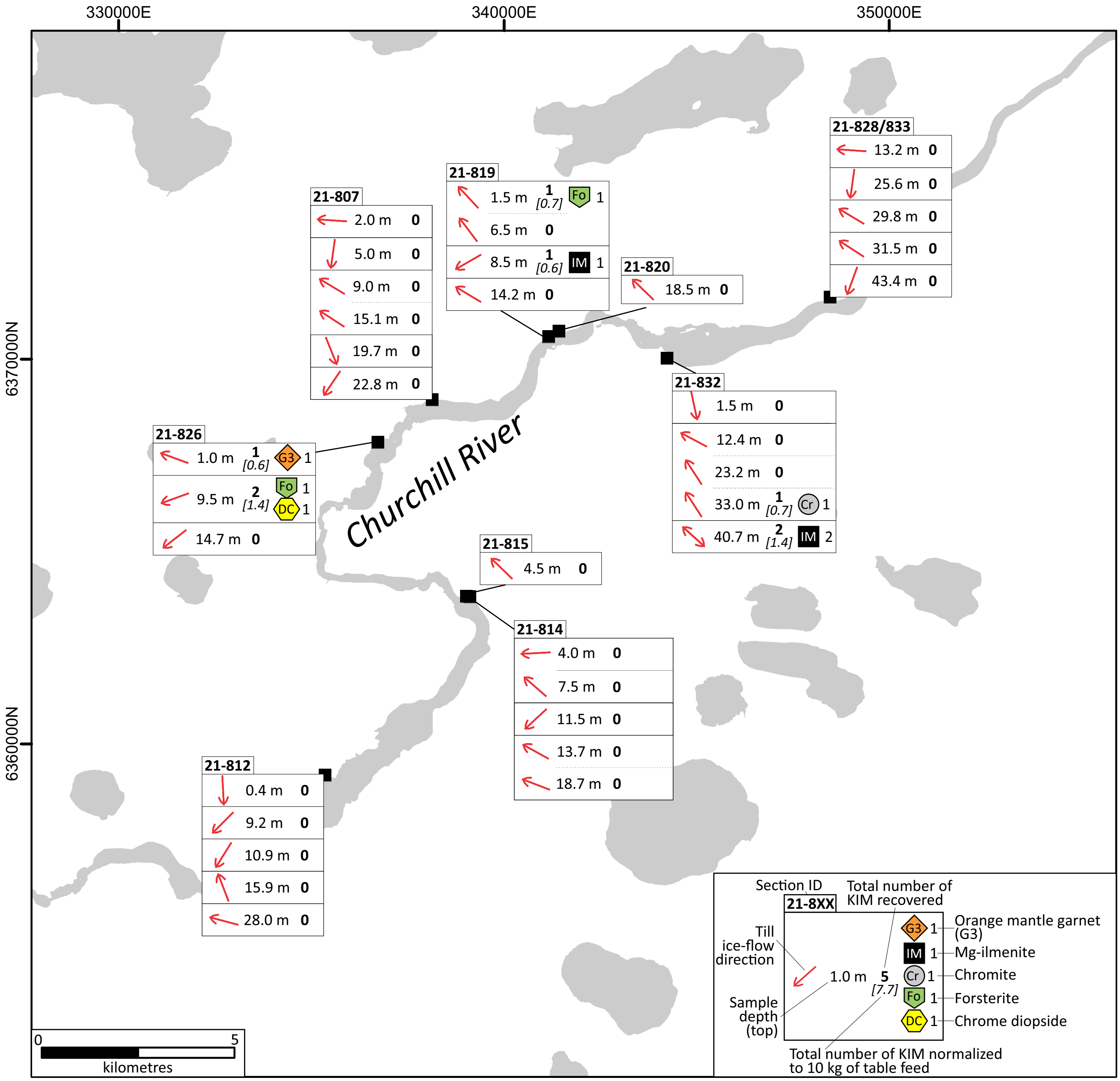
Supplemental Figure 4: *Magmatic or metamorphosed massive-sulphide–indicator minerals counts: river cut exposures in the Churchill River area. Note, station numbers have been abbreviated (e.g., 112-21-802 to 21-802) relative to those found in the accompanying data appendices. * Chromite and forsterite are also displayed as a KIM grain.*



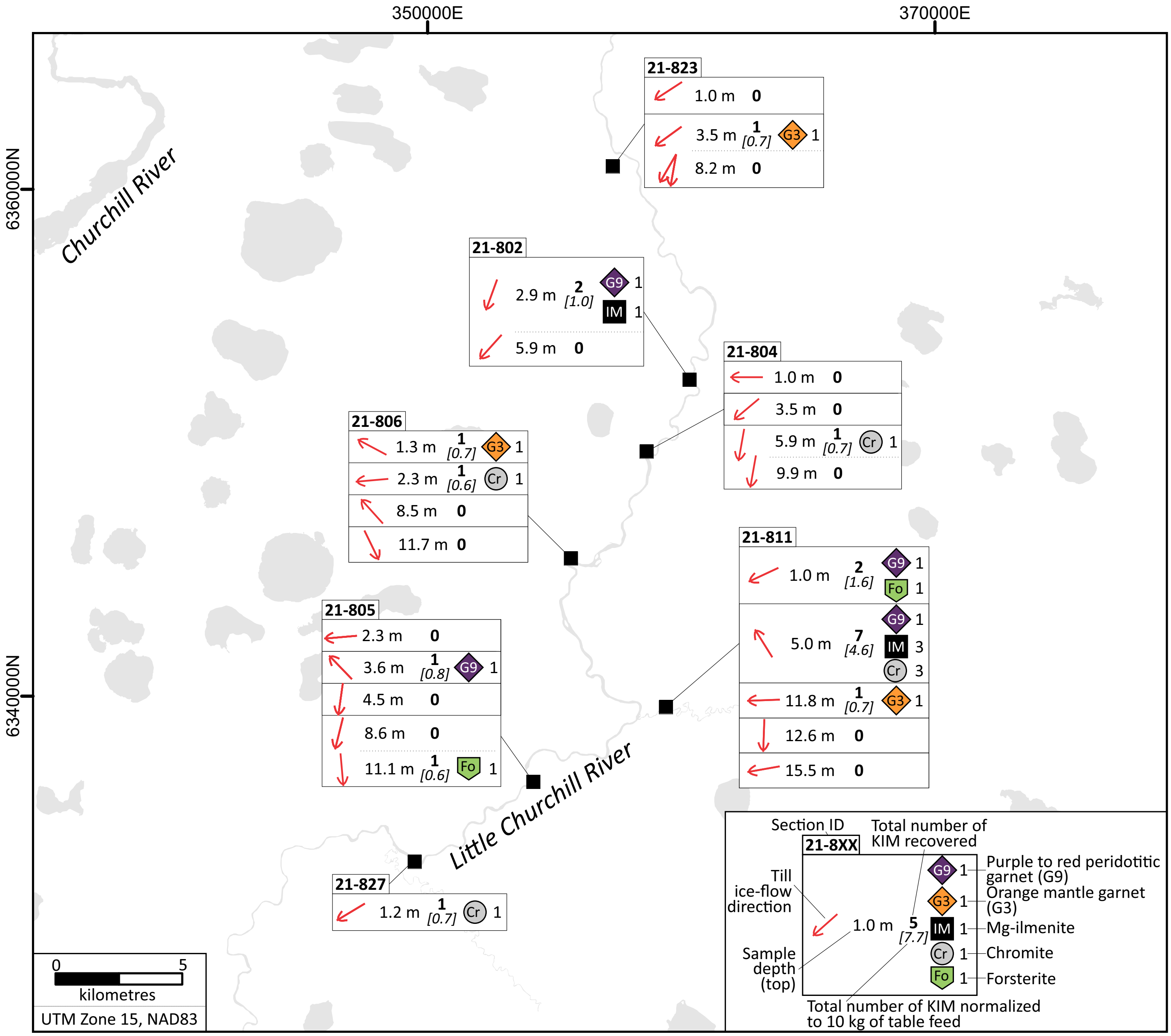
Supplemental Figure 5: *Magmatic or metamorphosed massive-sulphide–indicator minerals counts: river cut exposures in the Little Churchill River area. Note, station numbers have been abbreviated (e.g., 112-21-802 to 21-802) relative to those found in the accompanying data appendices.*
** Chromite and forsterite are also displayed as a KIM grain.*



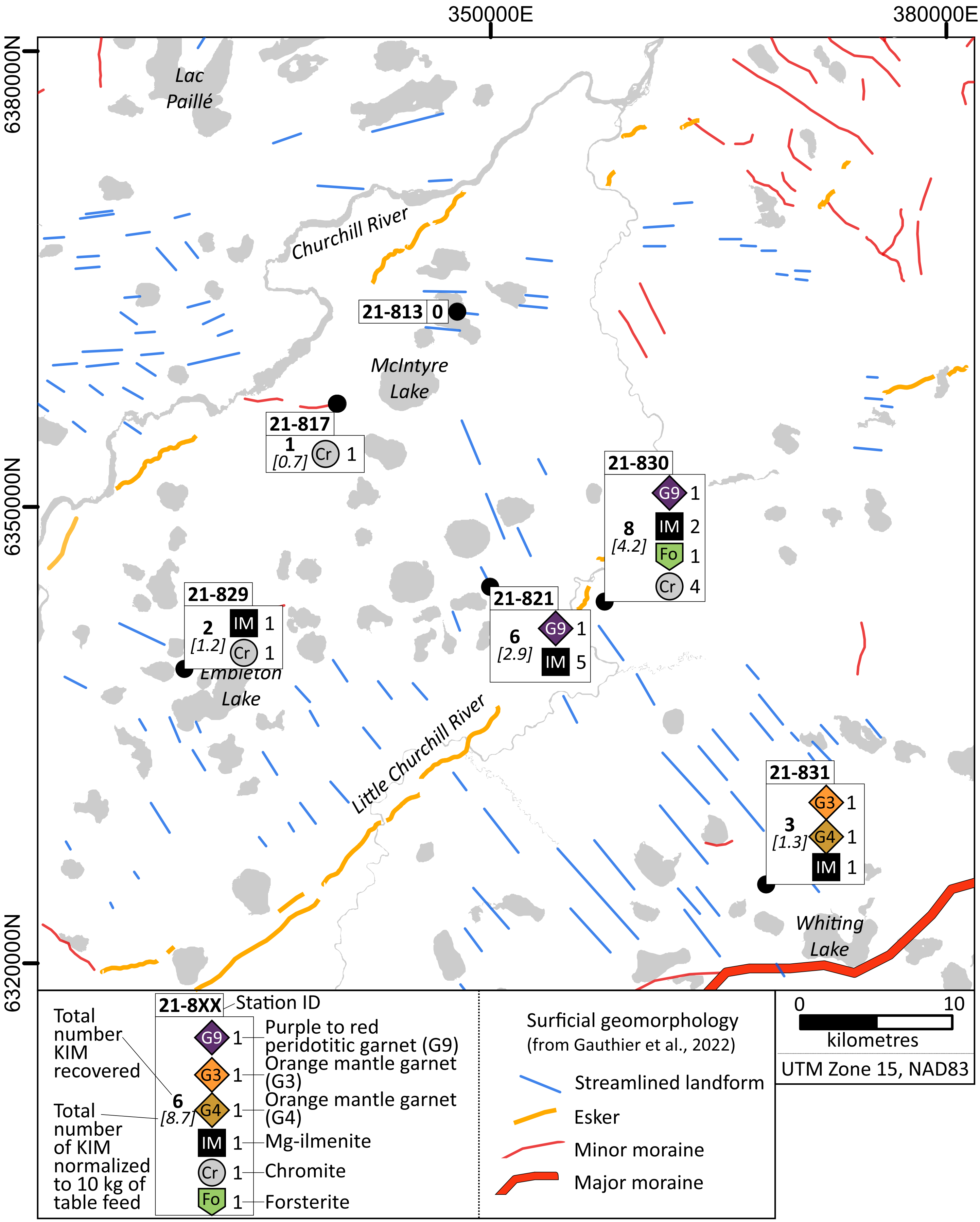
***Supplemental Figure 6:** Magmatic or metamorphosed massive-sulphide–indicator minerals counts: surface sites. Note, station numbers have been abbreviated (e.g., 112-21-802 to 21-802) relative to those found in the accompanying data appendices. * Chromite and forsterite are also displayed as a KIM grain.*



Supplemental Figure 7: *Kimberlite-indicator mineral counts: river cut exposures in the Churchill River area. Note, station numbers have been abbreviated (e.g., 112-21-802 to 21-802) relative to those found in the accompanying data appendices.*



Supplemental Figure 8: *Kimberlite-indicator mineral counts: river cut exposures in the Little Churchill River area. Note, station numbers have been abbreviated (e.g., 112-21-802 to 21-802) relative to those found in the accompanying data appendices.*



Supplemental Figure 9: *Kimberlite-indicator mineral counts: surface sites. Note, station numbers have been abbreviated (e.g., 112-21-802 to 21-802) relative to those found in the accompanying data appendices.*