Saskatchewan Ministry of Energy and Resources

GEOLOGICAL SURVEY OF CANADA

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SASKATCHEWAN MINISTRY OF ENERGY AND RESOURCES

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Till geochemistry from archived samples collected over the La Ronge and Rottenstone domains, central Saskatchewan

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Contribution to the Targeted Geoscience Initiative (TGI) 2005–2010.
Open files are products that have not gone through the GSC formal publication process.

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DIGITAL DATA
Appendices I to V presented in this report are included as digital data files in Microsoft Excel 2003 format. Appendices II, III and IV also include Adobe Acrobat files.

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INTRODUCTION

Geochemical analyses of archived till samples collected by the Saskatchewan Research Council (SRC) in 1974-1977 over the La Ronge and Rottenstone domains in Saskatchewan were completed in October 2007. The archived till samples, mainly collected from C-horizon soils, had never been geochemically analyzed. The study area lies within the Trans-Hudson Orogen, known to host some of the richest and most varied Paleoproterozoic mineral deposits in the Canadian Shield (Corrigan et al., 2007). Glacial deposits commonly cover the bedrock in the region; consequently, drift prospecting using till as a sample medium is a useful tool for outlining areas with potential to host mineralization and for stimulating further exploration within the region. This work is part of the Flin Flon Project in Manitoba-Saskatchewan, a contribution to the Geological Survey of Canada 5-year Targeted Geoscience Initiative (TGI-3: 2005-2010). The Flin Flon TGI-3 Project is a collaborative effort involving the Geological Survey of Canada (GSC), the Saskatchewan Northern Geological Survey (SNGS), the Manitoba Geological Survey and industry partners. It was designed to assist in the discovery of new reserves of base metals in established mining communities of the Trans-Hudson Orogen. The objective of the Quaternary component of the TGI-3 project is to provide the geologic framework for interpretation of drift compositional data, outline regions with potential to host mineralization (primarily base metals), and identify areas for further detailed drift sampling.

The Quaternary sub-project area in Saskatchewan encompasses the Rottenstone, La Ronge, Kisseynew, Glennie, and Flin Flon domains (Fig. 1). It is bordered by the Wathaman Batholith to the north and the Phanerozoic cover to the south. As a first step in building a trans-jurisdiction database of till composition across the various bedrock domains, SRC's archived till samples collected over the Kisseynew, Glennie and Flin Flon domains (cf. Fig. 1, blue outline) were analyzed in 2006 and the data were published in 2007 as GSC Open File report 5464 and Saskatchewan Industry and Resources OF 2007-13 (McMartin et al., 2007). The current report presents the results of geochemical and textural analyses from archived till samples collected in the La Ronge and Rottenstone domains in Saskatchewan (cf. Fig. 1, yellow outline). Two till samples collected in the Kakinagimak Lake area in 2007 over the Flin Flon Domain by Ralf Maxeiner (SNGS) were also analyzed and are reported here. This report also includes unpublished geochemical analyses of B-horizon soil samples collected over the La Ronge and Rottenstone domains and analyzed by SRC ("Project 20" data) from 1977 to 1979. A brief discussion of till provenance and its implications for base metal exploration is provided.

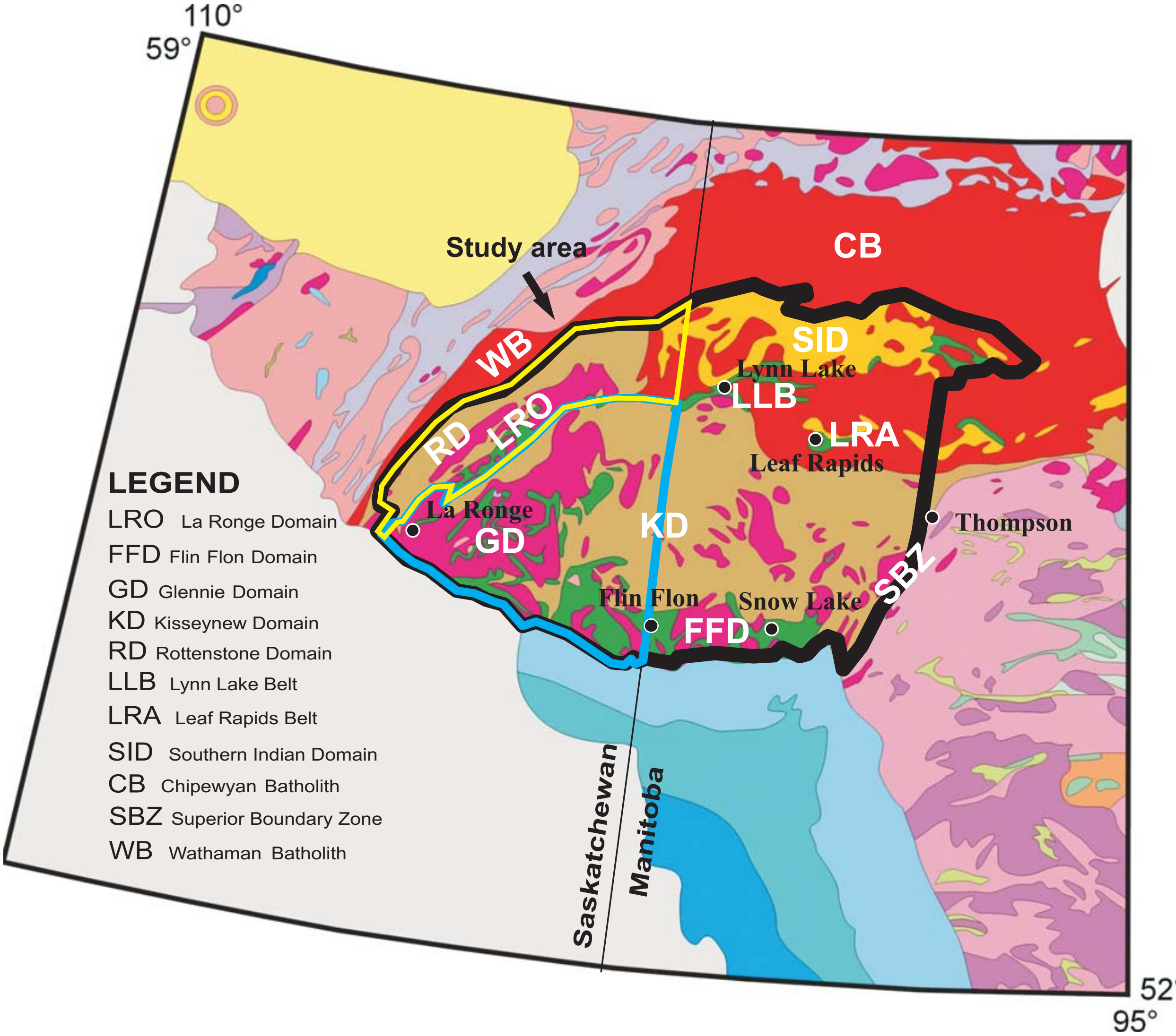


Figure 1. General location map of the Quaternary sub-project area (black outline) in Manitoba and Saskatchewan, with bedrock domains. The current study area for this report is outlined in yellow. Area covered by archived till samples analyzed in 2006 is outlined in blue (McMartin et al., 2007).

Location and physiography

The study area lies between latitudes 55° and 57°30' and longitudes 102° and 106° immediately south of the Wathaman Batholith. It includes the hamlet of Kinoosao along Reindeer Lake near the Manitoba border (Fig. 2). The area covers approximately 17,250 km^2 and includes parts of NTS 64D, 64E, 73P and 74A. It lies within the Churchill River Upland physiographic region (Padbury and Acton, 1994) and drainage is towards Hudson Bay via the Churchill and Nelson rivers. Physiography is typical of the Canadian Shield; strongly controlled by bedrock lithology and structure, with lakes, swamps and muskegs filling valleys and depressions between ridges, hills and knolls. A pronounced northeasterly structural trend in the area coincides with a strong topographic macro-fabric, with elevations ranging from 547 m a.s.l. 10 km northwest of Highway 102 to 337 m around Reindeer Lake (Fig. 2). The region lies within the zone of discontinuous permafrost. Permafrost tends to occur primarily in peatlands characterized by forested bog vegetation. Brunisols are the most common soils developed on sandy to silty till deposits (Acton and Padbury, 1984). Most brunisolic soils have undergone podzolization to some extent. Their Bm horizon ranges in thickness from 15 to more than 100 cm but the depth to which oxidation has affected the till varies, exceeding 5 m in sandy till (Schreiner, 1984). Gray Luvisols occur on glaciolacustrine and till deposits in which the clay-size fraction exceeds 5%.

GEOLOGY

Bedrock

The study area lies between the Archean Hearne and Superior cratons within the Paleoproterozoic Trans-Hudson Orogen (Hoffman, 1988; Lewry and Collerson, 1990), which forms a collage of tectonically accreted juvenile supracrustal belts, continental margin sedimentary rocks and microcontinents, and reactivated rocks of the adjacent cratons (Corrigan et al., 2007). Bedrock lithologies underlying the area are part of the northwest Reindeer zone which contains juvenile volcanic arcs, back-arcs, and associated sedimentary basins. They have been grouped into two major lithotectonic domains: the La Ronge Domain and the Rottenstone Domain (Sask. Geological Survey, 2003) (Fig. 3). The La Ronge Domain comprises predominantly ca. 1.90 to 1.83 volcanic, plutonic and minor sedimentary rocks, (Sask. Geol. Survey, 2003), while the structurally overlying Rottenstone Domain can be subdivided into two distinct belts: 1) the former tonalite-migmatite complex of Gilboy (1975), which comprises upper amphibolite facies migmatitic sedimentary rocks and leucogranitoid

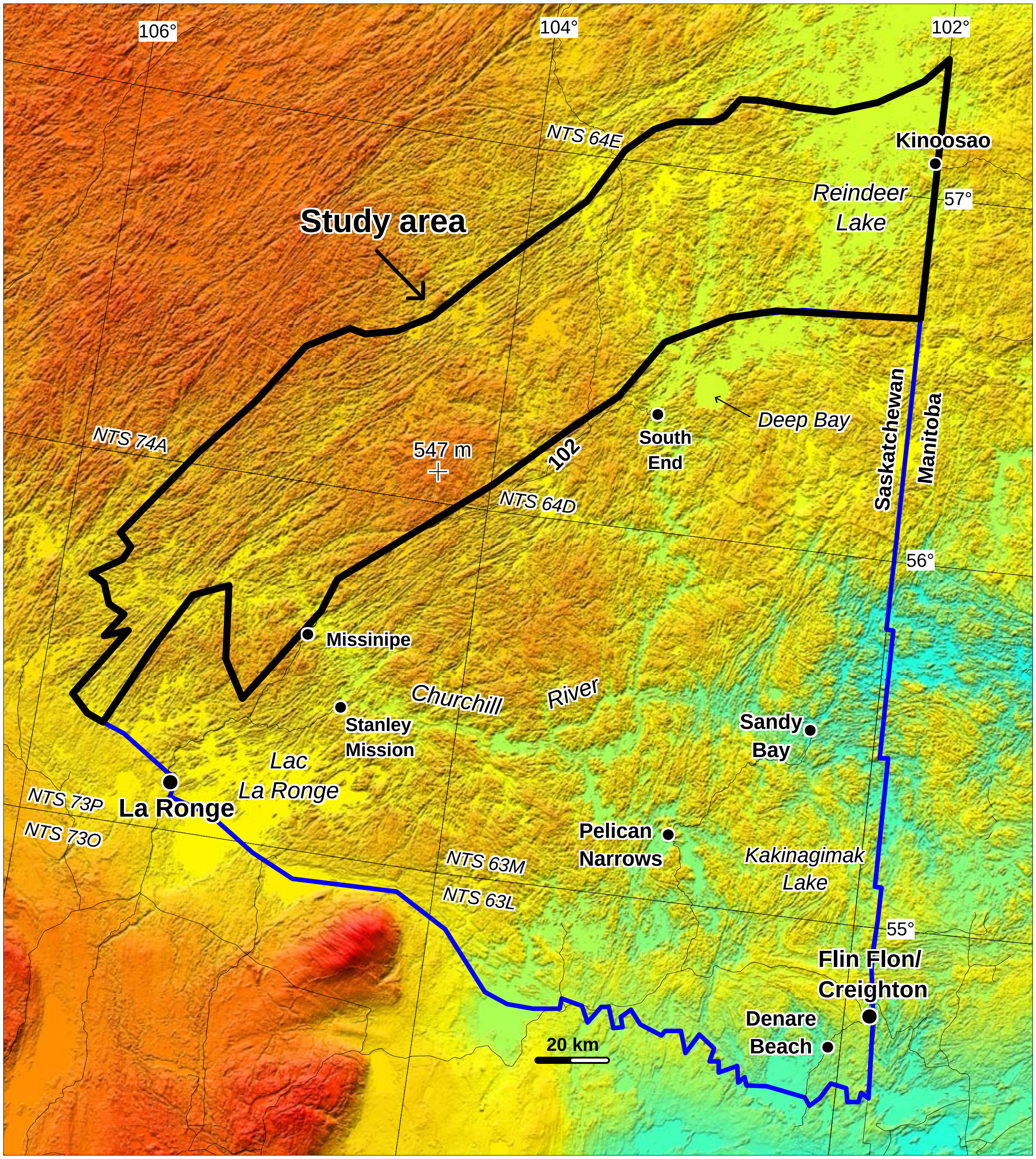


Figure 2. Topography within and around the study area (outlined in black). Area covered by previous archived till geochemistry release is outlined in blue (McMartin et al., 2007) .

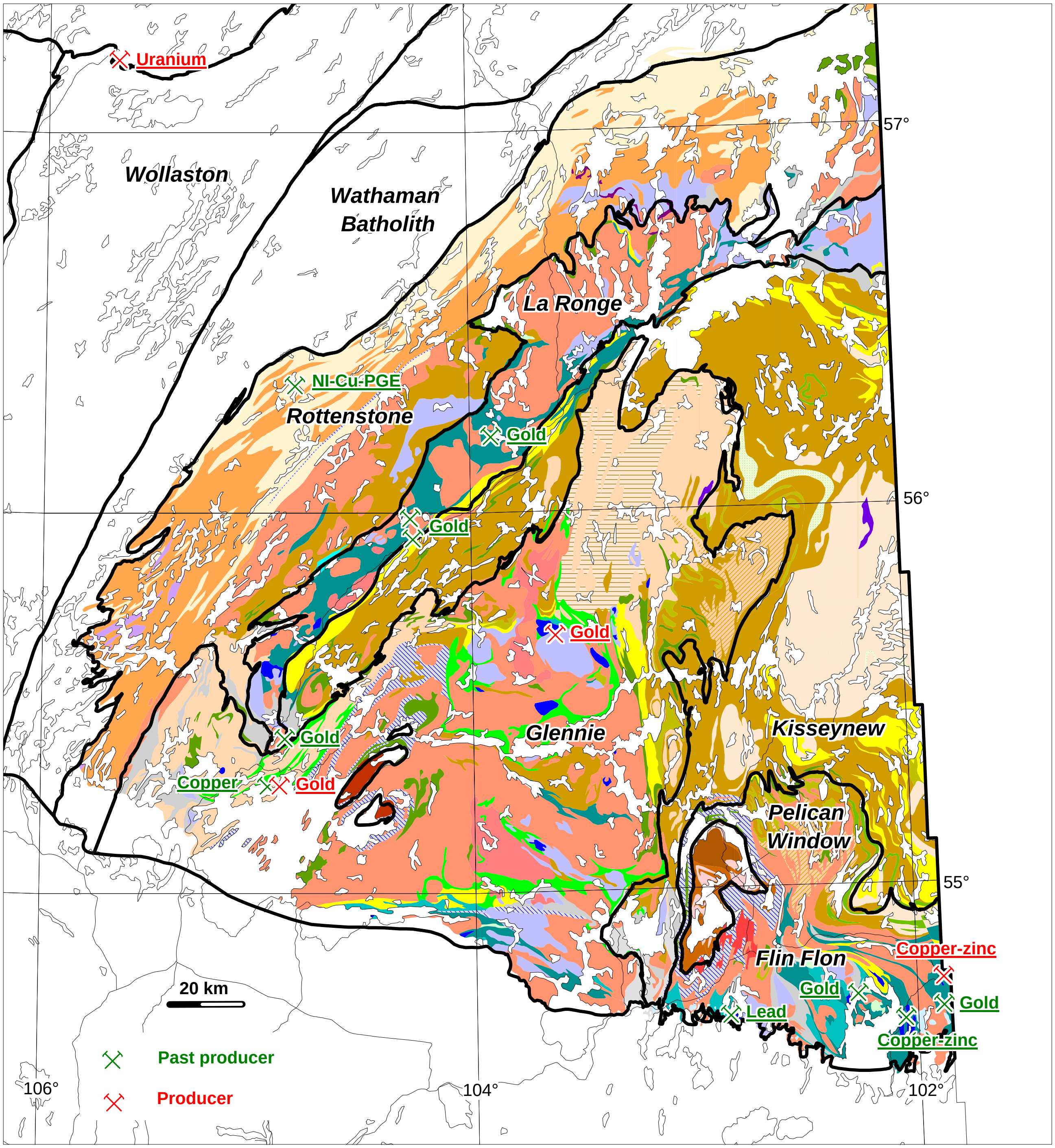


Figure 3. Generalized bedrock map with geological domains and mine locations (past and present) (from Geological Atlas of Saskatchewan, 2007). Study area comprises the La Ronge and Rottenstone domains.

Bedrock Legend

(for Figure 3)

- Granodiorite: Kgg, Kwg, Kf, Ff
- Sediments and sedimentary gneiss: Kr, Lr, Fr
- Basic to intermediate volcanics: Fvb, Lvb
- Greywacke, conglomerate: Fw, Lw
- Tonalite-diorite: Fbq, Lbq
- Granite-granodiorite-tonalite: Fgd, Lgd, MLgd
- Gneissic greywacke, psamite, pelitic gneiss: Kwn, CLwn, MLwn, Fwn
- Felsic orthogneiss: Ffn, Lfn, Kfn, MLfn
- Areas outside Quaternary sub-project area
- Granite to tonalite: Fg, Lg
- Gneissic charnockite: AS
- Paleozoic Red River Fm: Orr
- Acid volcanics: Fva, Lva
- Felsic to mafelsic gneiss (volc.): Fh, Kh
- Late pegmatite: FJ
- Interlayered supracrustal and orthogneiss: Fsg
- Metabasite/amphibolite (volc.): Fm, Lm, Km, MLm, CLm
- "Q gneiss" (Pelican Window): AQ
- Schist, phyllite, siltstone: Fs
- Migmatitic pelite: Ap
- Mylonitic gneiss: Az, z
- Gabbro: Fbb, Lbb
- Undivided volcanics: Fv, Lv
- Enderbite sills: Ke
- Metabasite/amphibolite: Km
- Plutonic/supracrustal gneisses: Fgs
- Acid to intermediate volcanics: Fvi
- Gneissic gabbro-diorite: Kbg, Fbg
- Mackenzie diabase dykes and sills: Md
- Trondjhemite-tonalite: PRt
- Wathaman granite: PW
- Crew L. Calc-silicate rocks: CLc
- Biotitic gneiss: PRp
- Gneissic granodiorite: AI

rocks derived from migmatization and 2) the former Crew Lake Belt, which comprises weakly migmatized upper amphibolite facies sedimentary rocks and granitoid plutons (Sask. Geol. Survey, 2003), with minor mafic and felsic rocks of volcanic origin. In the Reindeer Lake area, the Rottenstone Domain is subdivided into the Milton Lake Assemblage, a succession of graphite-bearing pelitic to psammopelitic gneisses, and the Park Island Assemblage, which consists of fluvial to littoral facies siliciclastic sedimentary rocks (Corrigan et al. 1998; Maxeiner,1999; Sask. Geol. Survey, 2003). Both domains are intruded by continental arc plutonic rocks of the Wathaman Batholith.

Although none of the small Cu-Zn volcanogenic massive sulphide (VMS) occurrences in the La Ronge Belt have proven economic thus far, their mineral and metamorphic associations suggest a genesis similar to that of the productive Fox and Ruttan VMS deposits in Manitoba (Corrigan et al., 2007). Both the La Ronge and Rottenstone domains are host to small but locally important magmatic Cu-Ni-(PGE) occurrences and deposits that occur mainly in mafic to ultramafic plugs and sill-like bodies, including the past-producing Rottenstone Lake deposit (1965-1968). Orogenic lode Au deposits are particularly abundant in the La Ronge Domain. They are mostly structurally controlled and of quartz-vein type, but also include VMS, epigenetic iron formation, and sediment-hosted deposits (Lafrance and Heaman, 2004). Past-producers include the Contact Lake, Star Lake, Jasper, Jolu and Komis deposits. Although there are no active Au mines in this domain, it continues to be an area of active gold exploration.

Quaternary

Several reports comment on the glacial history and the nature of surficial sediments in northern Saskatchewan (Elson, 1967; Langford, 1977; Schreiner, 1983, 1984, 1986; Campbell, 1986, 1987, 2007; Campbell and Schreiner, 1989). In the study area, the glacial erosional record indicates multiple ice-flow events, however, the last glacial advance and retreat have obliterated many, if not most, of the effects and deposits of earlier advances. Old west- to northwest-trending striations were reported in the Reindeer Lake area (Johnston, 1978; Campbell, 2003, 2004) while west, southeast and south-trending striations were found in the La Ronge Domain (Schreiner, 1984a, b). These early striations indicate the direction of successive glacial advances of competing ice masses prior to the last glacial maximum (LGM), from two major sectors of the Laurentide Ice Sheet, the Keewatin Sector and the Labrador Sector. They may represent older glacial events or ice flow during the onset of Early to Late Wisconsinan glaciation.

During and after the LGM, the ice flowed radially from a Keewatin dispersal centre, located in present day Nunavut and Northwest Territories, resulting in a dominant southwest flow direction across northern Saskatchewan (Fig. 4). Within the study area, pervasive south to southwest ice-flow indicators are thought to represent ice flow during the LGM and following deglaciation (Fig. 5). The direction ranges from 180° in the east to about 225° on the western limit of the study area. Local variations to this flow in the region include late west-southwest striations along Highway 102 near McLennan Lake (Schreiner and Alley, 1975) and late west-southwest oriented striae over the Flin Flon Domain (McMartin and Campbell, 1994). Late flows provide evidence for a strong influence by the underlying topography during deglaciation, or represent late shifts and/or re-advances in ice flow during ice retreat in front of, and into, Lake Agassiz.

In general, the till cover is relatively thin, ranging from 0 to 3 m in thickness, and yet it is fairly continuous in the study area. Its surface expression is generally a reflection of bedrock topography (Fig. 2). Thicker till deposits commonly occur as tails on the down-ice (southern) side of bedrock knobs and may fill isolated bedrock depressions. There are few streamlined drift landforms in the area although streamlined bedrock features have been observed (Schreiner, 1984). The Cree Lake Moraine (CLM) is a prominent landform that occurs south of Reindeer Lake and transects the study area between Nagle and Brabant lakes (cf. Figs. 4&5). It extends for about 800 km across the Shield from Alberta into Manitoba and is thought to reflect a major glacial re-advance as a response to Younger Dryas cooling at about 10 ka B.P. (Dyke, 2004). One of its segments west of Highway 102 forms a low, nearly continuous ridge about 10 m high and 25 km in length (Schreiner, 1984). At the western end of this segment, it curves toward the south and becomes an esker-kame complex pitted with large kettles. Between Jewett and Nagle lakes, the moraine is a nearly straight, single, narrow ridge of high relief rising as much as 35 m above the surrounding terrain. Eskers are relatively abundant north of the CLM in the study area and generally trend parallel to the flow direction of the last ice movement (Fig. 5).

At least two till units, which are associated with the last expansion of the Laurentide Ice Sheet (Late Wisconsinan), have been identified in this portion of the Shield (cf. Schreiner,

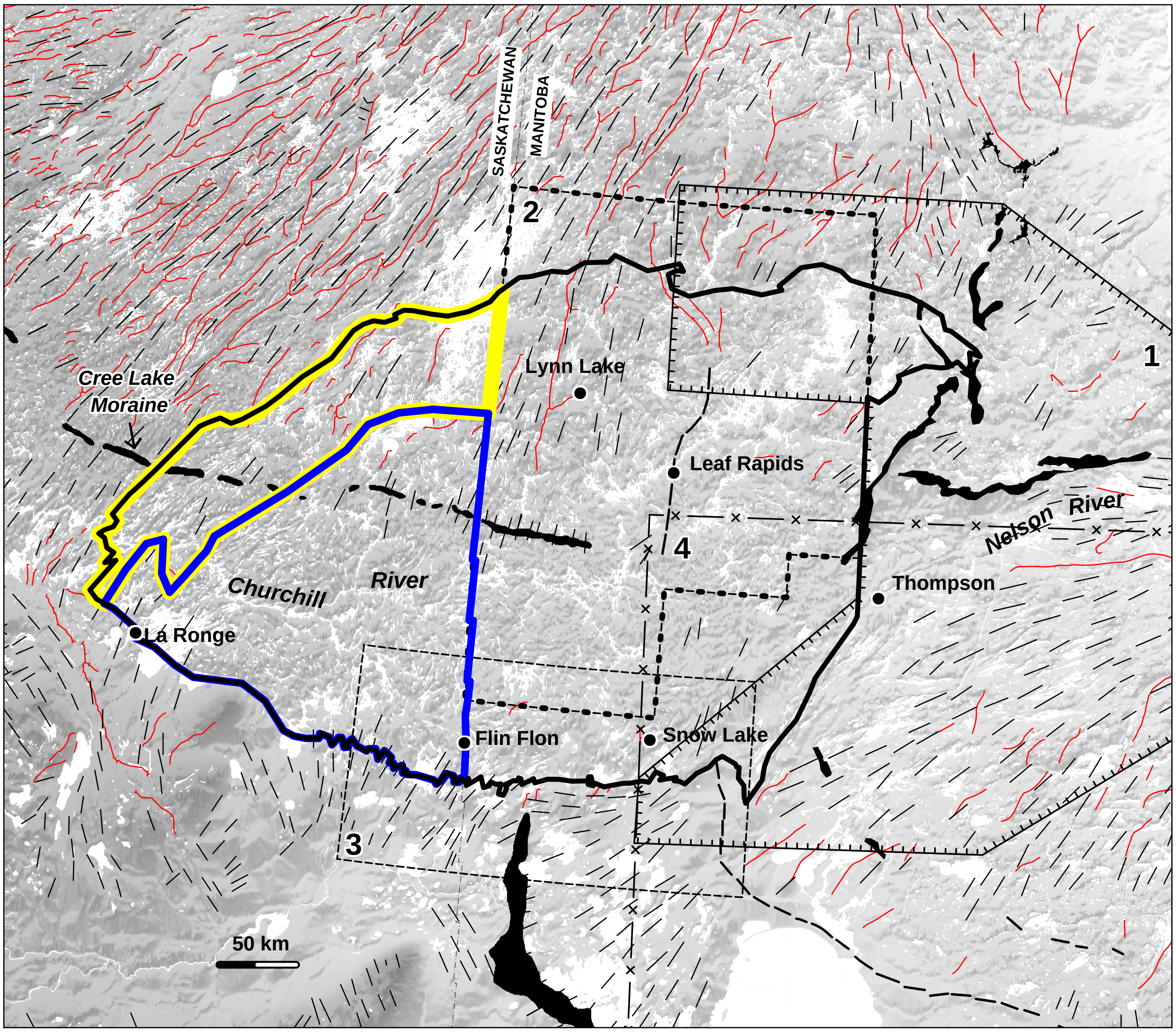


Figure 4. Generalized ice-flow map showing streamlined landforms, eskers and major moraines in northern Saskatchewan-Manitoba (after Fulton, 1995). Quaternary sub-project area is outlined in black. Study area for this report is outlined in yellow. Area covered by previous till geochemistry release is outlined in blue (McMartin et al., 2007). Regional till sampling programs from previous work within sub-project area are also outlined: GSC's North-central Manitoba (1), Northwestern Manitoba MDA (2), Shield Margin NATMAP (3), and Northeastern Manitoba (4).

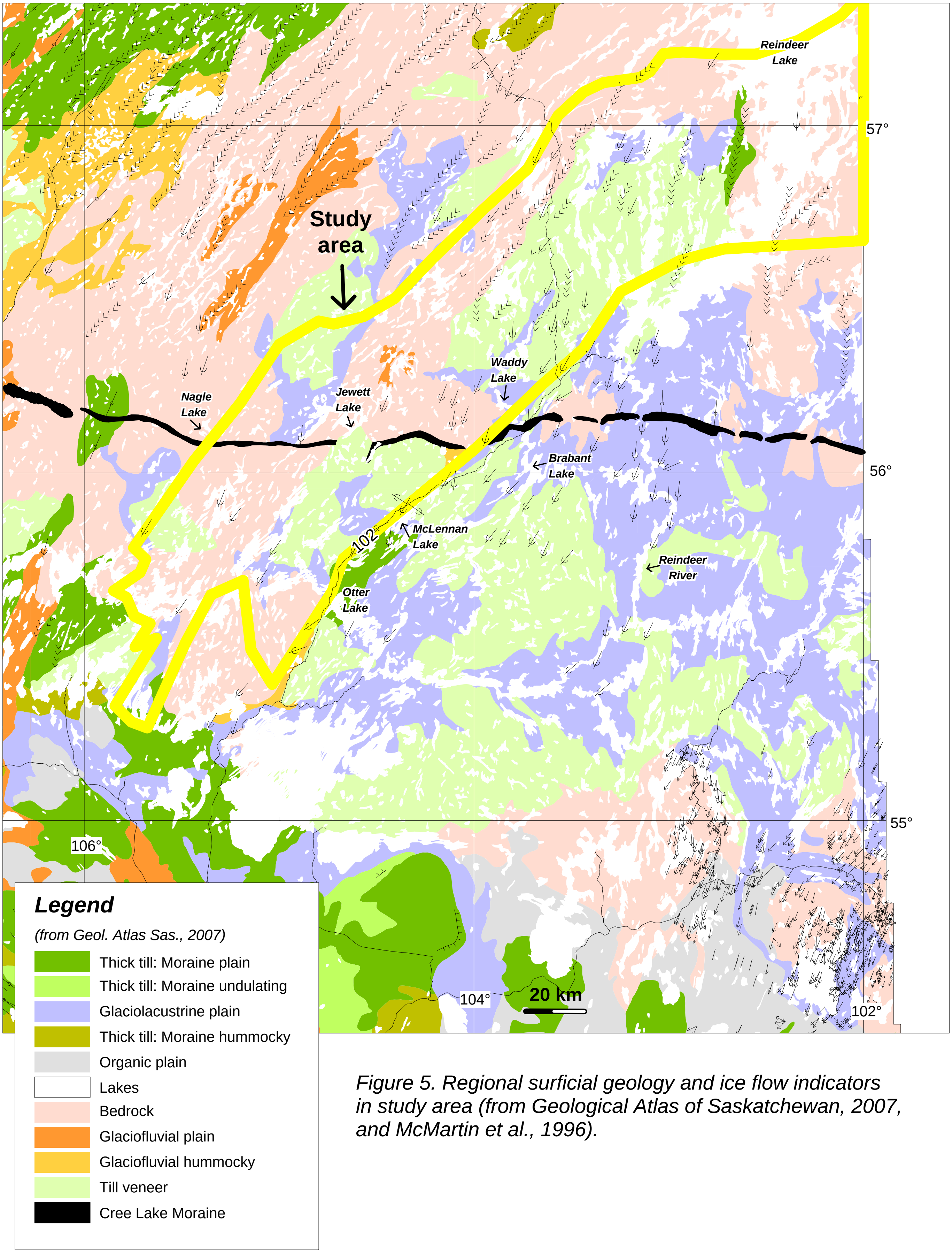


Figure 5. Regional surficial geology and ice flow indicators in study area (from Geological Atlas of Saskatchewan, 2007, and McMartin et al., 1996).

1986). The lower and most pervasive unit consists of a locally derived till overlying striated bedrock recording the predominant local ice-flow direction towards the south-southwest or southwest. This till is sandy and non-calcareous, and has a clast composition closely related to bedrock lithologies found immediately up-ice from sample sites; hence, it is the most favourable sampling medium for drift prospecting in the region. The unit forms a discontinuous cover, with thickest accumulations on the lee-side of bedrock knobs, and has been detected in exposures and augerholes in the region by Schreiner (1984) and Campbell (1986, 1987) in Waddy Lake and Sulphide Lake areas, by Campbell (1988) and Henderson and Campbell (1992) in the Amisk Lake area, and over the Shield Margin NATMAP area by McMartin et al. (1996). These same authors observed a thin, discontinuous, sandy-silty to clayey, mostly brown, non-calcareous diamicton at several sites overlying the lower till, glaciolacustrine sediments, or capping an ice contact glaciofluvial sequence. This upper till is thought to have been deposited during late glacial re-advance(s) into Lake Agassiz and should be avoided as a sampling medium.

During deglaciation, a large portion of the area was inundated by Glacial Lake Agassiz (cf. Schreiner, 1986) and as a result, surface till deposits may be covered by discontinuous, laminated or massive silt and clay sediments (cf. Fig. 5). Throughout most of the area, however, clay is present as a relatively thin veneer, draping topographic highs and filling topographic lows. Till and glaciofluvial deposits were also modified by post-depositional processes related to the step-wise drainage of Lake Agassiz (Schreiner, 1983; McMartin, 2000), producing a boulder lag overlying very sandy till in some areas (i.e. Campbell, 1987), and forming beaches, spits and sand blankets elsewhere. These deposits frequently form a thin veneer over undisturbed till, and it is important to distinguish these sandy nearshore deposits and modified very sandy till from sandy sub-glacial till when sampling in the region.

METHODOLOGY

A total of 303 SRC archived till samples collected from 291 sites (about 1 site per 60 km^2) during their reconnaissance mapping program in the 1970's, and the two samples from the Kakinagimak Lake area were analyzed in 2007 for geochemical composition (Fig. 6). Most samples were collected from hand dug pits in the upper C horizon, at an average depth of 80 cm, to obtain relatively unaltered parent material (Schreiner, 1984). These shallow surface samples can be classified as oxidized C-horizon material in which most labile minerals such as

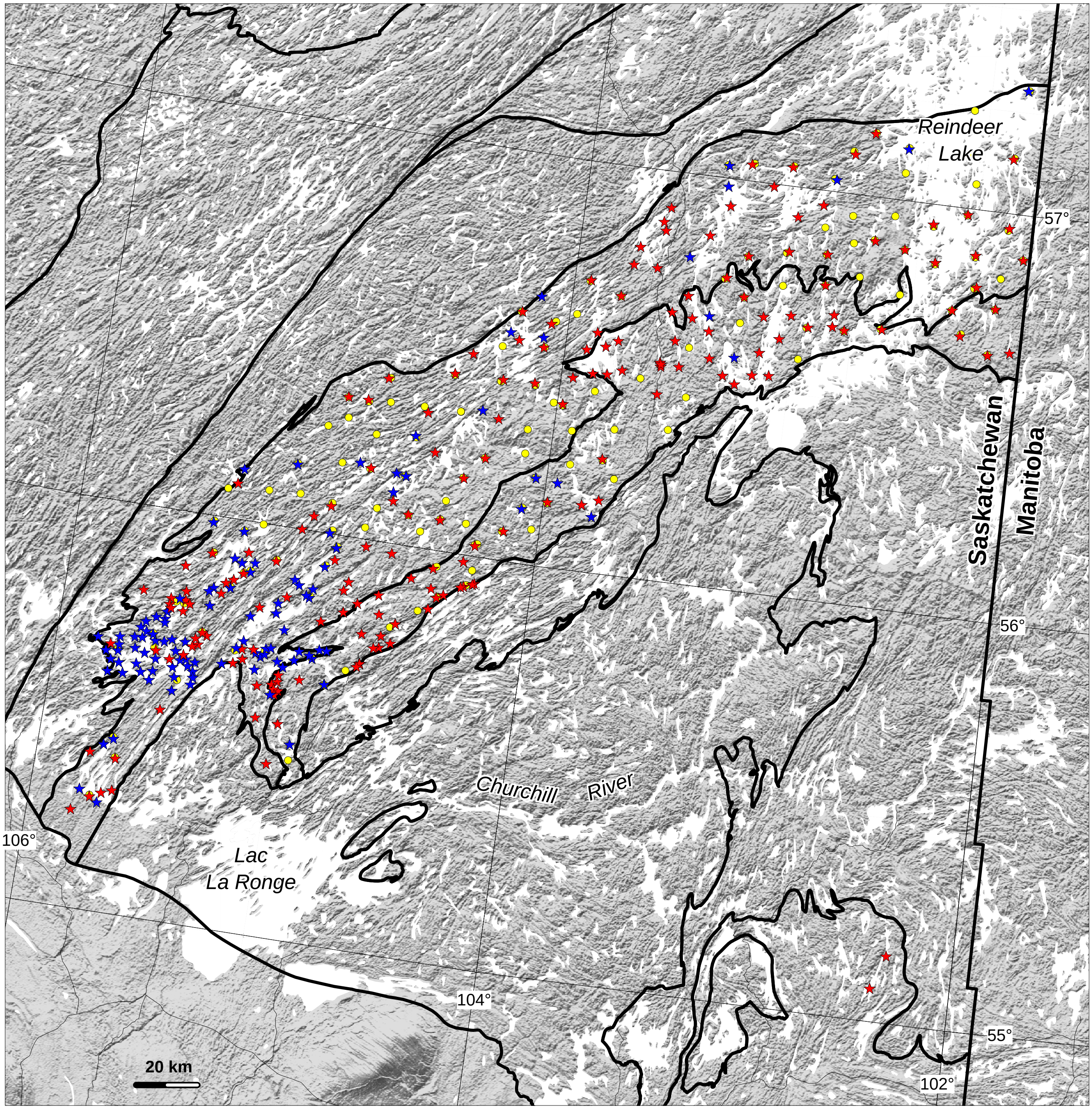


Figure 6. Location map of archived till samples within the Rottenstone and La Ronge geological domains. Locations of the two samples collected in the Flin Flon Domain in 2007 are also shown. Red stars represent samples collected in the C-horizon; blue stars represent samples collected in the lower B-horizon. Yellow dots represent B-horizon soil samples from the "Project 20" sampling program in Northern Saskatchewan (Schreiner, 1984) for which limited geochemical data are given in Appendix V.

sulphides have been weathered out. At a number of sites, samples were collected in the lower B or B/C transition zone at an average depth of 50 cm (cf. Fig. 6). At a few sites only, samples were collected at lower depths, from exposures in road cuts or borrow pits, or from augerholes (hand auger and power auger), where it was possible to sample several superimposed drift units or to evaluate compositional variability in response to secondary surface weathering. Sample locations and descriptions are presented in Appendix I.

The samples were submitted to the SRC's Geoanalytical Laboratory for geochemical analyses using their 4.3+4.3R, 62 element package (now called ICP1 – without the UFL3), the same method used for the previous archived samples analysed in 2006 (McMartin et al., 2007). Splits of the archived till samples were air-dried and wet-sieved using a stainless steel 230 mesh screen to obtain the <0.063 mm (silt and clay) fraction. Approximately 1 g of the <0.063 mm was analysed at SRC to determine trace element concentrations using ICP-AES after a partial digestion (HNO_3-HCl, 8:1, 1 hour at 95°C). A separate 0.25 g aliquot was gently heated in a mixture of HF/HNO_3/$HClO_4$ until dry; the residue was dissolved in dilute HNO_3 and analyzed using ICP-AES for determination of major and trace elements. Because of the lack of archived material, gold concentrations were determined on only 5 g aliquot of <0.063 mm pulp by Fire Assay/ICP-MS. It is important to note that since 2007, SRC has raised the lower detection limits for all trace elements analysed after the partial digestion and for many elements (K_2O, MgO, MnO, P_2O_5, TiO_2, Be, Cd, Gd, Hf, Ho, Sm and Tb) analysed after the near-total digestion. The lower detection limit for the Au analysis has also been raised by an order of magnitude.

Analyses of laboratory duplicate samples and analytical standards were used to monitor analytical precision and accuracy of geochemical results. In every analytical batch, about 3% laboratory duplicates and 5% standard samples were included, using SRC's in-house control reference samples (LSR4 for partial digestion; CG515 for near-total digestion). A QA/QC analysis was performed according to procedures established by the GSC's Sedimentology Laboratory (Girard et al., 2004). The results for the duplicate samples indicate that the analytical precision is very good for most elements analyzed by ICP-AES after the partial digestion. However, the method appears less effective for Bi and Sb because the 2006 and 2007 datasets show major batch differences that cannot be explained by geology, provenance, sample type or soil development, even when using the higher detection limits for the 2007 analysis. For Bi, all values in 2007 are very high in comparison with the 2006 analysis; in 2006, 97% of the results were <1 ppm – in 2007, only 29% are <1 ppm. For Sb, values in 2007 are very high in comparison with the 2006 analysis; in 2006, 79% of the results were <1 ppm – in 2007, only 40% are <1 ppm. For these 2 elements, we suggest that the two datasets be plotted separately and/or simply increase the lower detection limit (about 5 ppm for Bi and 3 ppm for Sb). Duplicate samples analyzed by ICP-AES after the near-total digestion also indicate that the analytical precision is good for most elements. However, the method is not so effective for a few trace elements, particularly W, since the values in 2007 for this element are especially high compared with the 2006 results, regardless of location. Also, but to a lesser extent, Ba, Be, Cs, Hf, Ho, Pb, Pr, Ta, Th and U values are higher in 2007 than in 2006. For these elements, the elevated values could be due in part to underlying bedrock types and/or glacial dispersal. Gold analyses in particular are not precise using FA-ICP-MS because only 5 g were available for analysis in 2007, generating a strong nugget effect in many samples. For Au and W, we therefore suggest not plotting the 2006 and 2007 results together and consider each dataset on its own.

Based on the standard analytical results, the accuracy appears to be acceptable for both the ICP-AES and FA-ICP-MS methods. However, the expected values reported by SRC for their in-house standards have a low precision; therefore the accuracy is probably lower than it appears. Lower detection limits, analytical results for the <0.063 mm fraction and the results of the QA/QC analysis are presented in Appendices II and III. Proportional dot plots for selected elements using natural breaks, equal count or equal ranges in Mapinfo Professional 7.8 are included in these appendices.

A separate 20 g aliquot from 153 of the archived till samples was used for textural analyses at SRC's Geoanalytical Laboratory. The percentage of sand (0.063-2 mm) was determined by wet sieving of the <2 mm fraction. The percentage of silt (0.002-0.063 mm) and clay (<0.002 mm) were determined by the Pipette method. The results were calculated as a percentage weight of the <2 mm fraction and are presented in Appendix IV. The results of laboratory duplicates, in-house analytical standards, and unpublished archived textural data from a number of samples (n=135) are also included in this Appendix.

Archived data relating to the geochemistry of soils in the area have also been included in this report. SRC's "Project 20" involved the collection and geochemical analysis of surface soil samples from B-horizons in conjunction with the 1974-77 C-horizon sampling and reconnaissance mapping program in the Precambrian Shield of Saskatchewan (Schreiner, 1984). Those soil sample sites located within the current study area are plotted on Figure 6, and corresponding archived geochemical data of the -150 mesh fraction (<0.106 mm) are included in Appendix V.

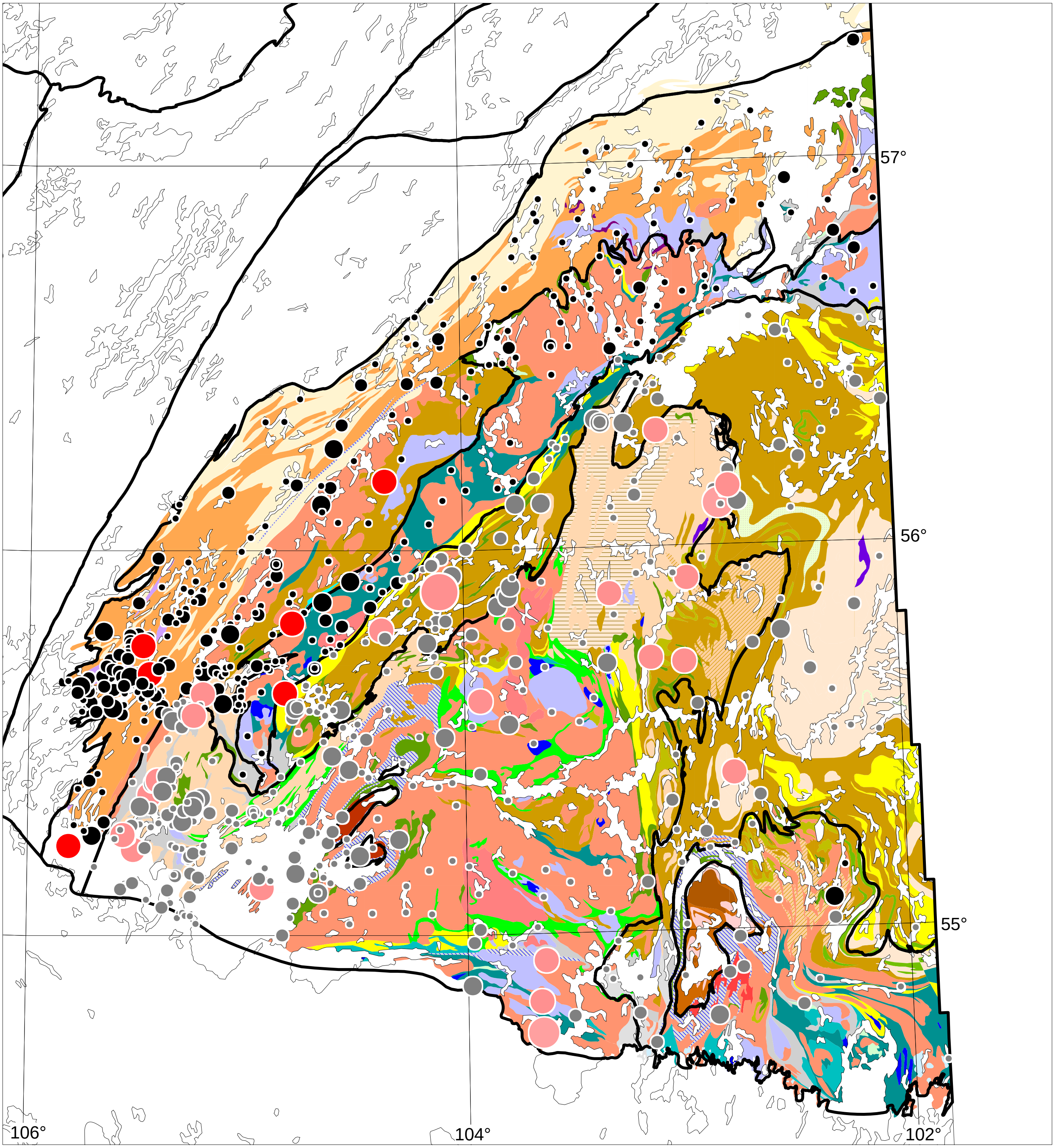
DISCUSSION

Till matrix texture

The matrix (<2 mm) of relatively unweathered till samples varies significantly across the study area. It consists of 10 to 96% sand, 3 to 69 % silt, and 0 to 53% clay, with an average of 64% sand, 30 % silt and 6% clay (combined archived and new textural data: Appendix IV). Matrix texture varies predominantly according to bedrock source, although soil horizon and till facies probably influence the till matrix texture as well. Till collected over the Rottenstone Domain, derived primarily from gneisses, plutonic rocks and clastic sedimentary rocks, is particularly sandy. Till rich in detritus from fine-grained supracrustal belt lithologies (i.e. La Ronge Domain) tends to be more silty, similar to till on either sides of Reindeer Lake. Clayey till (>10 % clay) occurs essentially south of the Cree Lake Moraine, probably reflecting the incorporation of clay material during a major glacial re-advance into Lake Agassiz ("upper till"; see above). Yet the clay content varies the least in the area with about 88% of the samples that contain <10% clay. This pattern is reflected in the clay to silt ratio which is fairly uniform, varying from 0 to 1.6 (average of 0.2) with about 91% of the samples having a ratio ≤ 0.4 (Fig. 7).

Geochemistry of the <0.063 mm fraction

Using descriptive statistics for all elements analysed by partial and total digestions (Tables 1 and 2), and proportional dot plots (see corresponding Appendices), several regional trends and local anomalies in the till geochemical data have been observed. Both partial and total digestions show similar regional patterns for most elements. Cu and U have near-equal values after both digestions; therefore the partial digestion represents near-total concentrations for these elements. For Ag, Co, Mo, Ni, Pb, V and Zn, regional patterns and anomalous areas are comparable but values are somewhat higher after a near-total digestion. Occasionally, a few single-site "anomalies" appear in either the partial or near-total data, suggesting poor reproducibility for some elements, sample heterogeneity, or significant differences in residence sites between till samples. For Pb and Zn particularly, this partial digestion (HNO_3-HCl, 8:1) is



Clay/Silt Ratio
GSC OF 5464/SIR OF 2007-13

0.00 to 0.25	(222)
0.25 to 0.50	(87)
0.50 to 1.00	(38)
1.00 to 2.00	(18)
2.00 to 3.00	(2)
3.00 to 4.41	(1)

Clay/Silt Ratio
This release

0.00 to 0.25	(195)
0.25 to 0.50	(74)
0.50 to 1.00	(13)
1.00 to 1.62	(6)

20 km

Figure 7. Clay to silt ratios in the <0.063 mm fraction of of till.

Table 1. Descriptive statistics. Till geochemistry, <0.063 mm, ICP-AES, partial digestion*

	Ag ppm	As ppm	Bi ppm	Co ppm	Cu ppm	Ge ppm	Hg ppm	Mo ppm	Ni ppm	Pb ppm	Sb ppm	Se ppm	Te ppm	U ppm	V ppm	Zn ppm
Mean	0.12	0.68	2.72	6.48	22.48	0.51	0.50	0.95	16.69	6.49	1.98	0.51	0.52	1.53	41.10	47.57
Standard Error	0.01	0.05	0.13	0.38	1.81	0.01	0.00	0.12	1.36	0.50	0.10	0.01	0.01	0.11	1.38	2.54
Median	<0.2	<1	2	5	12	<1	<1	<1	13	5	1	<1	<1	1	37	38
Mode	<0.2	<1	<1	<1	9	<1	<1	<1	6	4	1	<1	<1	<1	28	10
Standard Deviation	0.15	0.81	2.33	6.60	31.57	0.14	0.00	2.06	23.81	8.72	1.81	0.09	0.14	1.94	24.04	44.33
Sample Variance	0.02	0.65	5.44	43.52	996.54	0.02	0.00	4.25	567.05	75.97	3.29	0.01	0.02	3.75	577.76	1965.49
Kurtosis	222.75	63.76	1.53	45.77	13.05	305.00	-	75.11	157.06	139.35	3.39	249.34	99.65	52.91	1.86	16.82
Skewness	14.12	7.36	1.20	5.05	3.25	17.46	-	8.13	10.97	10.35	1.60	15.44	9.45	5.97	1.05	3.24
Range	2.4	9	13	77	246	3	0	24	367	129	11	2	2	22	154	379
Minimum	<0.2	1	1	1	2	1	1	1	1	2	1	1	1	1	4	5
Maximum	2.5	10	13	78	247	3	1	24	368	131	11	2	2	23	158	384
Count	305	305	305	305	305	305	305	305	305	305	305	305	305	305	305	305

** Values below detection limit have been replaced by 1/2 d.l.*

Table 2. Descriptive statistics. Till geochemistry, <0.063 mm, ICP-AES, near-total digestion*

	Al_2O_3 %	CaO %	Fe_2O_3 %	K_2O %	MgO %	MnO %	Na_2O %	P_2O_5 %	TiO_2 %	Ag ppm	Ba ppm	Be ppm	Cd ppm	Cs ppm	Co ppm	Cr ppm
Mean	13.77	2.02	4.86	2.86	1.77	0.05	2.79	0.30	0.56	0.15	834.92	1.58	0.69	84.32	10.01	82.48
Standard Error	0.09	0.04	0.20	0.03	0.06	0.00	0.04	0.02	0.01	0.02	8.43	0.02	0.02	5.26	0.47	3.77
Median	14.00	1.83	4.29	2.91	1.58	0.05	2.87	0.21	0.51	<0.2	840	1.6	<1	70	8	67
Mode	14.20	1.70	4.30	3.07	1.22	0.04	3.22	0.16	0.41	<0.2	1000	1.6	<1	60	8	49
Standard Deviation	1.55	0.77	3.44	0.55	1.10	0.03	0.63	0.29	0.20	0.27	146.93	0.33	0.27	91.73	8.12	65.77
Sample Variance	2.40	0.60	11.86	0.30	1.21	0.00	0.39	0.08	0.04	0.07	21587.35	0.11	0.07	8414.50	65.97	4325.99
Kurtosis	-0.22	2.67	42.85	0.29	19.72	19.09	0.95	11.56	9.96	83.42	0.35	2.32	-1.14	78.72	38.72	36.02
Skewness	-0.37	1.51	5.60	-0.44	3.21	3.43	-0.51	3.03	2.06	8.64	-0.38	0.28	0.80	8.42	4.55	4.93
Range	8.68	5.11	35.62	3.46	10.11	0.28	4.32	2.00	1.81	3.0	860	2.8	1	1022	93	628
Minimum	8.72	0.33	0.88	0.90	0.40	0.02	0.44	0.04	0.17	<0.2	340	0.5	<1	18	<1	20
Maximum	17.41	5.44	36.50	4.37	10.50	0.29	4.76	2.04	1.98	3.1	1200	3.3	1	1040	94	648
Count	304	304	304	304	304	304	304	304	304	304	304	304	304	304	304	304

	Cu ppm	Dy ppm	Er ppm	Eu ppm	Ga ppm	Gd ppm	Hf ppm	Ho ppm	La ppm	Li ppm	Mo ppm	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Pr ppm
Mean	26.55	2.79	2.02	1.12	18.12	3.91	7.82	1.06	39.74	29.62	1.16	8.65	29.56	27.93	19.01	6.45
Standard Error	1.95	0.05	0.03	0.02	0.25	0.07	0.15	0.03	1.18	0.89	0.15	0.16	0.56	1.88	0.54	0.17
Median	15	2.7	2.0	1.1	18	4	7.4	1	36	28	<1	8	28	21	18	6
Mode	8	2.2	2.0	1.0	14	3	6.2	<1	36	18	<1	8	25	17	17	5
Standard Deviation	34.08	0.79	0.49	0.31	4.41	1.30	2.66	0.59	20.61	15.49	2.70	2.82	9.80	32.85	9.37	3.02
Sample Variance	1161.48	0.62	0.24	0.10	19.45	1.69	7.06	0.35	424.93	239.81	7.28	7.98	95.94	1078.80	87.81	9.13
Kurtosis	12.03	4.34	1.81	10.59	4.25	4.64	16.27	-0.18	39.70	1.65	72.28	4.27	6.01	116.30	121.77	5.69
Skewness	3.18	1.06	0.92	2.01	1.11	1.45	2.83	0.79	5.12	0.92	8.15	1.37	1.94	9.34	9.41	1.59
Range	249	6.5	3.5	3.1	38	10	29	3	218	102	27	20	67	468	144	21
Minimum	1	<0.2	0.5	0.3	1	<1	<1	<1	12	6	<1	2	10	4	4	<1
Maximum	250	6.6	4.0	3.4	39	10	29	3	230	108	28	22	77	472	148	22
Count	304	304	304	304	304	304	304	304	304	304	304	304	304	304	304	304

	Sc ppm	Sm ppm	Sn ppm	Sr ppm	Ta ppm	Tb ppm	Th ppm	U ppm	V ppm	W ppm	Y ppm	Yb ppm	Zn ppm	Zr ppm	Au* ppb
Mean	10.73	4.93	3.57	294.67	1.11	0.52	11.53	2.46	90.79	3.37	18.98	1.88	75.55	277.93	20.81
Standard Error	0.23	0.09	0.62	4.37	0.04	0.01	0.29	0.13	1.99	1.58	0.51	0.02	3.16	5.55	1.04
Median	10	5	<1	294	1	<1	11	2	85	<1	17	1.8	64	265	16
Mode	8	4	<1	334	<1	<1	12	<2	65	<1	16	1.6	37	232	<2
Standard Deviation	3.97	1.63	10.78	76.26	0.71	0.13	5.10	2.22	34.71	27.50	8.87	0.38	55.04	96.74	17.46
Sample Variance	15.79	2.66	116.30	5816.29	0.51	0.02	26.05	4.94	1204.48	756.14	78.68	0.14	3029.07	9358.61	304.69
Kurtosis	0.39	6.12	84.95	7.41	1.23	48.03	6.67	25.86	0.68	267.00	89.88	1.23	17.05	7.62	-0.29
Skewness	0.88	2.01	8.09	1.36	1.25	6.76	1.80	3.74	0.90	15.95	8.29	0.93	3.40	1.87	0.70
Range	22	11	136	716	3	1	39	22	198	465	119	2.3	451	826	82
Minimum	3	2	<1	37	<1	<1	1	<2	31	<1	8	1.0	16	113	<2
Maximum	25	13	137	753	4	2	40	23	229	466	127	3.3	467	939	83
Sum	3262	1500.1	1086.5	89580	337	80.6	3504	749	27601	1023	5771	570.6	22967	84492	5869
Count	304	304	304	304	304	304	304	304	304	304	304	304	304	304	282

** Values below detection limit have been replaced by 1/2 d.l.*

likely too weak to dissolve all the Fe-Mn oxides/hydroxides and the sulphides, as opposed to the more commonly used aqua regia digestion ($HCl-HNO_3$, 3:1) (Hall, pers. comm., 2006).

Regional trends

At a regional scale, dispersal patterns in primary surficial sediments provide information regarding regional ice-flow history and till provenance. Secondary weathering processes are active mainly in the uppermost part of the glacial sediments but as most archived till samples were collected below the postglacial solum, geochemical composition at any given site should mainly reflect variations in the composition of the underlying bedrock plus, to some degree, the composition of the lithologies traversed up-ice along the regional glacial flow path.

A. The northeastern part of the study area, on either side of Reindeer Lake north of 56°30', has a distinct till geochemical signature, with elevated Hf-Zr, ± K_2O, ± REE (Dy-Er-Eu-Gd-Tb-Y) and ± Be-Ta-Te concentrations. This multi-element regional enrichment occurs over both the Rottenstone and La Ronge domains and extends southward into the Kisseynew Domain. A similar regional-scale enrichment is observed east in Manitoba, originating north of the Southern Indian Domain within the Chipewyan Batholith (Lenton and Kaszycki, 2005). We suggest this regional pattern represents evidence for southward glacial dispersal of debris from the Wathaman/Chipewyan Batholith lying immediately north of the study area, parallel to the main Late Wisconsinan ice-flow direction. The main body of this batholith is composed of K-feldspar granite, granodiorite, and quartz monzonite, with lesser amounts of diorite and gabbro (Corrigan et al., 1999). Plutonic rocks in this batholith are known to contain abundant zircons.

B. A large area south of the Cree Lake Moraine in the southwestern part of the study area has many till samples with high clay contents and relatively high clay to silt ratios. This area also corresponds to the presence of elevated Co-Li-V-Zn-Fe_2O_3-MnO-P_2O_5 concentrations and REE (Er-La-Nd-Tb-Y-Yb) values in the archived till samples. This regional enrichment extends across both domains and may be due in part to chemical partitioning associated with high clay contents in the samples. South of the moraine, Sopuck et al. (1980) have also identified a broad zone in which lake sediments display relatively high Co-Ni-Zn contents and corresponding high clay contents, in comparison to lake sediments to the north of the moraine. Clay-sized particles in till, which are dominated by Mg-bearing phyllosilicates, are commonly enriched in metallic elements in comparison to silt-sized particles (Shilts, 1984; Klassen, 2001). As discussed above, higher clay contents in surface till south of the CLM likely reflect the incorporation of clay material during a glacial re-advance into Lake Agassiz. However, since many of the archived till samples collected in this area are from the B/C horizon or lower B-horizon, some of the geochemical enrichments may reflect post-glacial weathering and precipitation or scavenging by amorphous Fe-Mn oxides/hydroxides or by clay-sized minerals.

C. The southern part of the La Ronge Domain has a distinct till geochemistry, with relatively high Cu-Co-Cr-Ni-Sc-V-W and ±As-Co-Li trace element concentrations and high CaO-Fe_2O_3-MgO-MnO major element contents. Most of these elements are significantly inter-correlated statistically and reflect the abundance of basic to intermediate volcanic and volcaniclastic rocks across the La Ronge Domain between Otter and Waddy lakes. This characteristic signature also supports the idea that ultramafic rocks (i.e. ophiolite) may be exposed along the southern margin of the La Ronge Domain as suggested by Maxeiner et al. (2005) based on lithogeochemistry and field relationships. Sulphide mineralization associated with small plugs of gabbro and hornblendite in the southwestern Rottenstone Domain (Crew Lake Belt) have been known to exist since the late 1950s. The Gochager Lake deposit was reported to have reserves of 1,700,000 tons grading 0.74% combined Ni and Cu (The Northern Miner, Nov. 4, 1989). Moreover, lode Au deposits and potential Cu-Zn rich VMS deposits would also contribute to a higher metal background values for till in this area. Similar patterns are present in lake sediments which have anomalous As-Au-Cu concentrations in the same region (Hornbrook et al., 1975). Enrichment in MgO-MnO and Co-Cr-Ni contents in some till samples overlying the southwestern part of the Kisseynew Domain (‘MacLean Lake Belt’) may indicate that glacial dispersal of mafic debris occurred south of the La Ronge Domain (McMartin et al., 2007).

D. A 60 km-long and 40 km-wide zone of Ba-enriched till lies on the western side of Reindeer Lake within NTS 64D. Long-distance southward glacial dispersal from the K feldspar-rich Wathaman Batholith may be responsible for the transport of distal debris over the La Ronge and Rottenstone domains. Alternatively, this Ba enrichment may be derived from local K feldspar-rich rocks in the Park Island Assemblage of the Rottenstone Domain or from local intrusions.

Local trends and geochemical anomalies

At the local scale, the source area for glacial erosion and dispersal is relatively small, resulting in relatively low concentrations of indicator elements and rapid dilution in the down-ice direction. This, coupled with irregular bedrock topography, results in dispersal trains that are commonly short and/or poorly developed. Studies of glacial dispersal at a detailed scale have been carried out in the Waddy and Sulphide lakes areas over the La Ronge Domain (Averill and Zimmerman, 1986; Campbell, 1986, 1987) and in the Lynn Lake – Leaf Rapids area in Manitoba (i.e. Nielsen, 1987a; 1987b; Nielsen and Fedikow, 1986, 1987). Results of this work indicate that down-ice transport of material derived from areas of known mineralization cannot be traced farther than 1 – 2 km. Because transport distance is short, dispersal trends may reflect late glacial shifts and/or topographic deflection of ice flow, rather than main Late Wisconsinan ice-flow trends. However, where ice-flow direction is sub-parallel to the regional structural bedrock fabric, known dispersal trains can be longer and narrower following the ridge-and-valley topography (Sopuck et al., 1986), or be a result of superimposed dispersal from multiple sources along a structure in the La Ronge Domain (Averill and Zimmerman, 1986). Local ice direction is therefore critical in determining the pathway for glacial dispersal of trace mineralization (i.e. Schreiner, 1986). In the study area, local dispersal trains and geochemical anomalies have been identified from the analysis of the archived till samples, and a few sites of high metal abundances are of particular interest for mineral exploration.

1) In the Stackhouse Bay area along the western shore of Reindeer Lake, within basic to intermediate volcanic rocks of the La Ronge Domain, elevated Ag-Ge-V ±As-Co-Pb concentrations are observed in a single surface till sample (# EC2-1-1). The sample was collected less than 400 m down-ice (south-southwest) of the Jenny Point Au-Ag showing (SMDI #0513; Geological Atlas of Saskatchewan, 2007). This multi-element enrichment likely represents glacial dispersal from the Jenny Point showing although it could be related to base metal mineralization in the volcanic rocks similar to the Stackhouse Bay showing (SMDI #1786: Cu-Zn-Au) located approximately 750 m to the southwest of the sample site (Maxeiner, 1996).

2) East of central Reindeer Lake, just north of the boundary between the Rottenstone and La Ronge domains within biotitic sedimentary rocks of the Milton Island Assemblage (Maxeiner et al., 2004), elevated Fe_2O_3 and Ag-As-Pb-U-V-Eu concentrations are observed in a single

surface till sample (#DA-375-1-1) collected at 50 cm depth in the upper C-horizon. This signature likely reflects the presence of large rafts of supracrustal rocks in the area, for example the Laxdal and Doucet belts (Corrigan et al., 1998). Felsic to mafic volcanic rocks are locally present north and south of the sample site (Johnston and Thomas, 1984). West of the sample site, the Milton Island Assemblage (MIA) is in highly strained contact with a granitoid intrusion; in close proximity to the pluton, the MIA is characterized by highly strained ferruginous psammite to psammopelite; there are also a number of pyrite and pyrrhotite occurrences both in sheared granitoids and in the psammitic rocks.

3) A significant multi-element anomaly occurs on an island in the Clements Island area of northeast Reindeer Lake area near the provincial border with Manitoba. The highly anomalous sample was collected over migmatitic pelitic to psammopelitic gneiss of the Rottenstone Domain, and near a well-known Zn-Pb showing (Paskwachi Bay showing: SMDI # 0568). High Cu-Pb-Sn-V-W-Zn concentrations are observed in surface till # BS1139-1-1, including the highest Cu-Pb-Sn concentrations of the entire till surveys (both 2006 and 2007 datasets). Although the sample was collected from the Bm soil horizon at 40 cm depth, the low amount of Fe_2O_3 suggests that the enrichment is not related to secondary weathering and oxidation of Fe. The presence of highly altered sedimentary and volcanic rocks with large cordierite and anthophyllite crystals and small massive sulphide bands in this area suggests a potential for VMS deposit (Corrigan et al., 2007). As the till sample was collected WNW of the known showing, this anomalous signature may be derived from unknown mineralization in the same general area (Corrigan, 2000).

4) A significant Co-Cr-Ni-MgO single-site anomaly occurs 5 km W of Waddy Lake within the La Ronge Domain in a region already characterized by a mafic-related elemental enrichment (cf. Regional trend C above). The anomalous sample (WL-54) was collected at 90 cm depth in the lower B-horizon, over a granitic pluton surrounded by basic to intermediate volcanic rocks. The source for this anomaly may be related to glacial erosion and transport of unknown ultramafic intrusive debris, similar in nature to the gabbronorite bodies found near Gochager Lake further south.

5) Elevated Ag-Bi-Cu-Ga-Mo-Nb-Pb-Sb-Sn-Zn, Fe_2O_3-MnO-TiO_2 and Ce-Dy-Gd concentrations are found in a group of till samples located in the southwestern Rottenstone Domain on

either sides of the Churchill River, where Archean gneiss (Bickford et al., 2001) and an abundance of juvenile and evolved arc plutons have been reported. Elevated Pb values in lake sediments are present in the same area (Hornbrook et al., 1975). There are a few known Py-Po occurrences in this area and a Cu-Ni showing at Olsen Lk but the source rocks for this large multi-element anomalous area are largely unknown. Iron formations containing ~1% Py-Po within sedimentary packages are common and there is a potential for magmatic Cu-Ni in the Rottenstone Domain (MacLachlan, 2003; MacLachlan et al., 2004). Till samples within this area were frequently collected within Bf horizons in which, by definition, amorphous material, principally Al and Fe combined with organic matter, is abundant. The clay to silt ratio is relatively high (>1) for a few but not all of these archived till samples (cf. Fig. 7).

6) Total Cr-Ni-MgO concentrations are elevated (especially in Cr) NNW of Deep Bay over basic to intermediate volcanic rocks of the La Ronge Domain. Anomalous sample DA497-1-1 was collected at 60 cm depth in the C-horizon, approximately 15 km down-ice from the type locality of the Lawrence Point Assemblage (Maxeiner, 1997) comprising a succession of ultramafic tectonite, harzburgite, partly pillowed mafic volcanic rocks, and exhalative horizons including oxide-facies iron formation. From its type locality, the Lawrence Point Assemblage continues to the southwest and northeast for a total strike length of at least 50 km and it has been interpreted as a supra-subduction zone ophiolite (Maxeiner et al., 2005).

7) The abundance of Au showings and occurrences in the La Ronge Domain is reflected in the analysis of the archived till samples which have relatively high As-Bi-Sb-Au concentrations. Lake sediments also have elevated Au-Cu-As concentrations in the same area (Hornbrook et al., 1975). Previous studies of Au content in tills over the La Ronge Domain have shown the Au to be fine-grained and delicate to irregular in shape, signifying short glacial transport (Averill and Zimmerman, 1986; Campbell, 1986, 1987; Schreiner, 1986; Sopuck et al., 1986; Campbell and Schreiner, 1989). Arsenic, Au, Cu, Mo and W concentrations can be elevated in mineralized bedrock within higher grade intersections within the La Ronge Domain (Sopuck et al., 1986) but studies have shown that Au in till is its own best pathfinder for drift prospecting.

SUMMARY

- The till cover in the study area is relatively thin but rather continuous over many areas. Its provenance reflects a south to southwest direction of glacial transport. Spatial associations and inter-correlations amongst certain elements analysed in the <0.063 mm fraction of archived, reasonably unaltered till samples suggest that till composition over the La Ronge and Rottenstone domains in Saskatchewan generally reflects variations in the underlying bedrock geology plus, to some degree at the regional scale, the composition of the lithologies in the glacial flow-path upstream direction. Therefore C-horizon surface till over much of the area is an appropriate sampling medium for drift prospecting.

- The matrix texture of till generally reflects the nature of the up-ice bedrock sources, but also till facies (or stratigraphy) and translocation of fine-grained particles below the post-glacial solum at some sites. The greatest impediment to till sampling in the area is: 1) the cover of Lake Agassiz sediments, specially in lower terrains, where it can inhibit drift prospecting by acting as a blanket covering anomalous bedrock and till, 2) the difficulty in differentiating between the lower, sub-glacial, locally-derived till from the upper, sandy to clayey till deposited during a glacial re-advance, and 3) the post-glacial lake reworking and (local) redistribution of till material. The locally derived till forms the most abundant and continuous cover and can usually be found on the down-ice side of most hill-forming bedrock highs.

- Several regional trends in the till geochemical data were identified. These patterns provide information on regional ice-flow directions and help to map out the regional patterns of glacial dispersal or outline regions naturally enriched in trace and major elements. Till in the northern part of the study area is enriched in Hf-Zr, ± K_2O, ± REE (Dy-Er-Eu-Gd-Tb-Y) and ± Be-Ta-Te and these enrichments are thought to be derived from southward glacial dispersal of granitic debris from the Wathaman/Chipewyan Batholith during the Late Wisconsinan glaciation. Till is enriched in Co-Li-V-Zn-Fe_2O_3-MnO-P_2O_5 and REE (La-Nd-Tb-Er-Yb) within a large area south of the Cree Lake Moraine in the study area. This enrichment may be due to a partitioning effect because of high clay contents in till deposited as a result of a glacial re-advance into Lake Agassiz, or may reflect post-glacial weathering and precipitation or scavenging by amorphous Fe-Mn oxides/hydroxides and by clay-sized minerals. The southern part of the La Ronge Domain has a distinct till geochemistry, with relatively high Cu-Co-Cr-Ni-Sc-V-W and ±As-Co-Li trace element concentrations and high CaO-Fe_2O_3-

MgO-MnO major element contents, and this mainly reflects the abundance of mafic to intermediate volcanic and volcaniclastic rocks between Otter and Waddy lakes, and the presence of lode Au deposits and potential Cu-Zn rich VMS showings.

- A few areas with local-scale multi-element anomalies were identified for potentially more detailed drift sampling and may be of further interest to mineral exploration. In the Stackhouse Bay area along the western shore of Reindeer Lake, high Ag-Ge-V ±As-Co-Pb concentrations are observed in a surface till sample located <400 m down-ice (south-southwest) of the Jenny Point Au-Ag showing. This multi-element enrichment could also be related to base metal mineralization in the local volcanic rocks. East of central Reindeer Lake, elevated Fe_2O_3 and Ag-As-Pb-U-V-Eu concentrations occur in a surface till sample and may reflect the presence of small, supracrustal extrusive rocks in the area. A significant multi-element (Cu-Pb-Sn-V-W-Zn) anomaly in till occurs in the Clements Island area of northeast Reindeer Lake area, WNW of a known Zn-Pb showing, suggesting this anomaly may be derived from a yet unknown mineralized zone of similar genesis. Elevated Ag-Bi-Cu-Ga-Mo-Nb-Pb-Sb-Sn-Zn, Fe_2O_3-MnO-TiO_2 and Ce-Dy-Gd concentrations are found in a group of till samples located in the SW Rottenstone Domain on either sides of the Churchill River. There are a few known Fe mineral (Py-Po) and Cu-Ni showings or occurrences in this area but the source rocks for this large multi-element anomaly remain largely unknown.

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