Northeast Wollaston Lake Project: Quaternary Investigations in the Wellbelove Bay–Ross Channel–Rabbabou Bay Area, Northeast Wollaston Lake, Saskatchewan (Parts of NTS 64L/06, /07, /10, and /11)

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Abstract

As part of the multi-year, multidisciplinary Wollaston Lake Project, 2007 Quaternary geological investigations focused on the northeast Wollaston Lake area (part of NTS map sheets 64L/06, /07, /10, and /11) to complement the bedrock mapping completed in 2005. The Quaternary component involves 1:50 000-scale surficial geological mapping, collection of ice-flow indicators, and a regional till sampling program.

Approximately 60% of the area is covered by drift, which includes till, organics and glaciofluvial terrains as the main surficial units. Till cover is variable, ranging from a veneer (<2 m) in the southwest to a thicker blanket composed of streamlined forms and stagnant ice deposits, in the northeast. Thick organic deposits are generally found in lows and are adjacent to boulder fields. Large esker systems and associated ice-contact glaciofluvial veneers are found throughout the area. Their presence suggests abundant meltwater drainage beneath the ice. Eskers formed as the result of meltwater confined to subglacial channels, whereas scarped slopes and flat-topped drumlins were the result of broad unconfined turbulent sheet flows. Small deposits of glaciolacustrine sediments are found sporadically throughout much of the field area as raised beaches and fine offshore deposits. Two raised beaches were identified at separate localities in the southwest at 415 and 420 m above sea level. These elevations are related to Glacial Lake Wollaston and are the first and highest identified in the northern part of Wollaston Lake basin.

Over 390 new ice-flow indicators were recorded indicating multiple ice-flow directions, but relative age relationships could only be established at 25 sites. Three main regional ice-flow directions were identified, along with two rare ice-flow occurrences. Initial flow was to the west (270º; rare occurrence) and was followed by a shift to the west-southwest to southwest (229º). A subsequent southerly ice flow occurred prior to the establishment of the main regional south-southwest ice flow (213º). A rare orientation of northwest-southeast (322º to 142º) was also identified. The main regional south-southwest ice flow (213º) varies from 213º in the west to 217º in the east. This regional flow is found throughout northeast Saskatchewan and northwest Manitoba and represents sustained ice flow during Late Wisconsinan deglaciation.

Keywords: *surficial geology, Quaternary geology, glacial history, till sampling, drift prospecting, Glacial Lake Wollaston, Wollaston Lake, Saskatchewan, Late Wisconsinan, ice flow, Lake Agassiz.*

1. Introduction

Following the success of the Quaternary mapping and till geochemical program in the Cochrane River and Charcoal Lake area during the summer of 2006 (Smith, 2006), Quaternary geological investigations in 2007 focused on northeast Wollaston Lake (parts of NTS 64L/06, /07, /10, and /11). This area was the focus of a bedrock mapping program (Harper *et al.*, 2005) in the summer of 2005, which began after completion of an airborne geophysical survey in 2004 (Ford *et al.*, 2005). The main objective of that project was to update the geological and geophysical data sets east and northeast of the uranium-enriched eastern Athabasca Basin, in order to provide an improved framework for assessing the area's mineral potential. The Quaternary geological investigations were designed to complement the bedrock and geophysical components.

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Objectives of this summer's field work were fourfold: 1) to complete surficial geological mapping in the northeast Wollaston Lake area at a scale of 1: 50 000, 2) to document the extent of Glacial Lake Wollaston, 3) to record the ice-flow history, and 4) to conduct a regional till sampling program.

2. Location and Access

The study area encompasses the north portion of Wollaston Lake in northern Saskatchewan, and is centred approximately 50 km north of the village of Wollaston Lake, and 75 km east-northeast of Points North Landing (Figure 1). It lies between 102º31' and 103º25'W and 58º14' and 58º40'N, and includes parts of NTS map sheets 64L/06, /07, /10, and /11. The area has been divided along 58º30'N latitude, to create a northern and a southern map sheet.

The locations of Greenway, Nowosad, and Larson islands (named west to east) mark the southern extent of the field area. The northern limit of the field area is located approximately 10 km downstream of where the Cochrane River drains Wollaston Lake (the southern boundary of the 2006 field area). Access to the eastern side of the field area is provided by the many bays and inlets of Wollaston Lake, but is generally limited to 2 to 3 km of the shoreline. Remote areas of NTS map sheets 64L/07 and /10 were reached by float plane and helicopter. Wollaston Lake is accessible from the boat launch at Hidden Bay, adjacent to Highway 905 or by float-equipped aircraft from Points North Landing.

3. Regional Setting

a) Physiography

The northeast Wollaston Lake area is part of the Selwyn Upland (Padbury and Acton, 1994), which is an undulating terrain composed of glacial deposits, bedrock ridges, wetlands, and lakes which drain into both the Arctic Ocean and Hudson Bay drainage basins. Although thick glacial deposits have subdued the topography, the regional northeasterly trend of ridges produced by glacially enhanced bedrock structures remains apparent. A maximum elevation of 480 m is reached on the west side of Ross Channel; however, most of the field area lies below 430 m.

The gently northeast-sloping Selwyn Upland is within the Taiga Shield ecozone (Padbury and Acton, 1994), which forms a transition zone between the boreal forest and the arctic ecosystems. Trees, dominated by black spruce and jack pine, are generally shorter and more widely spaced than in the boreal forest.

b) Bedrock Geology

The field area lies entirely within the Wollaston Domain of the Hearne Province (see Figure 2 in Harper *et al.*, this volume and the accompanying map separates) and comprises basement rocks of the Archean Hearne Craton and overlying Paleoproterozoic supracrustal rocks of the Wollaston Supergroup (Harper *et al.*, 2005; Yeo and Delaney, 2007). Basement rocks lie within elongate, overturned structural domes or inliers and include tonalite gneiss, migmatite, granite gneiss, leucogranite, pegmatite, and rare amphibolitic gneiss (Harper *et al.*, 2005). Rocks of the Wollaston Supergroup have been divided into three sequences by Harper *et al.* (2005): 1) a lower sequence containing quartzite, amphibolite, quartzofeldspathic rocks, and iron formation; 2) a middle sequence of calcareous rocks, psammopelite, pelite, psammite, and arkose; and 3) an upper sequence of conglomerate, psammopelite, psammite, and calcareous rocks.

c) Glacial History

Many glaciations have influenced the landscape of northern Saskatchewan; however, it was the last, the Late Wisconsinan glaciation, that was responsible for many of the features of the present landscape. During the last glacial maximum, approximately 23,000 years ago, the entire province was glaciated, with the exception of the southwest corner (*i.e.*, the Cypress Hills area; Christiansen, 1979). Ice extended southwest from a dispersal center in the Keewatin Sector of the Laurentide Ice Sheet in Nunavut (Prest *et al.*, 1968; Prest, 1984) and had retreated onto the Precambrian Shield by about 10,000 years ago (Schreiner, 1984a; Dyke, 2004). During the retreat, ice flow in the northeast part of the province was toward the southwest (Schreiner, 1984a). Northeastern Wollaston Lake was ice free by at least 8,335 ±160 years ago (C^{14} date, Rabbit Lake; Schreiner, 1984a). Models depicting the pattern and history of deglaciation for northern Saskatchewan are discussed in Schreiner (1984a), Dyke and Prest (1987), Dyke and Dredge (1989), and Dyke (2004). During deglaciation, water collected in the Wollaston Lake basin forming Glacial Lake Wollaston (Phase 6, Schreiner, 1984a). Schreiner suggested that the presence of raised strandlines at the south end of the lake indicate water levels were 24 m higher than present. Present lake levels in Wollaston Lake are approximately 396 m above sea level (asl). Water drained southeast through the Swan Spillway to Lake Agassiz until the ice retreated from the Fond du Lac and Cochrane rivers, which

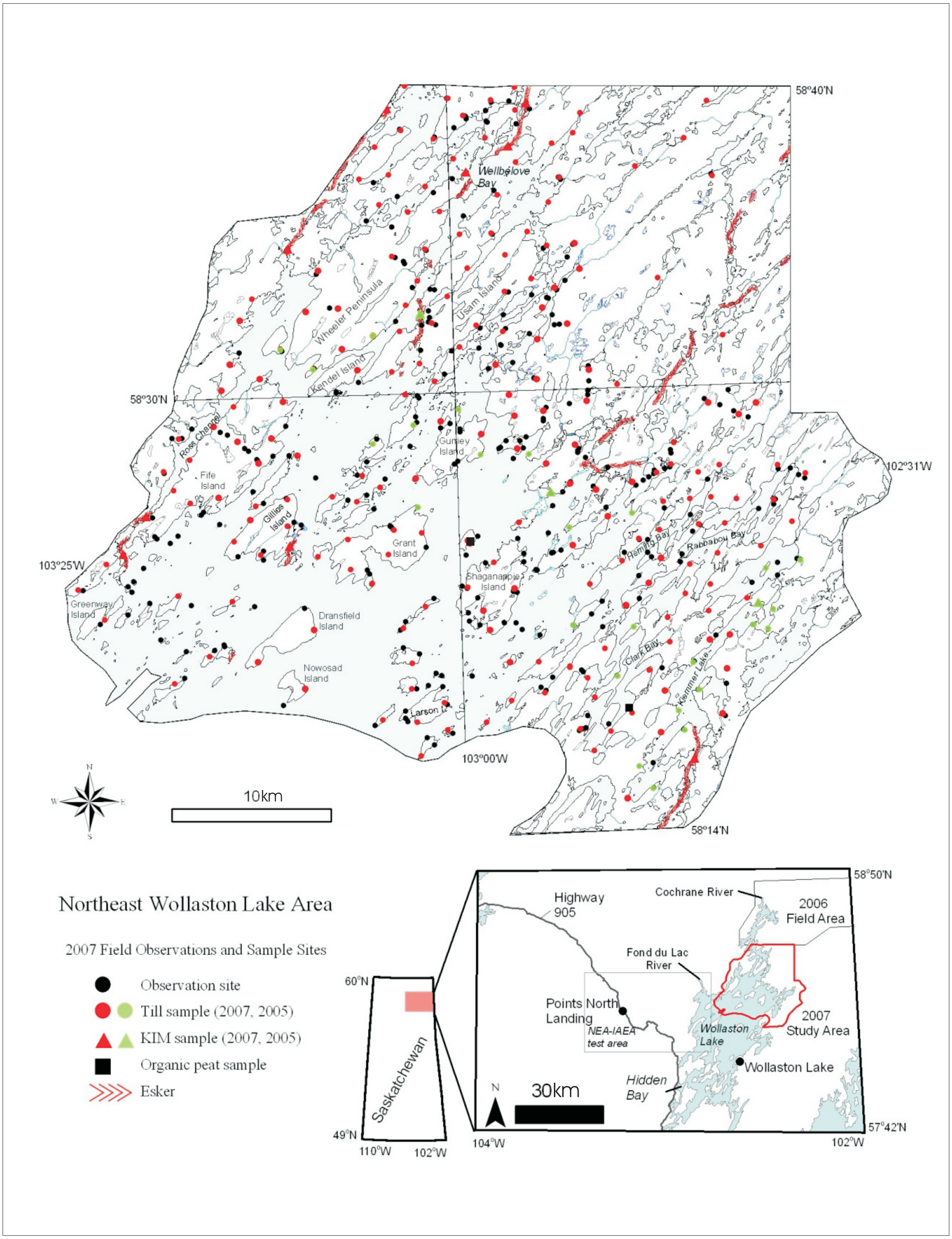

Figure 1 - Location of the northeast Wollaston Lake study area in northeastern Saskatchewan. Map identifies locations mentioned in the text as well as locations of observation and sample sites. The location of the NEA-IAEA study area is shown by the box in the inset map. KIM, kimberlite indicator mineral.

allowed drainage to the north into Glacial Lake Athabasca and Lake Agassiz, respectively (Schreiner, 1984a). As a result of this glaciation, glacial deposits cover approximately 60% of the study area. The majority of the sediment cover is a pebbly to bouldery till that ranges from a veneer to a thick blanket/plain. Large, typically southwest-trending esker systems are common and are usually on valley floors (Schreiner, 1984b).

4. Previous Work

Wallis (1971) briefly described surficial deposits in the Hidden Bay area as part of his geological mapping program. The surficial deposits of the Wollaston Lake map sheet (NTS map sheet 64L) were mapped in more detail by Schreiner (1984a, 1984b) at a scale of 1:250 000 as part of a Quaternary reconnaissance mapping program of the Precambrian Shield of Saskatchewan by the Saskatchewan Research Council (SRC).

Much geological exploration has been conducted in the northeast Wollaston Lake area in search of uranium deposits; however, very few companies have conducted detailed Quaternary geological studies within the field area (Saskatchewan Ministry of Energy and Resources Assessment Files 64L-0017, 64L06-0059, and 64L10-0018). More detailed Quaternary work has been completed to the southwest, where Schreiner (1983) mapped the surficial sediments at 1:100 000-scale in the Nuclear Energy Agency–International Atomic Energy Agency (NEA-IAEA) test area as part of a multidisciplinary project in support of uranium exploration. In the same area, Campbell and Shives (2000) and Campbell *et al.* (2002, 2003) conducted detailed integrated Quaternary investigations to support the interpretation of airborne radiometric data. The Quaternary geology and stratigraphy of the eastern Athabasca Basin adjacent to the field area was reviewed by Campbell (2007).

Detailed mapping was completed to the north in the Charcoal Lake–Cochrane River area by Smith *et al.* (2006a, 2006b). Further north, Campbell (2001a, 2001b, 2002a, 2002b) mapped the northern half of NTS map sheet 64M at 1:100 000 scale. To the south, the northwest Reindeer Lake area (parts of NTS map sheets 64E/10, /15, and /16) was mapped by Campbell (2003a, 2003b, 2004a, 2004b) at 1:50,000 scale. Dredge *et al.* (1985) mapped the surficial geology of the area east of NTS 64L in Manitoba at a scale of 1:500 000.

In northeastern Saskatchewan, Swanson (1996) conducted a regional reconnaissance sampling program of eskers for diamond indicator minerals. Only two samples (FS-95-26 and -27), however, were collected within the northeast Wollaston Lake study area. No silicate, chromite or gold grains were identified from those samples, but low numbers of possible indicator minerals were recovered in NTS map sheet 64M, north of the present study area (Swanson, 1996).

5. Current Work

Prior to fieldwork, preliminary interpretation of the surficial geology of northern Wollaston Lake area was completed using 1:63,360-scale aerial photographs taken in 1955. The classification of surficial materials follows the protocol used by the Northern Geological Survey Branch (*e.g.,* Campbell, 2003a). Surficial units on aerial photographs were differentiated based on their reflective characteristics, textural properties, and surface patterns.

Fieldwork included the examination of surficial sediments to ground-truth the preliminary interpretation of the surficial geology, measuring of glacial ice-flow indicators, and the collection of till, organic, and kimberlite indicator mineral samples (KIMS). The glacial ice-flow history was determined by measuring the orientation of striae, chattermarks, roches moutonées, and large-scale streamlined features such as drumlins. Typically, the median orientation of measured striae was recorded at each site. Direction and relative age(s) of multiple directions were determined by stoss/lee relationships, crosscutting relationships, and preservation of older striae in the lee of younger ones. The presence of exotic clasts also provided information on ice-flow movement.

An area of approximately 1657 km^2 was mapped this summer. Over 500 sites were visited by boat, foot traverse, float plane or helicopter. Sample spacing ranged from one sample per 2 km^2 along lakeshore areas to one sample per 5 to 7 km^2 in float plane– and helicopter-accessible areas. Two hundred and sixteen, 1 kg samples were collected and placed in plastic bags for textural analysis and major and trace element geochemistry of the fine fraction (<63 μm) at SRC Geoanalytical Laboratories. At 98 of these sample sites, 9 to 10 kg bulk-till samples were collected for indicator mineral and Au grain analyses to be completed at a later date. An additional 25 till samples were collected as part of the 2005 bedrock mapping program (Harper, pers. comm., 2007). Duplicate 1 kg and bulk samples were collected every 20 sample sites. Duplicate samples are used as a means to check for field reproducibility of elemental concentrations as part of the quality assurance–quality control (QA-QC) process. Samples were collected from hand-dug pits that had an average depth of 93 cm. The sample target was the C-horizon till, but some of the samples were collected from the B and B/C horizons in areas where soil was too thin for the C horizon to be present or where till was too bouldery to reach greater depths. A few samples were collected near the bedrock-till interface. Despite some problematic sampling sites, more than 90% of samples were taken from the C horizon.

KIMS were collected from 12 esker sites throughout the study area (three by Harper in 2005, Harper, pers. comm., 2007). Approximately 25 kg of sand-sized sediment was collected from 1 m-deep hand-dug pits at the crest of the eskers. Pink garnetiferous sand was sampled from a beach in close proximity to a large esker sample.

a) Ice-flow Record

As a result of abundant bedrock exposure in the northeast Wollaston Lake area, 335 striae measurements were recorded at 257 sites during the 2005 (Harper *et al.*, 2005) and 2007 field seasons (Figure 2), as well as the orientation of 56 drumlins.

Erosional ice-flow indicators indicate that ice flow varied throughout the region (270º to 182º). The large range in ice-flow direction likely represents older glacial events as well as shifts in response to changing glacial conditions during the last advance and retreat. Although 63 multidirectional sites were recorded, age relationships were only determined at 25 sites. The following is a preliminary interpretation of the ice-flow chronology.

The age relationship data indicates the rare westerly flow (range 280 to 260º, median 270º) is older than the west-southwest to southwest (range 255 to 221º, median 229º) flow. Relative age data suggests the main south-southwest flow (range 220 to 200º, median 213º) is younger than the southwest flow. The age relationships at two sites suggest that the southerly (range 198 to171º, median 182º) flow also predates the dominant south-southwest flow. In addition, a rare orientation of northwest-southeast (322° to 142º) was recorded at two locations. No evidence is found to indicate how this northwest-southeast flow relates to the other ice-flow directions.

This year’s interpretation of the ice-flow history is similar to that recorded last year in the Charcoal Lake–Cochrane River area to the north, and to ice-flow histories reported from the eastern Athabasca Basin, northeastern Saskatchewan, and northwestern Manitoba (Schreiner, 1983; Dredge *et al.*, 1986; Kaszycki, 1989a, 1989b; Campbell, 2001b, 2002b, 2003b, 2004b, 2007; Campbell *et al.*, 2002; Smith, 2006).

There are three distinct regional ice-flow phases: a west-southwest to southwest flow (229º), a south-southwest flow (213º), and a southerly flow (182º).

Phase 1

There is almost a continuum in ice-flow directions ranging from west-southwest (255º) to southwest (221º). This phase of ice flow is widespread and has been identified in much of northeast Saskatchewan (Campbell, 2001b, 2002b, 2003b, 2004b, 2007) and in northwest Manitoba (Dredge *et al.*, 1986). Crosscutting relationships and the regional pattern of glacial landforms indicate that the southwest-trending striae predate the southward-trending striae. The same relationship is seen in northeast Saskatchewan (Campbell, 2003a, 2003b, 2004a, 2004b; Smith, 2006). This is the oldest regional phase identified within the northeast Wollaston Lake area as well as in northeast Saskatchewan (*ibid.*).

Phase 2

The southward ice flow recorded in the northeast Wollaston Lake area is related to the regional southward ice flow identified throughout northeast Saskatchewan (Campbell, 2001b, 2002b, 2003b, 2004b, 2007; Smith, 2006) and northwest Manitoba (Dredge *et al.*, 1986). Most workers agree that this southward flow predates the main south-southwest (213º) flow (Dredge *et al.*, 1986; Campbell, 2001b, 2002b, 2003b, 2004b; Smith, 2006). Dredge *et al.* (1986) interpreted the south direction as the main ice-flow during the glacial maximum. The southward flow identified along the eastern Athabasca Basin margin is believed to be younger then the main flow (208° to 215º) representing a late-stage re-advance of the ice front during deglaciation (Geddes, 1982; Schreiner, 1983; Campbell, 2007; Ministry of Energy and Resources Assessment File 74I01-0091). This re-advance was not identified to the northeast Wollaston Lake area.

Phase 3

The south-southwest flow is the most pervasive and dominant regional ice flow. Covering hundreds of kilometres from northwest Manitoba south into northeast Saskatchewan (northwest Reindeer Lake) the direction of flow varies less than 10º (Dredge *et al.*, 1986; Kaszycki, 1989a, 1989b; Campbell, 2001b, 2002b, 2003b, 2004b, 2007; Smith, 2006). In a few areas, there appears to be a transition from the south ice-flow phase to the main south-southwest flow as recorded by the continuum of striae orientated 175º to 212º (Kaszycki, 1989a, 1989b; Campbell, 2004a).

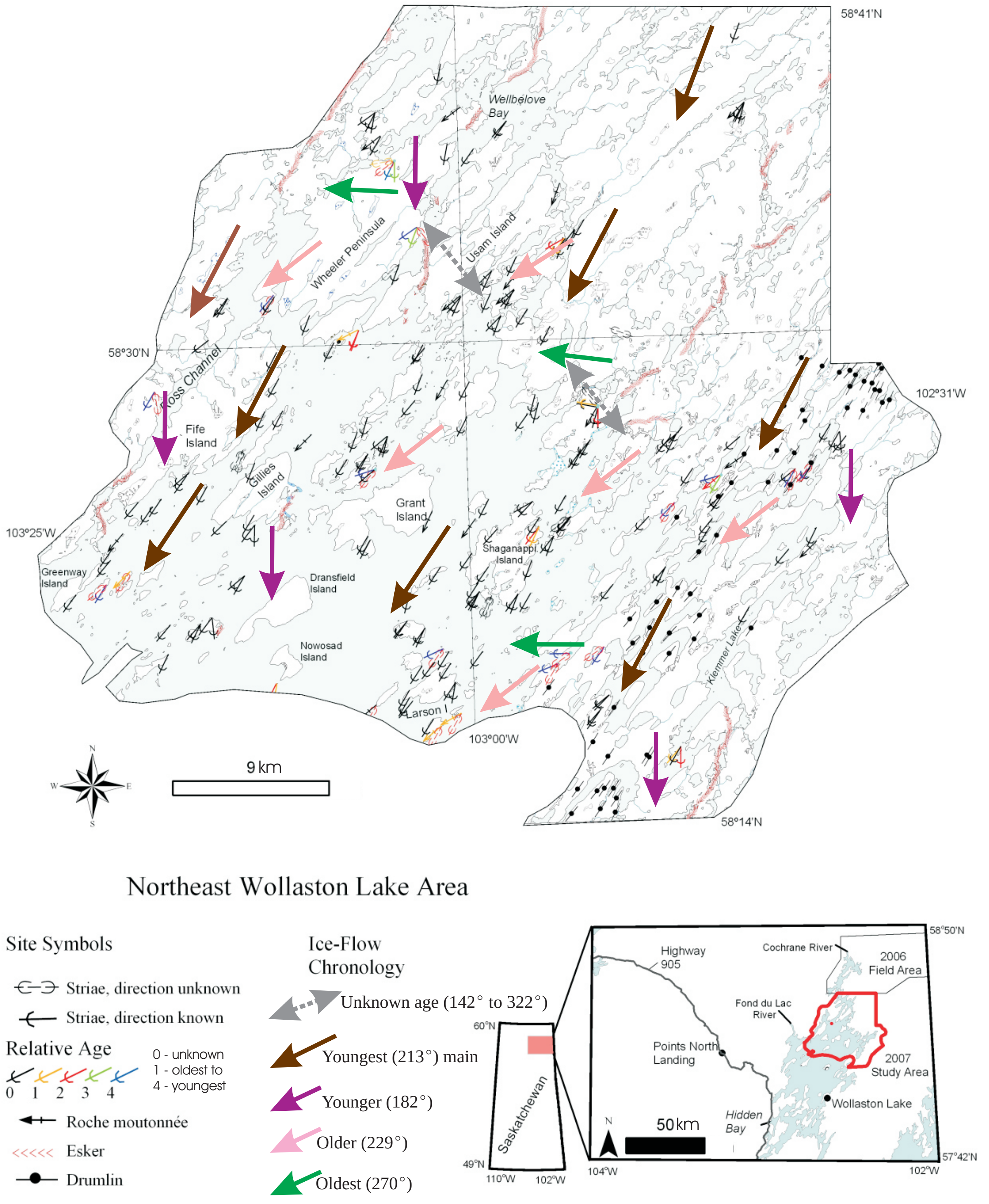

Figure 2- Distribution and relationship of ice-flow indicators measured in the Wollaston Lake study area. Multiple ice-flow indicators at a site are given relative ages, with zero representing unknown, one is the oldest and four is the youngest. Larger arrows denote the interpreted ice-flow history of the area. The main flow (213º) is marked by large brown arrows, while older flows are noted by smaller green, pink and purple arrows. A rare ice flow is denoted by grey double-ended dashed arrow, indicating the direction is unknown.

This transition to the main south-southwest flow likely occurred between the glacial maximum and deglaciation related to the retreat of the Laurentide Ice Sheet (Dredge *et al.*, 1986).

Other Ice Flows

Rare occurrences of an old westerly ice flow, including bidirectional east-west–trending striae, have also been identified in northwest Manitoba (Dredge *et al.*, 1986; Kaszycki, 1989a), south Reindeer Lake area (Johnson, 1978; Schreiner, 1984a), northwest Reindeer Lake (Campbell, 2004b), and northeast Saskatchewan (Campbell, 2002b), but have led to differing interpretations. The crosscutting relationship identified by Dredge *et al.*, (1986) in northwest Manitoba indicates the east-west–trending striae predate the southerly flow. The proposed easterly flow was interpreted to be the result of an ice divide, located in the south-central part of the Northwest Territories (NWT) and extending to the Fond du Lac River in Saskatchewan (Dredge *et al.* 1986; Campbell, 2002b). Conversely, other workers have proposed a westerly flow (Johnson, 1978; Schreiner, 1984a; Kaszycki, 1989a, 1989b). This westerly flow is plausible as it has been identified in more localities throughout northeast Saskatchewan and northwest Manitoba. It is also supported by the presence of distinctive greywacke erratics found to the south across the Prairies and interpreted to have been derived from eastern Hudson Bay, as a result of a pre-Late Wisconsinan advance of the Labradorean Ice Sheet (Kaszycki, 1989a, 1989b; Campbell, 2004b). Johnson (1978) believed that the westerly striae were older than the southwesterly flow and that they formed during the last glaciation. Schreiner (1984a) suggested that they formed during the advance of the last glaciation.

Northwest-southeast (322° to 142º) ice-flow indicators were only identified at two locations on Wollaston Lake. While the spatial distribution suggests it was also a regional flow, there is some uncertainty about direction of movement. A south-southeast (151º) striae direction was identified in northwestern Manitoba (Kaszycki, 1989a, 1989b) and in the western part of the Peter Lake domain (Schreiner, 1984a). Campbell (2003a, 2004a) identified bidirectional south-southeast–north-northwest–trending striae in the northern Reindeer Lake and Peter Lake and proposed that the flow was to the south-southeast; whereas, northwest- to west-trending ice-flow directions were recorded in the southern part of Reindeer Lake (Johnson, 1978; Schreiner, 1984c). The relative age relationship with the other ice-flow phases identified in the Wollaston area is unknown. Based on the infrequency of occurrences, this ice-flow was interpreted to predate the 213º ice-flow event (Kaszycki, 1989a, 1989b).

b) Exotic Clasts

Boulder-sized and pebble-sized exotic clasts were identified in till and glaciofluvial sediments, respectively. They include undeformed to slightly deformed blue-grey arenite, argillite and conglomerate from the upper Hurwitz Group (Figure 3A) and red felsic volcanic rocks from the Pitz Formation rhyolites of the Wharton Group (Harper, pers. comm., 2007; Figure 3B). Sources of the Hurwitz Group sedimentary rocks lie to the northeast in Nunavut (Aspler and Chiarenzelli, 1996), while sources for the Pitz Formation rhyolites are found in the Baker Lake area in Nunavut (Peterson *et al.*, 2002). Erratics of Pitz Formation rhyolites have also been found in the Keseechewan Lake and Fond du Lac areas (Campbell, 2002b, 2006), and in the vicinity of Points North Landing, eastern Athabasca Basin (Figure 1; Campbell *et al.*, 2002) areas. Similar Hurwitz Group clasts have been found in the Keseechewan and northwest Reindeer Lake areas (Campbell, 2002b, 2004b). The distribution of Pitz Formation rhyolites and the Hurwitz Group clasts denotes a large regional dispersal pattern in which transport distances range from 300 km in a southwest direction to 500 km in a southerly direction (Campbell, 2002b; Campbell *et al.*, 2002). Other peculiar erratics of undetermined source include angular, dark grey, slightly metamorphosed siltstone (Figure 3C), green siltstone (Harper, per comm., 2007), and a slightly altered, dark grey, silty mudstone with interbeds of sand.

c) Surficial Geology

The northeast Wollaston Lake area is predominately drift covered. The surficial material includes widespread till, glaciofluvial sands and gravels, and organic deposits, with lesser amounts of boulder fields and glaciolacustrine deposits. Till is the most common surficial material and is generally thicker in the east and northeast where bedrock is scarce. The many islands of Wollaston Lake are overlain with a veneer of ground moraine. Large esker systems are common and are found in subtle subglacial valleys. Ice-contact veneer is extensive and overlies much of the till. Organic deposits are common within topographic lows along the edges of ponds, lakes, and streams. Glaciolacustrine sediments are sporadic and are also typically found in topographic lows. The spatial distribution and stratigraphic relationship between these units suggests an interesting and complex geological history related to the advance and retreat of the Laurentide Ice Sheet during the Late Wisconsinan. These surficial units are similar to those described by Schreiner's (1984b) 1:250 000-scale surficial map of the Wollaston Lake area as well as those identified to the west in the NEA-IAEA test area (Schreiner, 1983).

The thickness of overburden in the Wollaston Lake area is difficult to determine due to the lack of exposed sections and drill hole information. Drill hole data from the west side of the study area and on some of the eastern islands indicate overburden thicknesses range from 0 to 45 m in that region (Ministry of Energy and Resources Assessment Files 64L06-0015, -0020, -0022, -0031, -0032, -0035, -0059, and 64L 11-0041).

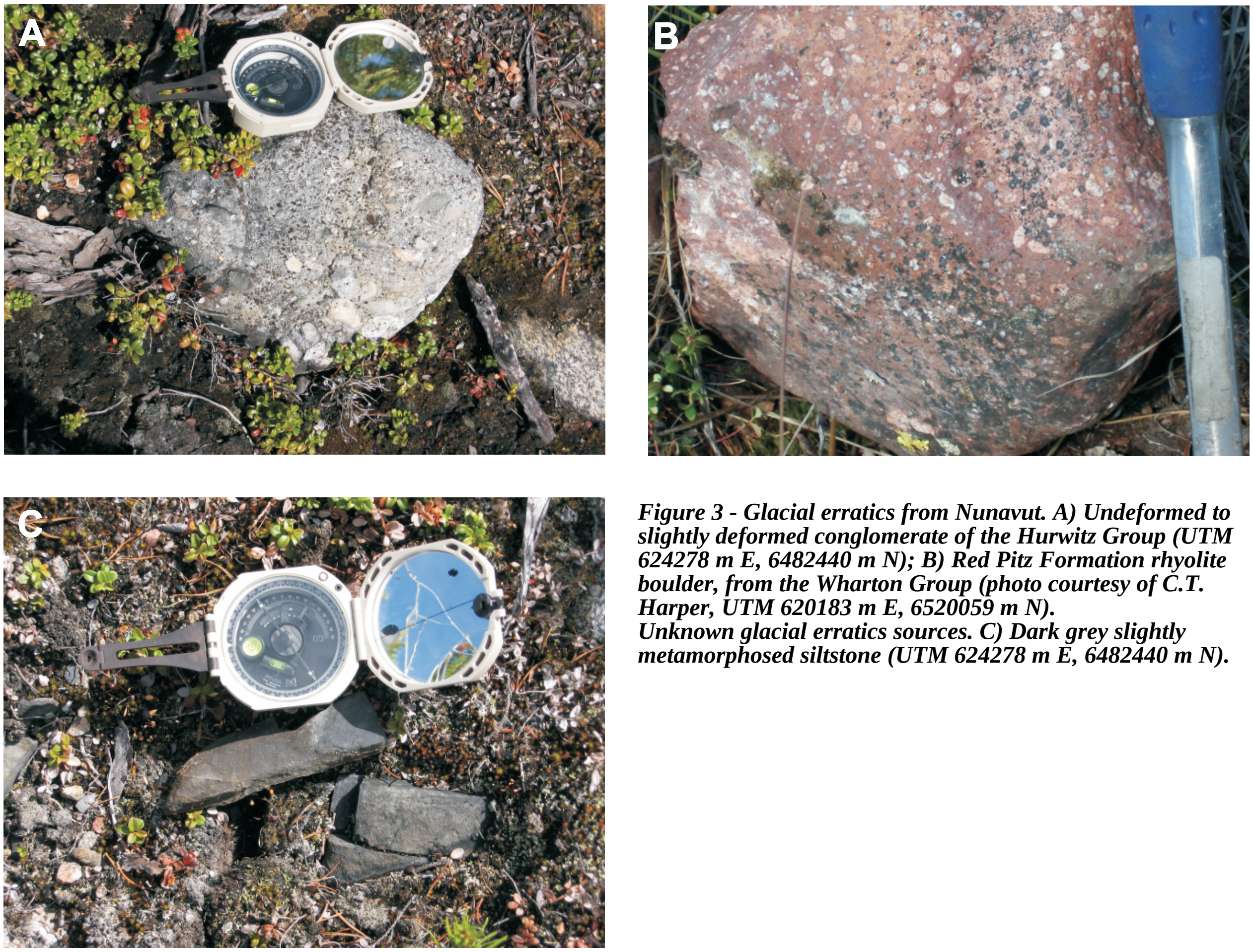

Figure 3 - Glacial erratics from Nunavut. A) Undeformed to slightly deformed conglomerate of the Hurwitz Group (UTM 624278 m E, 6482440 m N); B) Red Pitz Formation rhyolite boulder, from the Wharton Group (photo courtesy of C.T. Harper, UTM 620183 m E, 6520059 m N).
Unknown glacial erratics sources. C) Dark grey slightly metamorphosed siltstone (UTM 624278 m E, 6482440 m N).

Till

Within the northeast Wollaston Lake area, deposits of till include ground moraine (veneer, blanket), hummocky stagnant-ice moraine, and streamlined forms. Despite the variation in morphological expression of the till, only two stratigraphic units of till were identified and are described below.

The lowermost till (lower till) is the most widespread and is the main stratigraphic unit. It is generally massive, moderately compact, matrix supported, and poorly sorted (Figure 4A). Clast content ranges from 5 to 50%, but is commonly 15 to 20%. Clast size in the sample pits ranged from 0.02 to 50 cm in diameter. Subangular to subrounded boulders 0.3 to1 m in diameter are commonly found on the surface (Figure 4B). The majority of the clasts are of local origin, but exotic clasts were also present (see section on exotic clasts). In addition to boulders, large angular blocks of local bedrock are typically associated with stagnant ice and veneers (Figure 4C). Their large size and local composition is suggestive of short transport distances. The matrix of the till ranges from grey silt to medium grained silty-sand. The majority of the till observed had a silty-sand to sandy matrix. Similar to the Cochrane River–Charcoal Lake area to the north, four textural facies of till were identified: silty-sand, sandy, sandy-silt, and silty. Although there does not appear to be any meaning to the spatial distribution of these facies, they may, in a general sense, be linked to till morphology. Sandier, more clast-rich tills are commonly associated with hummocky stagnant ice terrain. Tills with more silt or sandy-silt in the matrix and less clasts (5%, <2 cm) appear to be associated with deposition in a glaciolacustrine environment (Figure 4D). These tills are common in the southeast field area. In one locality, the silty-sandy till (lower till; Figure 4E) was overlain by a sandier, clast-rich till (upper till; Figure 4E). The contact between the two units is sharp and irregular. The upper till is massive, moderately compact, clast supported, and poorly sorted. Clast content is 50%; clasts range in size from 0.5 to15 cm in diameter and are angular to subangular in shape. The matrix is composed of fine to medium sand with very little silt. This upper till was interpreted to be meltout from stagnant ice and was deposited over a subglacial till (lower till).

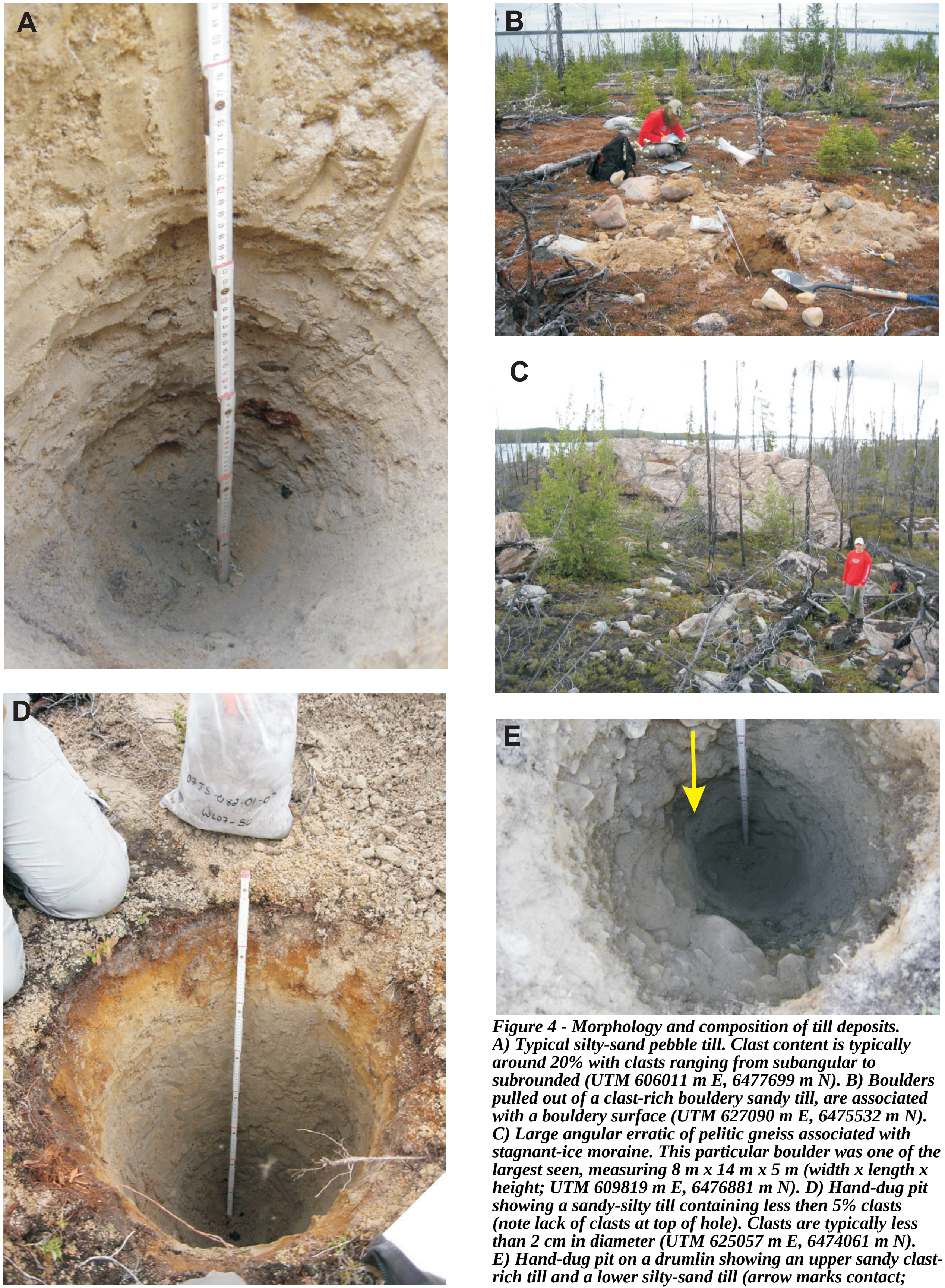

***Figure 4** - Morphology and composition of till deposits. A) Typical silty-sand pebble till. Clast content is typically around 20% with clasts ranging from subangular to subrounded (UTM 606011 m E, 6477699 m N). B) Boulders pulled out of a clast-rich bouldery sandy till, are associated with a bouldery surface (UTM 627090 m E, 6475532 m N). C) Large angular erratic of pelitic gneiss associated with stagnant-ice moraine. This particular boulder was one of the largest seen, measuring 8 m x 14 m x 5 m (width x length x height; UTM 609819 m E, 6476881 m N). D) Hand-dug pit showing a sandy-silty till containing less then 5% clasts (note lack of clasts at top of hole). Clasts are typically less than 2 cm in diameter (UTM 625057 m E, 6474061 m N). E) Hand-dug pit on a drumlin showing an upper sandy clast-rich till and a lower silty-sand till (arrow marks contact; UTM 631347 m E, 6475325 m N).*

Three till units separated by stratified sediments were documented to the west along the margin of the Athabasca Basin (Geddes, 1982; Schreiner, 1983; Campbell, 2007; Ministry of Energy and Resources Assessment Files 64L05-0019 and 64L06-0059). The regional till (lower till) identified in the Wollaston Lake area appears similar to that of the Till 2 summarized by Campbell (2007). Till 2 is the equivalent of Geddes (1982) Lower Till. It is composed of an ablation till subunit and basal till subunit, which consists of both a melt-out and a lodgement facies. The interpretation summarized in Campbell (2007) indicates that Till 2 was deposited by the main Late Wisconsinan ice advance.

Boulder Fields

Both boulder fields and block fields are present, but their location and distribution are difficult to assess from aerial photography and on the ground. From the air, it is obvious that boulder fields are quite abundant, particularly in low-lying areas, along the shoreline of small ponds, lakes and streams, and at the base of slopes between streamline forms and till plains (Figure 5A). Although abundant, they are typically small, rarely reaching 1000 m^2, and cannot be represented on a 1:50 000-scale geological map. Commonly, the boulder fields are clast-supported and composed predominately of a locally derived lithology (Figure 5B). These boulders range in size from 0.3 to 2 m in length and are often subangular to angular in shape; exotic clasts are present in some fields. Boulder fields are believed to be remnants of till, in which meltwater has removed the fines leaving behind boulder lags.

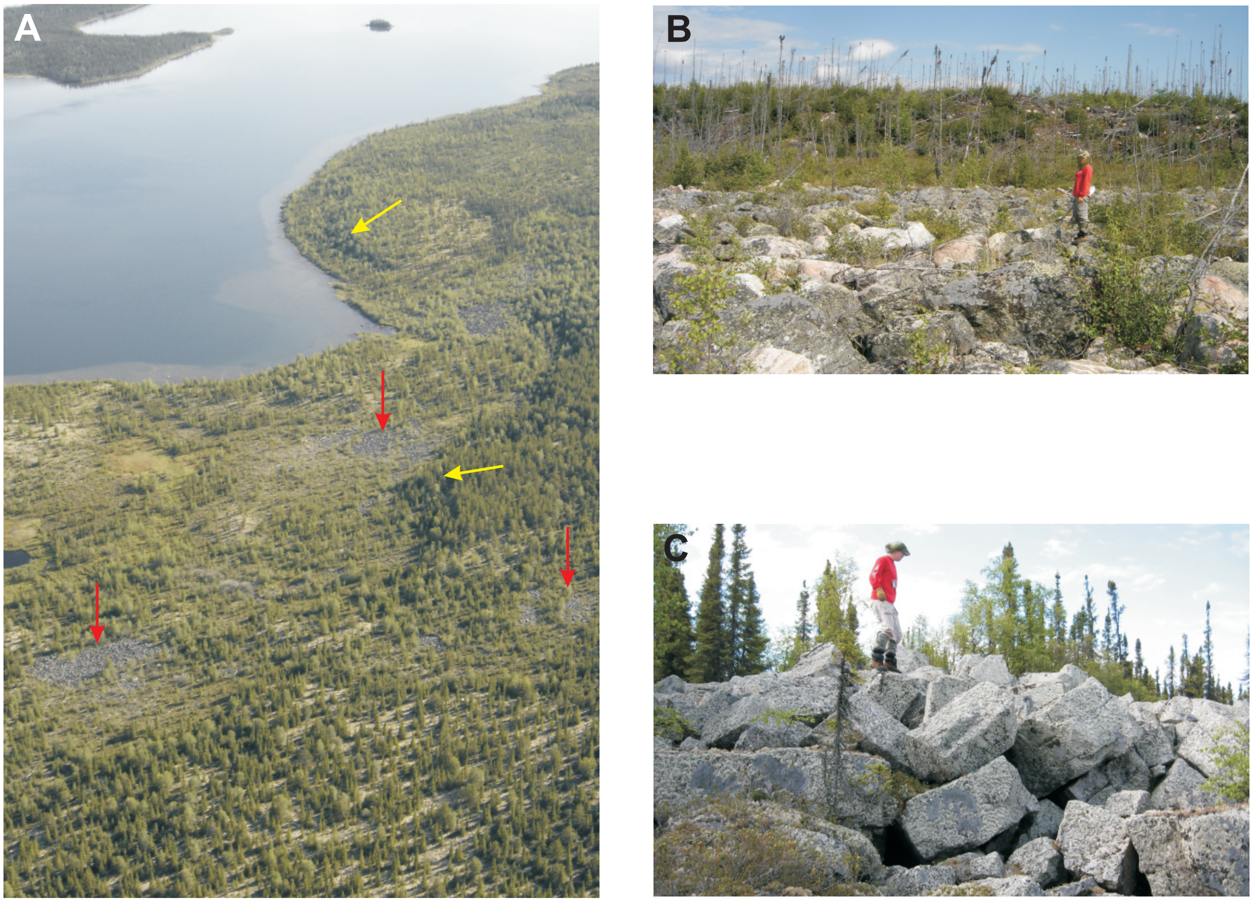

Figure 5 - Boulder fields as seen from the air and ground. A) High concentrations of boulders (red arrows) are often found at the base of sculpted slopes (yellow arrows) of till plains (UTM 617243 m E, 6503487 m N). B) On the ground, boulder fields are generally clast supported, free of matrix, and consist of large angular to sub-angular monolithological clasts. Exotic clasts are sparse. Note boulder-covered slope in background (UTM 599364 m E, 6483228 m N). C) Typical block field consisting of large, angular, monolithologic **in situ** ***frost-heaved blocks of local pegmatitic bedrock (UTM 617107 m E, 6497241 m N).***

Block fields were generally found in areas of thin veneer, and are composed of large, very angular to subangular blocks ranging in size from 0.5 to 6 m in length. The block fields, which are typically smaller than boulder fields, span less than 100 m^2, are clast-supported, monolithological, and representative of the local lithology. The blocks are frost-heaved from underlying sources (Figure 5C) and their angularity suggests little to no glacial transport.

Geomorphic Features Developed in Till

Much of the southern part of the field area is dominated by a thin veneer of till, typically less than a metre, with thicker deposits in bedrock depressions. Ice-push boulder ridges are common on the shores of islands. These matrix-free ridges are formed by winter lake ice pushing the boulders up onto shore.

Stagnant-ice moraine is much less prevalent than in the Cochrane River–Charcoal Lake area (Smith, 2006; Smith *et al.*, 2006a, 2006b). Most of the stagnant-ice moraine is found on Usam Island and to the east (Figure 6A) and associated with the large eskers found throughout the field area. Hummocky terrain is the common morphology associated with this type of deposit. It consists of rounded steep-sided hummocks with an undulating surface (Figure 6B).

Hummocks typically range from 2 to 5 m in height with diameters of up to tens of metres. Angular to subrounded clasts, 0.1 to 2 m in diameter, cover the hummock's surface. The sediment associated with stagnant-ice moraine is generally composed of sandy pebble- to boulder-rich till, which contains little to no silt. Clasts within the till are angular to subangular, and are derived from both local and distal sources. Bouldery stagnant-ice deposits form veneers in areas with exposed bedrock and may also form thicker, slightly undulating deposits. Other common features within stagnant-ice moraine deposits include scarps, kettles, and boulder fields. It is not uncommon to see stagnate-ice moraine sediments overlying other till deposits.

Drumlins and streamlined forms dominate the landscape east of Shaganappie Island. The drumlins are part of a regional field which extends outside the map area. More than 50 drumlins were identified on narrow peninsulas separating Heming, Rabbabou, and Clark bays. Drumlins range in length from 0.7 to 1.5 km and are typically less than 400 m wide. They are commonly found between 400 and 420 m elevations and are 10 to 15 m high. The axis azimuth of these features range from 202º to 222º. The average azimuth, 213º, is the same recorded by the main south-southwest ice-flow phase.

The morphology of the drumlins is variable, ranging from classic spoon shaped, spindle shaped to flat-topped (Figures 7A and 7B). A few rock-cored drumlins were identified and many others are believed to be rock-cored due to the close proximity to bedrock outcrops. Over 50% of the drumlin sites visited are flat-topped (Figure 7B) with steep scarped slopes, making them appear as if they were carved out of a flat till plain. The drumlin surface is generally free of boulders. A <1 m-thick veneer of sandy-gravely diamicton commonly overlies the till (Figure 7C) with a sharp and erosional contact. The veneer is composed of medium to coarse sand with 5 to 35%, subangular to subrounded clasts up to 15 cm in diameter. Many clasts have silt caps that are thin and appear washed. Although boulders are not generally found on the surface of flat-topped drumlins, they are present on the slopes (Figure 7D).

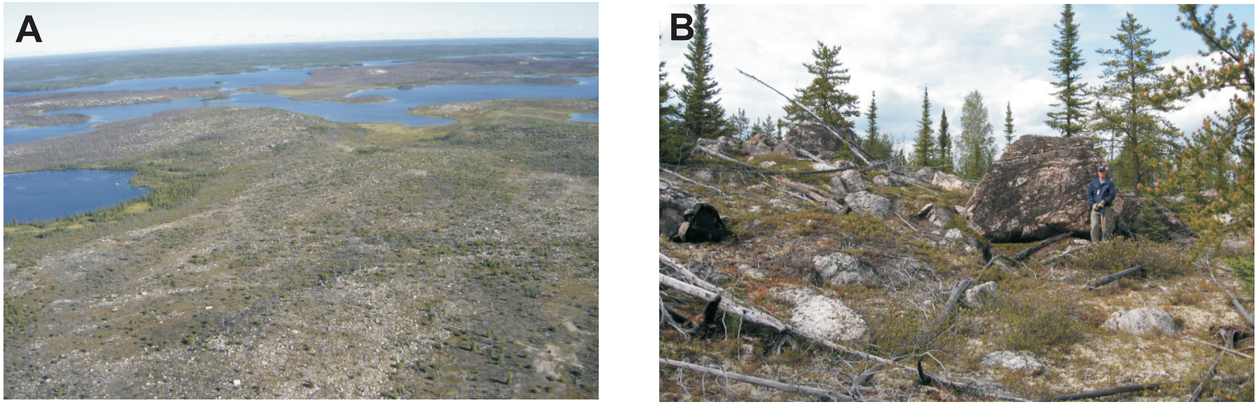

Figure 6 - Stagnant-ice moraine as seen from the air and ground. A) Bouldery stagnant-ice terrain as seen from the air (UTM 619881 m E, 6486747 m N). This terrain is easily identifiable in areas of burn. B) Boulder-covered hummock on the ground. Note size and angularity of clasts (UTM 623123 m E, 6499676 m N).

Figure 7 - Varying morphologies and composition of streamlined forms. A) A classic spoon-shaped drumlin (arrow) located northwest of Rabbabou Bay (UTM 635092 m E, 6481746 m N). B) The surface of a flat-topped drumlin, free of clasts (UTM 629594 m E, 6468807 m N). C) Sandy-gravely diamicton overlying till on a flat-topped drumlin. Contact (arrow) is sharp and erosional (UTM 631347 m E, 6475325 m N). D) Boulder-covered slope of flat-topped drumlin (UTM 631347 m E, 6475325 m N).

The till underlying the sandy-gravely diamicton is generally a silty-sandy till with 10 to 35% angular to subangular clasts up to 22 cm in diameter. At one site, the sandy-gravely diamicton was absent and two tills were present, the upper forming a sandy clast-rich till and the lower a silty-sand till (Figure 4E).

Subglacial ice processes and meltwater erosion are two mechanisms commonly cited for the formation of drumlins (Shaw *et al.*, 1989, Shaw, 1996; Benn and Evans, 1998). To distinguish the mechanism responsible requires detailed stratigraphic and compositional work through the drumlin. Hand-dug pits in the Wollaston Lake area only reached depths of 1 m allowing only surface materials to be identified. As a result, the mechanism(s) responsible for the formation of these drumlins have not been identified. However, the presence of steep scarp slopes, boulder fields in the lows, boulders on the slopes, the flat-topped surface and gravely diamicton identified on the top of many drumlins suggest that turbulent subglacial meltwater sheet-flow played an active role in the formation of the flat-topped drumlins. Shaw (1996) suggests classical spoon-shaped drumlins or Beverleys, including those that are flat-topped, are a product of meltwater erosion in which the release of phenomenal amounts of water, as subglacial meltwater sheet flows, carved out the streamlined forms, removing excessive amounts of material between the drumlins. While the flat-topped drumlins seen in the Wollaston Lake area fit Shaw's (1996) description of morphology, he has not identified any ice-contact glaciofluvial material overlying till drumlins. Rampton (2000) has identified a till-cored drumlin covered in gravel in the NWT, and suggested it resulted from high velocity subglacial meltwater erosion within a meltwater corridor. However, further investigation has to be conducted in order to determine whether the glaciofluvial veneers identified in the Wollaston Lake area were the result of subglacial or proglacial meltwater flows. Turbulent meltwater flow is responsible for similar deposits and erosional features in the NWT (Rampton, 2000) and northwestern Manitoba (Anderson *et al.*, 2005; Matile, 2006). Flat-topped streamlined forms were also identified by Campbell (2001a, 2001b, 2002a, 2002b) in the Phelps Lake area of northern Saskatchewan; however, those lacked the glaciofluvial veneer.

Steep-sided sculpted slopes are associated with many of the till morphologies (Figure 8). The eroded scarps, present throughout the area, are identified through airphoto interpretation. These scarped slopes are commonly encountered 50 to 200 m inland of the current shoreline, generally between 400 and 410 m asl. The steepness of the slopes varies from very steep to moderate. Boulder fields are commonly found in low areas when approaching these boulder strewn slopes (Figures 5A and 5B). Holes dug at the top of the slope and at the bottom often showed the same undisturbed till. Occasionally a veneer of sandy diamicton is found overlying the till in the lows and was interpreted as glaciofluvial ice-contact material.

Similar slopes, deposits, and elevations were identified in the Cochrane River–Charcoal Lake field area to the north. Material found in the lows were described and mapped as eroded till. In retrospect, this eroded till material is very similar to the glaciofluvial ice-contact material seen this year.

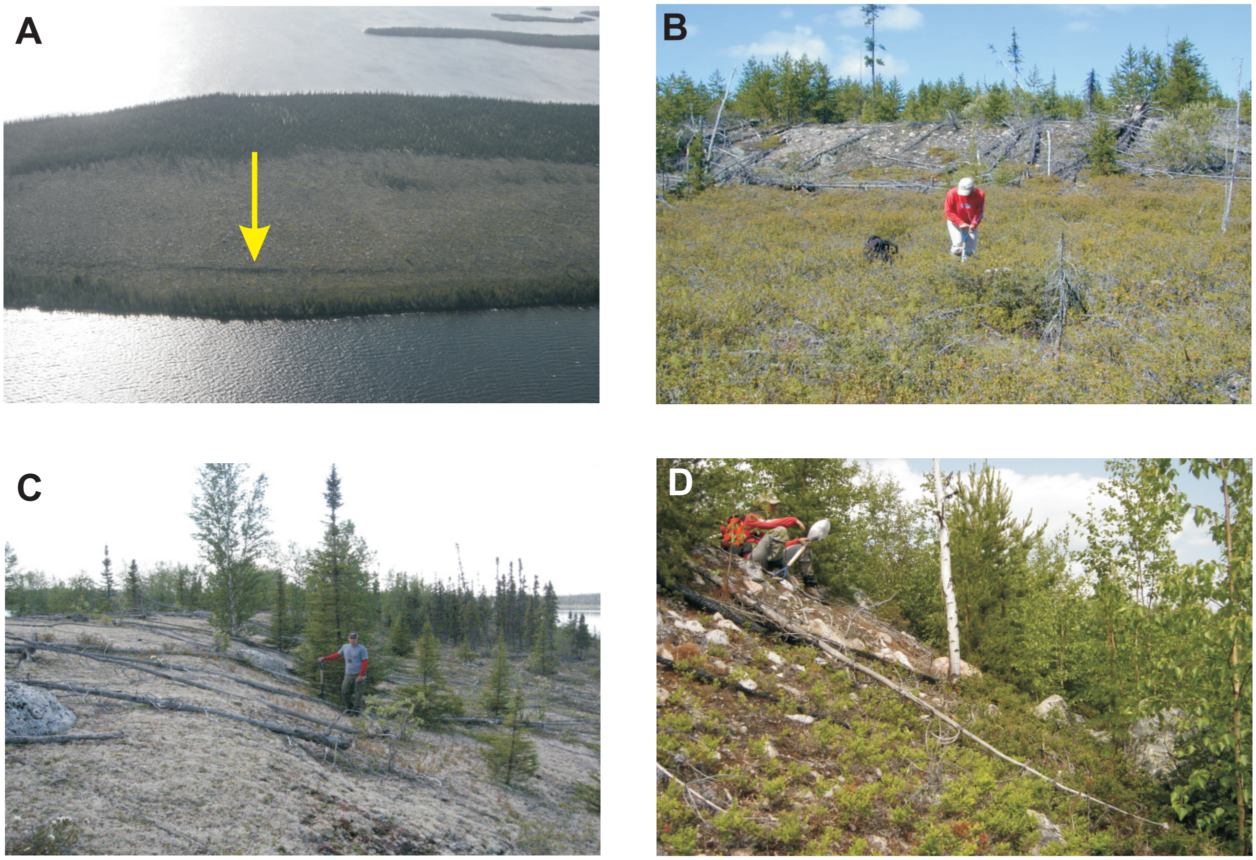

Figure 8 - Steep-sided scarped slopes as seen from the air and ground. A) Scarped slope (arrow) as seen from air (UTM 625412 m E, 6474670 m N). B) Three-metre high sculpted slope covered in boulders. Till on the top of the slope is the same identified at the bottom of the slope (UTM 624800 m E, 6465014 m N. C) Moderately steep slope located 15 m from the shoreline. Notice the lack of boulders on the slope (UTM 615906 m E, 6487294 m N). D) Steep, boulder-covered, scarped slope at the edge of a till plain (UTM 597124 m E, 6478917 m N).

It is uncertain how these slopes were formed. Rampton (2000), Campbell (2001b, 2002b, 2003b, 2004b), Anderson *et al.* (2005), Matile (2006), and Smith (2006) have identified similar steep slopes in northern Saskatchewan, Manitoba, and the NWT and suggest that subglacial meltwater sheet flows are capable of forming such features; however, another mechanism is possible, given the location and elevation of these features. Many of the slopes occur near present lakeshores and their elevation appears to be consistent with the 410 m contour; these slopes may have been created or modified by higher levels of Glacial Lake Wollaston. Further investigation and completion of the surficial maps should provide additional insight to their formation. For example, the slopes may be confined to meltwater corridors or they may be found within the area covered by Glacial Lake Wollaston.

Winnowed till was identified at only a few sites. These were typically found below the 410 m elevation. These deposits were characterized by sandy tills containing little to no silt, and generally had a lag of boulders in the upper part of the dug hole. The surface typically has a high concentration of boulders and looks like a boulder pavement. Fines are removed by winnowing due to onshore wave action. The low density of winnowed sediments may suggest that higher lake levels were not maintained for very long.

Glaciofluvial Sands and Gravels

Glaciofluvial deposits represent approximately 25% of the surficial deposits. The majority of these sediments are associated with ice-contact deposits including subglacial channels, esker systems, and stagnant-ice moraine. A veneer of sandy to gravely diamicton commonly overlies till throughout the field area (Figure 9). In NTS map sheets 64L/06, /10, and /11, it is present as sporadic deposits adjacent to esker systems. It is more widespread on NTS 64L/07. This veneer varies in thickness from 20 to 95 cm. It is composed of loose to hard, compacted, medium to coarse sand and contains, on average, 30% clasts. The clasts are generally subangular and range in size from 2 to 45 cm diameter. Many clasts contain thin remnant silt caps, which appear washed. In addition, clasts are commonly striated and faceted. The contact between the glaciofluvial veneer and the underlying till was commonly sharp and erosional, but gradational contacts were also identified. The glaciofluvial veneer is commonly associated with boulders on the surface, and is indistinguishable from till deposits on aerial photographs. In the southeast, where it overlies streamlined forms, it is generally not associated with boulders.

This glaciofluvial material is believed to have been originally deposited as a till, and was subsequently reworked and redeposited under subglacial ice-contact conditions, as indicated by the presence of remnant silt caps, striated and faceted clasts within the sandy-gravely diamicton, and the sharp and erosional contact with the underlying till. Rampton (2000) notes similar sandy-gravely deposits overlying till in the NWT, where they are associated with esker systems, scoured till slopes, scoured bedrock, high concentrations of boulders, gravel dunes, and transverse gravel ridges and boulder lags. The Keseechewun Lake area contains similar erosional features such as boulder lags, sculpted slopes, and boulder fields (Campbell, 2002b), but lacks the depositional features described by Rampton (2000).

The glaciofluvial veneers and associated esker systems are interpreted to be the same as those summarized in the Upper Stratified Sediments Unit found along the Athabasca Basin margin (Campbell, 2007). Composed of ice-contact and proglacial stratified sediments, this unit was deposited during late deglaciation as the ice retreated from the area (Campbell, 2007).

Eskers and Subglacial Channels

Four large south-southwest–trending esker systems cross the field area. They are discontinuous with the largest segment extending for 13 km. In two locations, smaller east-west–trending eskers join the larger systems.

The large eskers are commonly found in shallow valleys and are straight to moderately sinuous (Figure 10A). These systems are roughly parallel to each other and are spaced approximately 8 to14 km apart. Despite being discontinuous, they can be traced further north in Saskatchewan (Campbell 2001a, 2001b, 2002a, 2002b; Smith 2006; Smith *et al.*, 2006a, 2006b), as well as to the northeast into Manitoba and Nunavut and are likely part of larger drainage systems that originated in the Keewatin District, NWT and Nunavut during the last glaciation (Dredge *et al.*, 1985, 1986; Alysworth and Shilts, 1989). This conclusion is supported by exotic clasts contained in the esker from the Hurwitz and Wharton groups in Nunavut.

Esker morphology is quite variable, commonly with steep sides and crests, but flat-topped segments are also present (Figures 10B and 10C). Heights range from 10 to 20 m and widths can vary from tens to hundreds of metres. The widest parts of the esker systems are where secondary channels merged, the main channel bifurcated, or where small outwash plains formed (Figure 10A).

***Figure 9** - Examples of ice-contact glaciofluvial veneers. A) A crudely stratified medium sand to granule gravel diamicton overlying a silty-sandy till. Contact between the two units is sharp and erosional (UTM 614424 m E, 6463234 m N). B) Close-up of a sandy glaciofluvial veneer overlying a silty till (UTM 628116 m E, 6476946 m N). C) A clast-rich sandy to gravely diamicton overlying a silty till. The contact is sharp and erosional (UTM 613398 m E, 6505411 m N).*

The composition and grain size of sediments associated with esker complexes is also quite variable, commonly changing multiple times along the length of a single esker (Figures 10D and 10E). The sediments are typically brown in colour, loosely compact, and variably sorted. The matrix ranges from fine to, more typically, coarse sand. The deposits are bedded; either thin laminations or beds of coarser material, sometimes exhibiting soft sediment deformation structures (Figure 10E). Over 40% of the holes dug on eskers contained no clasts, while the remainder had up to 45% clasts. The clasts ranged from angular to well rounded, 0.02 to 25 cm in size. The eskers contained a higher percentage of exotic clasts than any other sediment type in the area. Hurwitz Group sedimentary rocks and volcanic rocks from the Wharton Group were identified in many of the eskers (Figures 3A and B). The concentration of boulders on the surface of the eskers was typically low (Figure 10C), although at several locations, both the top and slopes were armoured with cobbles and boulders (Figure 10F).

Figure 10 - Morphology and composition of esker deposits. A) Large south-southwest–trending esker (red arrows). The yellow arrow points to a flat glaciofluvial plain associated with the esker (UTM 622198 m E, 6507534 m N). B) Very narrow, steep-sloped esker containing very few clasts on surface. The crest of the esker is less than 3 m wide (UTM 595706 m E, 6475909 m N). C) Flat-topped esker located on the east side of Gillies Island. Surface contains very few clasts (UTM 606184 m E, 6476443 m N). D) Esker composed of clast-supported, sub-round to very well-rounded pebbles and cobbles. Matrix contains fine sand to granule gravel (UTM 626161 m E, 6481407 m N). E) Esker composed of fine to coarse-bedded sand. The arrow points to an area of soft sediment deformation (UTM 612277 m E, 6503976 m N). F) Esker surface armoured with cobbles (UTM 626161 m E, 6481407 m N).

The orientation of esker systems was influenced by the pre-existing landscape and bedrock structure. Esker systems are commonly found in topographic lows where they typically follow pre-existing valleys. Boundaries between eskers and adjacent glacial deposits are sharp; indicated by are either ice-contact or meltwater-sculpted scarps.

Sculpted slopes in pre-existing valleys containing eskers are indicative of subglacial meltwater flow, in which the valley acted as a channel, transporting meltwater towards the ice margin. Rampton (2000) suggested the presence of gravel dunes, transverse gravel ridges, and scoured bedrock are also indicative of subglacial meltwater corridors. A number of narrow channels have been identified through aerial photographic interpretation; generally these are between 100 and 500 m wide. They are characterized by scarped edges, eroded till, scoured bedrock, and boulder lags as seen from the air.

The aerial extent and relationship of these narrow channels and wide corridors to larger subglacial esker systems is not yet known. Narrow channels identified in the study area appear to be continuations of those from the Cochrane River–Charcoal Lake area. Similar large esker systems, subglacial channels and corridors, and areas of meltwater erosion were noted north of Phelps Lake (Campbell, 2001b, 2002b). The presence of large esker systems and subglacial channels indicate that meltwater played a large role in sculpting the landscape in northeastern Saskatchewan.

Glaciolacustrine Deposits

Glaciolacustrine sediments are rare and were encountered at only 5% of the field sites. The sites were found throughout the field area at or below elevations of 420 m asl. These elevations presented here are estimations derived from a GPS-barometric altimeter which has a degree of accuracy of ±5 m. Caution is advised when comparing these elevations with other quantitative paleo-lake elevation data. These deposits are divided into two groups: near-shore sediments consisting of moderately well– to well-sorted, medium to course sand, and offshore sediments, consisting of fine sand and silt.

Glaciolacustrine near-shore sediments consist of raised beaches found between 398 to 420 ±5 m asl. These are very subtle features on the ground. One raised beach was identified at 420 ±5 m asl on the west side of Gillies Island (Figures 11A and 11B). It is associated with a noticeable break in slope, approximately 10 m wide and 100 m long, that is very flat with very few clasts found on the surface. A hand-dug pit revealed nearly horizontally bedded medium sand with moderately to well-sorted granule gravel beds (Figure 11C). Till was encountered 100 m farther inland and up slope. To the east, on the west side of Grant Island, a subtle break in slope at 415 ±5 m asl was interpreted as another raised beach. A hand-dug test pit contained medium-coarse sand with slightly dipping, coarse sand to granule gravel bed. Very few boulders were seen in this area. A silty-sandy till was encountered less than 100 m farther inland and up slope, and clast-rich sandy till is present 150 m shoreward and down slope from the raised beach deposit. The increase in boulders and sandier nature of the down-slope till suggests it was modified by wave winnowing. Moderately to well-developed raised beach berms were more common below 403 m asl (Figure 11D). These were generally less than 1 m high and composed of loose medium-coarse sand.

Some modern beaches had high concentrations of purple-pink garnetiferous sand and a black unidentified mineral (Figure 11E). Reworked glaciofluvial sediments were the sources for these beaches. Due to their close proximity to a major esker system, samples were taken for kimberlite indicator mineral testing.

Glaciolacustrine offshore deposits were generally found below 405 m asl, in flat topographical lows. Deposits are made up of moderately compact, well-sorted, fine sandy silt, and are typically less than 1 m thick (Figure 11F). Boulders are rare. Clasts make up less than 1% and are typically less than 1 cm in diameter. Soft-sediment deformation structures were present in the upper portion of several holes. At a number of sites, the sandy-silt grades down into till. The glaciolacustrine offshore sediments were deposited in quiet energy regimes, such as in deeper water or in restricted areas cut off from the main lake basin.

Glacial Lake Wollaston was defined by Schreiner (1984a) based on strandlines found in the southwest part of the present Wollaston Lake. He identified the same cobble beaches at 420 m asl in Pow Bay as Wallis had in 1971, as well as stratified sands at the same elevation along Wollaston Lake road. The beaches identified on Gillies and Grant islands are subtle and inconspicuous features that are not identifiable on aerial photographs. Their elevation suggest Glacial Lake Wollaston also reached 420 m asl in the north part of Wollaston Lake. These higher elevation beaches probably formed prior to the opening of the Fond du Lac River to the west, but high lake levels were likely short-lived based on the lack of shoreline features above 410 m asl. The absence of strandline features above 405 m asl in the area to the north of Gillies and Grant islands, may indicate that this area was covered by ice when the proglacial lake was present. The presence of many beaches at lower elevations (*i.e.*, 403 m asl) suggests that Glacial Wollaston Lake existed at the lower lake levels for longer periods of time. However, the relationship between the timing of beach formation, the opening of Fond du Lac and Cochrane River outlets, and the draining of Glacial Lake Wollaston is unknown. The Wollaston Lake area was ice free and Glacial Lake Wollaston had drained by 8,335 years ago as indicated by a radiocarbon date of a peat deposit from the bottom of Rabbit Lake (Schreiner, 1984a).

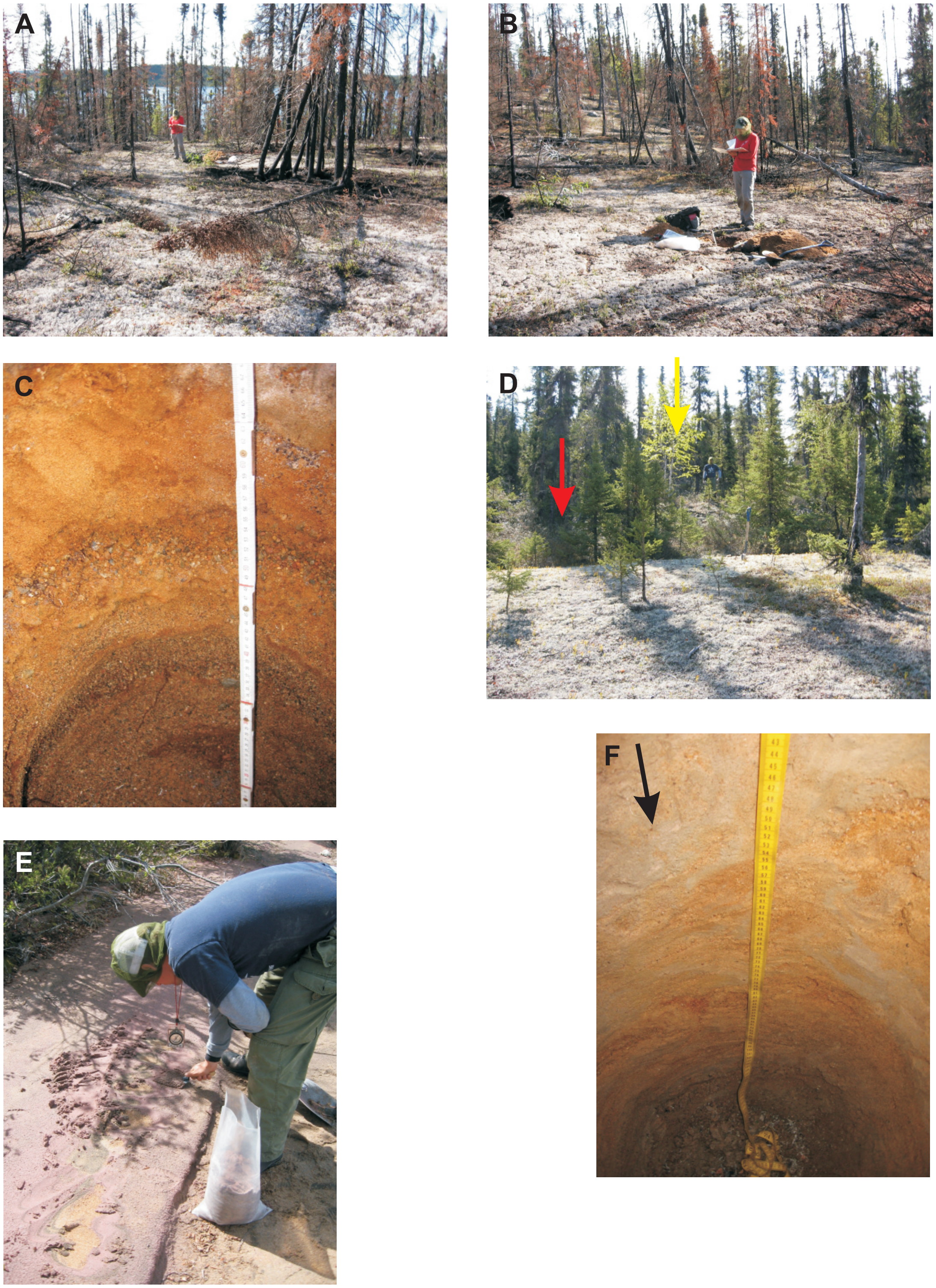

Figure 11 - A) Location of beach identified at 420 m asl on Gillies Island, looking northwest. Note that the area is flat and contains very few boulders; description of sediments found at this location are described below (UTM 605941 m E, 6479462 m N, co-ordinates the same for B and C). B) Same location looking south, background gently slopes, and a few boulders can be seen on the surface. C) Close up of medium sand with granule bed, representing nearly horizontally bedded beach sands on Gillies Island. D) Two raised beach berms identified at 398 m asl (red arrow) and 400 m asl (yellow arrow; UTM 618518 m E, 6503208 m N). E) Modern beach containing high concentrations of garnetiferous pink sand and layers of an unidentified black mineral (UTM 617278 m E, 6499977 m N). F) Fine-grained offshore glaciolacustrine deposit composed of silty sand to sandy silt exhibiting soft sediment deformation structures (arrow; UTM 621666 m E, 6474968 m N).

High lake levels indicated by raised strandlines and ice-contact deltas were recorded by Campbell (425 to 430 m asl; 2003a, 2003b, 2004a, 2004b) in northeastern Reindeer Lake, and by Dredge *et al.* (1986; 425 m asl) and Kaszycki and Way Nee (1990; 410 m asl) in northwest Manitoba. The correlation between strandlines identified between 420 and 430 m asl in the Wollaston Lake–Reindeer Lake–northwestern Manitoba area suggests that Glacial Lake Wollaston and Glacial Lake Reindeer were connected and that this larger proglacial lake extended into Manitoba (Dredge *et al.*, 1986; Campbell, 2005). Campbell (2005) questioned whether the regional extent of these raised strandlines suggested that the larger proglacial lake was the northwest extent of Lake Agassiz or the presence of a separate large proglacial lake that drained northward via the Fond du Lac and Cochrane River spillways. If this proglacial lake is part of Lake Agassiz, then the latter was more extensive than recorded previously by Schreiner (1983, 1984a), Teller *et al.* (1983), Teller and Leverington (2004), and Campbell (2004b, 2005). However, the higher lake levels identified in northeast Saskatchewan and northwest Manitoba do not correlate to the present models for the history of Lake Agassiz (Campbell, 2005; Dyke *et al.*, 2005). As a result, more research is needed to fully explain the significance of the higher lake levels in the deglaciation history for this area and the relevance to Lake Agassiz.

Organic Deposits

Organic deposits cover approximately 30% of the field area. They include bogs and fens bordering lakes and streams in the areas below 430 m. They are typically found in areas where drainage is poor, such as surface depressions, valleys, between outcrops of bedrock, between drumlins, and are flanked by boulder fields. Relatively thick organic mats are also associated with gently sloping black spruce forest floors. These organic mats have a distinctive smooth to lineated texture and medium grey tone on aerial photographs. A number of these areas were cored to determine thickness. Thickness ranged from 30 to 65 cm; in most cases the shallow depths are the result of frozen organic material. In a couple of localities, where mineral soil was reached, the underlying sediment was identified as till.

The flat to gently sloping, thicker organic deposits mask the underlying morphology forming plains or blankets. These blankets are locally dotted with round depressions, likely thermokarst features, which develop in areas of melting permafrost. In at least two localities, peat sections are exposed at the lakeshore (Figures 12A and 12B). The peat thickness was 1.8 to 2.2 m and, in both localities, till underlies the peat. Generally, the peat is fine to medium grained; coarser material, such as wood, was identified in one locality (Figure 12C). This wood will be submitted for accelerator mass spectrometry dating along with a bulk peat sample at the peat/till interface that will be submitted for conventional radiocarbon dating. The radiocarbon age will provide a minimum date for ice-free conditions in this area.

6. Implications for Drift Prospecting

Although results from till geochemical, textural, and indicator mineral analyses are not yet available, some preliminary comments can be made with respect to drift prospecting in the northeast Wollaston Lake area.

1) The complex ice flow identified in the northeast Wollaston Lake area reflects multiple glaciations as well as directional shifts in flows during the last glacial advance and retreat. Therefore, care must be taken when inferring the direction of mineralized dispersal trains as shifting ice flows may be responsible for the deposition of different till units.
2) Areas of thin veneer with local boulders, including areas of block fields, are more favourable for conducting drift prospecting as the till was likely deposited by the main regional ice-flow event (Phase 3) from local sources. Identifying the relationship between the till and the direction of the last ice-flow event allows for mineralization in till and boulders to be more accurately sourced.
3) Thick organic deposits overlie one-third of the study area and are often frozen. Acquiring till samples in these areas can be difficult, particularly if no specialized tools are used. These areas can be avoided with planning a till sampling survey, as their morphology on air photos is often distinct. If the underlying till is the sample target, then a motorized auger or drilling equipment will be needed.
4) In the areas of meltwater erosion, *i.e.*, meltwater channels and corridors, the role of meltwater must be taken into account when planning, sampling, and interpreting till geochemical surveys. The following are important points to keep in mind:
    - Bedrock outcrops are often associated with corridors of meltwater erosion and therefore an excellent spot to look for outcrops.
    - The composition of surface tills found in regions within or adjacent to these meltwater corridors and/or channels may vary as a result of being affected by meltwater erosion. Reworked surface sediments, *i.e.*, glaciofluvial ice-contact veneer, in which the fine fraction has been redistributed, may cap the till; therefore

when sampling tills in areas of meltwater erosion, it is important that the sample is taken from the undisturbed till below the reworked horizon. The reworking and/or truncation of the upper till surfaces may result in the exposure of till of different provenance(s) than the till on the uplands.

- The distribution pattern of these sediments and boulders within corridors of meltwater channels reflects the drainage direction of the meltwater, not the ice-flow direction.
- Esker ridges are not necessarily associated with every meltwater corridor or channel. Areas of meltwater erosion may be identified by scarped slopes, scoured surfaces (including bedrock) as well as depositional features such as gravel dunes and transverse gravel ridges (Rampton, 2000).
- While these areas are generally unfavourable for till sampling, large esker systems are a good target for regional KIM sampling.

5) The stagnant-ice moraine present in the northeast Wollaston Lake area is less suitable for drift prospecting programs. There is generally a high proportion of distally derived material and, due to varying amounts of associated meltwater, deposits tend to contain less fines (*i.e.*, sandier and less silt) and are better sorted. The resulting sampling medium is less likely to reflect the local geology making it less suitable for drift prospecting. The partial removal of fines may result in a higher proportion of heavy minerals, which would not be identified in adjacent till that has not been modified.

7. Summary

The Quaternary geology of the northeast Wollaston Lake area is complex. Despite having been glaciated multiple times, today's landscape is primarily the result of ice advance and retreat during the Late Wisconsinan glacial event.

Figure 12 - A) Peat section as seen from offshore. Section is approximately 2 m thick (UTM 617546 m E, 6476633 m N). B) Close-up of another 2 m-thick peat section. Pushed boulders along the shore are the result of winter ice push (UTM 627524 m E, 6466298 m N). C) Fine- to medium-grained organics. Organics located above the ruler represent the base of the peat section, as sandy organic-rich material was collected in the bottom of the auger (UTM 617546 m E, 6476633 m N).

A slowly retreating ice margin that deposited ice blocks covered with subglacial debris formed the stagnant ice-contact moraine found in the northeast part of the study area. As the margin retreated, meltwater collected in the Wollaston Lake basin forming Glacial Lake Wollaston. During this time, raised beaches were formed as high as 420 m asl at least as far north as Gillies and Grant islands. The scarcity of these raised beaches suggests the glacial lake was short lived. The 420 m asl water level would have connected Glacial Lake Wollaston and Glacial Lake Reindeer forming a large proglacial lake that extended into Manitoba, which may represent a northwestern extension of Lake Agassiz. Subsequent opening of the Fond du Lac River and Cochrane River spillways to the north drained the lake of a large volume of water by 8,335 years ago (Schreiner, 1984a)

The presence of multiple, well-developed eskers is indicative of abundant meltwater produced during the downwasting of the retreating ice margin. The sharp erosional scarps on streamlined till landforms and plains, ice-contact glaciofluvial veneer, and well-developed boulder lags suggest that broad meltwater sheet flows played a significant role in the development of the landscape. The presence of similar terrain to the north in Cochrane River–Charcoal Lake area (Smith, 2006), north of Phelps Lake, northern Saskatchewan (Campbell, 2001b, 2002b), the Kasmere-Putahow lakes area (Matile, 2006) and Nejanilini Lake area (Anderson *et al.*, 2005), northwestern Manitoba, as well as in adjacent parts of the NWT (Rampton, 2000) indicate that the amount of meltwater released from the ice sheet was enormous and extensive.

8. Acknowledgments

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9. References

Alysworth, J.M. and Shilts, W.W. (1989): Glacial Features Around the Keewatin Ice Divide: Districts of the MacKenzie and Keewatin; Geol. Surv. Can., Pap. 88-24, 19p.

Anderson, S.D., Böhm, C.O., and Matile, G.L.D. (2005): Bedrock and surficial geological field investigations in the Nejanilini Lake area, northern Manitoba (parts of NTS 64P5, 12, 13); *in* Report of Activities 2005, Manitoba Industry, Development and Mines, Manitoba Geological Survey, p92-103.

Aspler, L.B. and Chiarenzelli, J.R. (1996): Stratigraphy, sedimentology and physical volcanology of the Henik Group, central Ennadai-Rankin greenstone belt, Northwest Territories, Canada: late Archean paleogeography of the Hearne Province and tectonic implications: Precamb. Resear., v77, p59-89.

Benn, D.I. and Evans, D.J.A. (1998): Glaciers and Glaciation; Arnold, London, 743p.

Campbell, J.E. (2001a): Phelps Lake Project: surficial geology of the Bonokoski Lake area (NTS 64M-11, -12, -13 and -14); 1: 100 000-scale map *with* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.2.

__________(2001b): Phelps Lake Project: highlights of Quaternary investigations in the Bonokoski Lake area (NTS 64M-11, -12, -13, and -14); *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.2, CD-ROM, p19-27.

__________ (2002a): Phelps Lake Project: surficial geology of the Keseechewun Lake area (NTS 64M-09, -10, -15, and -16); 1: 100 000-scale map *with* Summary of Investigations 2002, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2002-4.2.

__________ (2002b):Phelps Lake Project: highlights of Quaternary investigations in the Keseechewun Lake area (NTS 64M-09, -10, -15, and -16); *in* Summary of Investigations 2002, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2002-4.2, CD-ROM, Paper A-2, 16p.

__________ (2003a): Surficial geology of the Patterson Island area, Reindeer Lake (parts of NTS 64E/10 and /15); 1:50 000-scale prelim. map *with* Summary of Investigations 2003, Volume 2, Saskatchewan Geological Survey, Sask. Industry and Resources, Misc. Rep. 2003-4.2.

__________ (2003b): Quaternary investigations in the Patterson Island area (part of NTS 64E-10 and -15), Reindeer Lake, Eastern Peter Lake Domain; *in* Summary of Investigations 2003, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2003-4.2, CD-ROM, Paper A-7, 16p.

__________ (2004a): Surficial geology of the northwest Reindeer Lake area (parts 64E/15 and /16); 1:50 000-scale prelim. map *with* Summary of Investigations 2004, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2004-4.2.

__________ (2004b): Peter Lake Domain Project: Quaternary investigations in the Northwest Reindeer Lake area (parts of NTS 64E-15, and -16); *in* Summary of Investigations 2004, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2004-4.2, CD-ROM, Paper A-5, 19p.

__________ (2005): The presence of proglacial lakes in the Reindeer Lake area, northeastern Saskatchewan; *in* Water, Ice, Land, and Life: The Quaternary Interface, CANQUA2005 Conference, Winnipeg, Manitoba, June 5 to 8, Prog. Abstr., pA11.

__________ (2006): Quaternary investigations west of Fond-du-Lac, northeast Lake Athabasca (part of NTS 74OE-5, and -6), Fond-du-Lac Project; *in* Summary of Investigations 2006, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2006-4.2, CD-ROM, Paper A-2, 19p.

__________ (2007): Quaternary geology of the eastern Athabasca Basin, Saskatchewan; *in* Jefferson, C.W. and Delaney, G. (eds.), EXTECH IV: Geology and Uranium EXploration TECHnology of the Proterozoic Athabasca Basin, Saskatchewan and Alberta, Geol. Surv. Can., Bull. 588/Sask. Geol. Soc., Spec. Publ. 18/Geol. Assoc. Can., Spec. Publ. 4, p211-228.

Campbell, J. and Shives, R. (2000): Status report on the surficial geological framework for the NEA-IAEA study area, eastern Athabasca Basin; *in* Summary of Investigations 2000, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2000-4.2, p170-172.

Campbell, J.E., Shives, R.B.K., and Klassen, R.A. (2002): Integrated field investigations of airborne radiometric spectral domains, NEA-IAEA test area, eastern Athabasca Basin: a preliminary report; *in* Summary of Investigations 2002, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2002-4.2, CD-ROM, Paper D-13, 22p.

__________(2003): Field investigations of airborne gamma-ray spectral domain D, NEA–IAEA Test Area, eastern Athabasca Basin; *in* Summary of Investigations 2003, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2003-4.2, Paper D-2, 14p.

Christiansen, E.A. (1979): The Wisconsinan deglaciation of southern Saskatchewan and adjacent areas; Can. J. Earth Sci., v16, p913-938.

Dredge, L.A., Nixon, F.M., and Richardson, R.J. (1985): Surficial Geology, Northwestern Manitoba; Geol. Surv. Can., Map 1608A, 1:500 000 scale.

__________ (1986): Quaternary Geology and Geomorphology of Northwestern Manitoba; Geol. Surv. Can., Mem. 418, 38p and 1:500 000-scale map.

Dyke, A.S. (2004): An outline of North American deglaciation with emphasis on central and northern Canada; *in* Ehlers, J. and Gibbard, P.L. (eds.), Quaternary Glaciations – Extent and Chronology, Part III. Elsevier, Amsterdam, p273-424.

Dyke, A.S., Dredge, L.A., and Hodgson, D.A. (2005): North American Deglacial marine- and lake-limit surfaces; Géographie physique et Quaternaire, v59, n2-3, p155-185.

Dyke, A.S. and Dredge, L.A. (1989): Quaternary geology of the northwestern Canadian Shield; *in* Fulton, R.J. (ed.). Quaternary Geology of Canada and Greenland, Geology of Canada, No. 1, Geol. Surv. Can., p189-214.

Dyke, A.S. and Prest, V.K. (1987): Late Wisconsinan and Holocene Retreat of the Laurentide Ice Sheet; Geol. Surv. Can., Map 1702A, 1:5 000 000 scale.

Ford, K.L., Carson, J.M., Dumont, R., Potvin, J., Shives, R.B.K., Delaney, G., and Slimmon, W. (2005): Geophysical series - NTS 64L - Wollaston Lake, Saskatchewan; Geol. Surv. Can. Open File 4865, Sask. Industry Resources, Open File 2005-19, 10 sheets.

Geddes, R.S. (1982): The Vixen Lake indicator train, northern Saskatchewan; *in* Davenport, P.H. (ed.), Prospecting in Areas of Glaciated Terrain – 1982, Can. Inst. Min. Metal., p264-283.

Harper, C.T., Ebel, C., Yeo, G., Card, C., and Nelson, C. (2005): Wollaston Lake Project: geology of the Wollaston Supergroup in the Rabbabou Bay–Wellbelove Bay area, northeast Wollaston Lake, Saskatchewan (parts of NTS 64L-6, -7, -10, and -11); *in* Summary of Investigations 2005, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2005-4.2, CD-ROM, Paper A-6, 25p.

Johnston, W.G.Q. (1978): Lake Agassiz's northernmost arm and other Quaternary features in the region around the southern part of Reindeer Lake, northern Saskatchewan; Musk-Ox, n21, p39-40.

Kaszycki, C.A. (1989a): Surficial geology and drift prospecting, northwestern Manitoba; *in* Investigations by the Geological Survey of Canada in Manitoba and Saskatchewan during the 1984-1989 Mineral Development Agreements, Geol. Surv. Can., Open File 2133, p131-154.

__________(1989b): Surficial geology and till composition, northwestern Manitoba; Geol. Surv. Can., Open File 2118, 73p.

Kaszycki, C.A. and Way Nee, V.J. (comps.) (1990): Surficial Geology, Brochet, Manitoba; Geol. Surv. Can., Map 1760A, 1:250 000 scale.

Matile, G.L.D. (2006): Surficial geological investigations in the Kasmere-Putahow lakes area, northwestern Manitoba (parts of NTS 64N10, 11, 14, 15); *in* Report of Activities 2006, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p148-154.

Padbury, G.A. and Acton, D.F. (1994): Ecoregions of Saskatchewan; Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada, poster.

Peterson, T.D., Van Breemen, O., Sandeman, H., and Cosens, B. (2002): Proterozoic (1.85-1.75 Ga) igneous suites of the Western Churchill Province: granitoid and ultrapotassic magmatism in a reworked Archean hinterland; Precamb. Resear., v119, p73-100.

Prest, V.K. (1984): The Late Wisconsin glacier complex; *in* Fulton, P.J. (ed.), Quaternary Stratigraphy of Canada – A Canadian Contribution to the IGCP Project 24, Geol. Surv. Can., Pap. 84-10, p22-36 and Map 1584A, 1:5 000 000 scale.

Prest, V.K., Grant, D.R., and Rampton, V.N. (1968): Glacial Map of Canada; Geol. Surv. Can., Map 1253A, 1:5 000 000 scale.

Rampton, V.N. (2000): Large-scale effects of subglacial meltwater flow in the southern Slave Province, Northwest Territories, Canada: Can. J. Earth Sci., v37, p81-93.

Schreiner, B.T. (1983): Quaternary Geology of the NEA/IAEA Athabasca Test Area; *in* Cameron, Eion M. (ed.), Uranium Exploration in Athabasca Basin, Saskatchewan, Canada, Geol. Surv. Can., Pap. 82-11, p27-32.

__________ (1984a): Quaternary Geology of the Precambrian Shield, Saskatchewan; Sask. Energy Mines, Rep. 221, 106p and 1:100 000-scale map.

__________ (1984b): Quaternary geology of the Wollaston Lake area (64-L), Saskatchewan; Sask. Energy Mines, Open File Rep. 84-14, 1:250 000-scale map.

__________ (1984c): Quaternary geology of the Reindeer Lake north area 64-E, Saskatchewan; Sask. Energy Mines, Open File Rep. 84-10, 1:250 000-scale map.

Shaw, J. (1996): A Meltwater Model for Laurentide Subglacial Landscapes; *in* McCann, S.B. and Ford, D.C. (eds.), Geomorphology Sans Frontières, John Wiley & Sons Ltd., Chichester, p181-236.

Shaw, J., Kvill, D., and Rains, B. (1989): Drumlins and catastrophic subglacial floods; Sediment. Geol., v62, p177-202.

Smith, J.S. (2006): Northeast Wollaston Lake Project: Quaternary investigations of the Cochrane River (NTS map sheets 64L-10, -11, -14, and -15) and Charcoal Lake (NTS map sheets 64L-9, and -16) areas; *in* Summary of Investigations 2006, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2006-4.2, CD-ROM, Paper A-6, 15p.

Smith, J.S., Campbell, J.E., Card, C.D., Harper, C.T., Lesperance, J., and Barsi, N. (2006a): Surficial geology of the Cochrane River area, northeast Saskatchewan (NTS map sheet 64L/15 and parts of 10, 11, and 14); 1:50 000-scale preliminary map *with* Summary of Investigations 2006, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2006-4.2.

__________ (2006b): Surficial geology of the Cochrane River area, northeast Saskatchewan (NTS area 64L/15 and parts of 10, 11, and 14); 1:50 000-scale preliminary map *with* Summary of Investigations 2006, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2006-4.2.

Swanson, F.J. (1996): Reconnaissance sampling for diamond indicator minerals in the exposed Precambrian Shield, northeastern Saskatchewan (NTS 74H, I, and P and 64E, L, and M); *in* Summary of Investigations 1996, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 96-4, p95-101.

Teller, J.T. and Leverington, D.W. (2004): Glacial Lake Agassiz: a 500 yr history of change and its relationship to the δ^{18} O record of Greenland; Geol. Amer. Bull., v116, p729-742.

Teller, J.T., Thorleifson, L.H., Dredge, L.A., Hobbs, H.C., and Schreiner, B.T. (1983). Maximum extent and major features of Lake Agassiz; *in* Teller, J.T. and Clayton, L. (eds.), Glacial Lake Agassiz, Geol. Assoc. Can., Spec. Pap. 26, p43-48.

Wallis, R.H. (1971): The Geology of the Hidden Bay Area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 137, 74p.

Yeo, G.M. and Delaney, G.D. (2007): The Wollaston Supergroup, stratigraphy and metallogeny of a Paleoproterozoic Wilson Cycle in the Trans-Hudson Orogen, Saskatchewan; *in* Jefferson, C.W. and Delaney, G. (eds.), EXTECH IV: Geology and Uranium EXploration TECHnology of the Proterozoic Athabasca Basin, Saskatchewan and Alberta, Geol. Surv. Can., Bull. 588/Sask. Geol. Soc., Spec. Publ. 18/Geol. Assoc. Can., Spec. Publ. 4, p89-117.