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

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Abstract

Quaternary geological investigations were initiated in the Cochrane River–Charcoal Lake area (NTS map sheets 64L-9 -10, -11, -14, -15, and -16) as part of the multidisciplinary, multi-year Wollaston Lake Project. The Quaternary component involves 1:50 000-scale surficial geological mapping, collection of ice-flow indicators, and a regional till sampling program.

Drift cover is extensive and includes till, organics, and glaciofluvial terrains as the main surficial units. Glacial landforms include hummocky stagnant ice-contact drift, thick blankets and plains, streamlined forms, and boulder fields. Large esker systems extend over the entire map area. These features are attributed to a slowly retreating ice margin, at which there was an abundance of meltwater that flowed both in channels and occasionally as turbulent sheet flows.

Multiple ice-flow directions were documented; however, the ice-flow history remains preliminary as age relationships were only identified at five sites. The main regional ice flow was towards the south-southwest (207º). Initial flow ranged between the west-southwest to southwest (258º to 235º), and was followed by a southward (190º) flow before the main flow was established. Rare striae recording a south-southeast flow (163º) and a flow orientated west-northwest–south-southeast (295º to 115º) were also identified.

Keywords: *surficial geology, Quaternary geology, glacial history, till sampling, till geochemistry, drift prospecting, Charcoal Lake, Cochrane River, northern Saskatchewan.*

1. Introduction

Following an airborne geophysical survey in the summer of 2004 (Ford *et al*., 2005), the bedrock mapping component of the Wollaston Lake Project began during the summer of 2005. The main objective of this project was to update the geological and geophysical data sets east and northeast of the uranium-enriched eastern Athabasca Basin (Harper *et al*., 2005) and to provide an improved framework for assessing the area's mineral potential. During the 2006 field season, Quaternary geological investigations were initiated to the northeast of Wollaston Lake in the Cochrane River and Charcoal Lake areas to complement concurrent bedrock mapping.

Objectives of this summer's field work were threefold: 1) to complete surficial geological mapping in the Cochrane River–Charcoal Lake areas at a scale of 1:50 000, 2) to record the glacial history, and 3) to conduct a regional till sampling program.

2. Location and Access

The study area is located in the Wollaston Lake region of northern Saskatchewan, approximately 70 km from the village of Wollaston Lake and 80 km northeast of Points North Landing (Figure 1). It lies between 102º and 103º7'W and 58º41' and 59º00'N and includes all of 1:50 000 NTS map sheets 64L-15 and -16 as well as parts of NTS map sheets 64L-9, -10, -11, and -14. Due to the large area, the map has been divided at the boundary between NTS map sheets 64L-15 and -16, forming the Cochrane River (west half) sheet and the Charcoal Lake (east half) sheet.

The study area begins approximately 10 km downstream of where Cochrane River drains Wollaston Lake. The river flows north to northeast and provides entry into Bannock, Pikusikun, and Charcoal lakes. Access is generally limited to 2 to 4 km of the shoreline. Selected remote areas were reached by float plane.

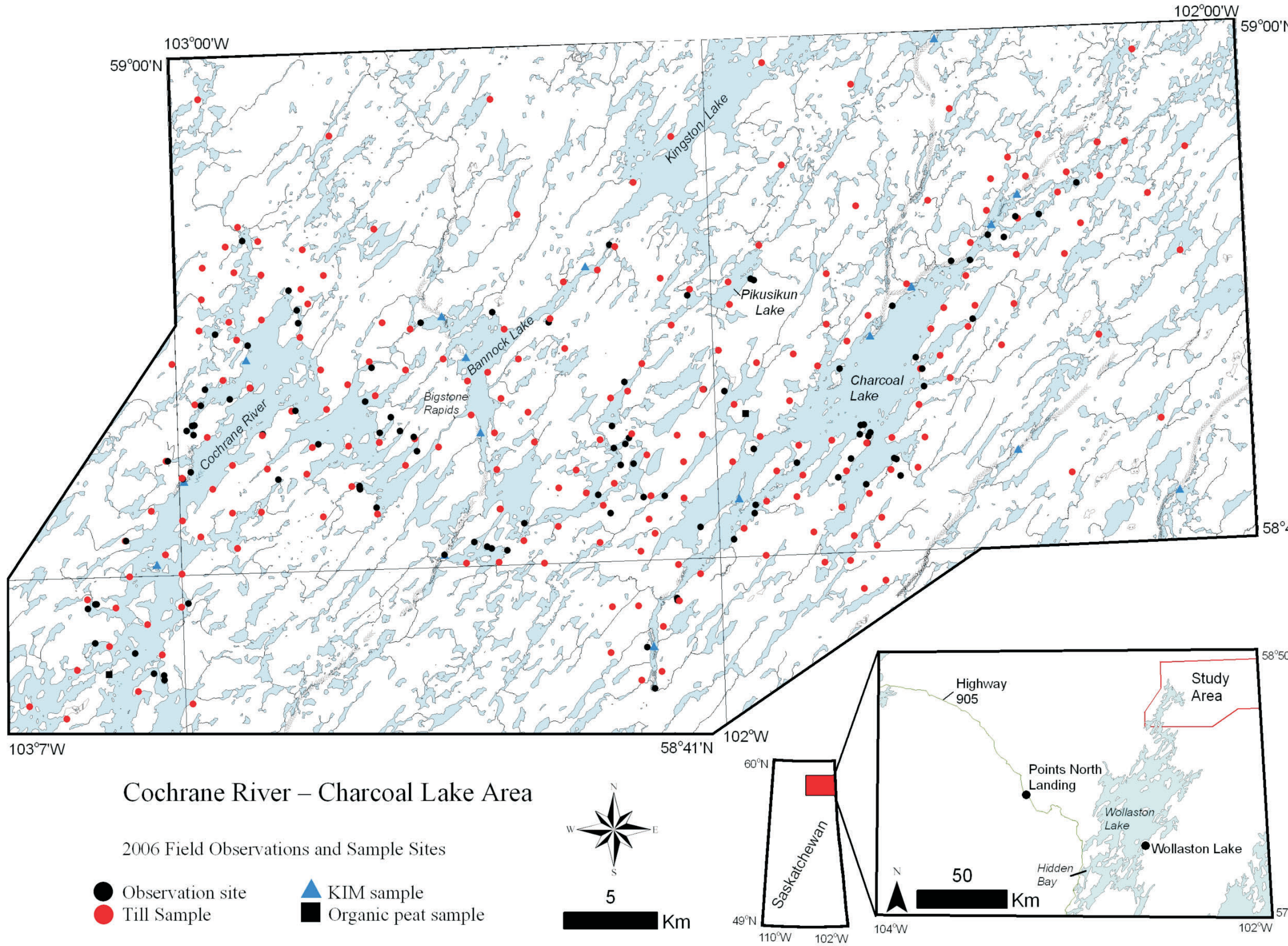

Figure 1 - Location of the Cochrane River–Charcoal Lake study area in northeastern Saskatchewan. Map identifies locations mentioned in the text as well as locations of observation and sample sites.

The Cochrane River 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 Cochrane River–Charcoal Lake area is part of the Selwyn upland (Padbury and Acton, 1994). This is an undulating surface composed of glacial deposits, bedrock ridges, wetlands, and lakes which lies within the Hudson Bay drainage basin. Thick glacial deposits have subdued the topography; however, the regional trend of bedrock ridges are apparent. The northeast-southwest orientation of these ridges typically coincides with the regional bedrock structure, which has been enhanced by glacial erosion. A maximum elevation of 486 m is located in the north surrounding Kingston Lake, however, most of the field area lies below 430 m. The upland slopes gently to the northeast. This change is most evident at Bigstone Rapids where water levels upstream of the rapids are at approximately 396 m and downstream they decrease to 379 m.

The Selwyn upland is within the Taiga Shield ecozone (Padbury and Acton, 1994), which forms an important transition zone where the boreal forest and arctic ecosystems meet. Forests are generally shorter and more open, consisting of black spruce and jack pine with a lichen understorey.

b) Bedrock Geology

The majority of the Cochrane River–Charcoal Lake area is within the northeast part of the Wollaston Domain. The extreme northwest corner of Cochrane River area lies within the Mudjatik Domain of the Hearne Province (see Figure 2 in Card *et al*., this volume). The field area contains two main packages of rocks: basement rocks of the Hearne Craton and supracrustal rocks of the Paleoproterozoic Wollaston Supergroup (Card *et al*., this volume). Basement rocks consist of tonalite, granite, charnokitic granite, and quartz diorite to granodiorite. The basement is commonly overlain by a graphitic pelite unit of the Wollaston Supergroup. Much of the Wollaston Supergroup consists of psammopelite to pelite containing garnet and cordierite (Card *et al*., this volume). A more detailed description of the region's bedrock geology including stratigraphy and structural aspects are discussed by Card *et al*. (this volume).

c) Glacial History

Many glaciations have influenced the landscape of northern Saskatchewan. However, it was the last, Late Wisconsin glaciation that was responsible for many of the features of the present landscape. Over 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). Ice had retreated on to the Precambrian Shield by about 10,000 years ago (Schreiner, 1984a; Dyke, 2004). During the retreat in the northeast part of the province, ice flow was toward the southwest (Schreiner, 1984a). The Cochrane River–Charcoal Lake study area was ice free 8,500 years ago (Dyke, 2004). Models depicting the pattern of deglaciation are discussed in Schreiner (1984a), Dyke and Prest (1987), Dyke and Dredge (1989), and Dyke (2004). As a result of this glaciation, glacial deposits cover approximately 80% of the study area. The majority of the sediment cover is a bouldery till that ranges from a veneer to a thick blanket/plain depending on the presence of bedrock. Large, typically southeast-trending esker systems are common and are usually in valley bottoms (Schreiner, 1984b).

4. Previous Work

The surficial deposits of the Wollaston Lake map sheet (NTS map sheet 64L) were mapped 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.

Geological investigators working in the northeast Wollaston area (Scott, 1972; Ray, 1978) have commented on various landforms, sediment types and glacial striae, however, no detailed Quaternary mapping projects have been undertaken. Detailed Quaternary mapping was completed both north and south of the Wollaston Lake map sheet (NTS map sheet 64L). Campbell (2001a, 2001b, 2002a, 2002b) mapped the northern half of NTS map sheet 64M at 1:100 000 scale and the northwest Reindeer Lake area (parts of NTS map sheets 64E-10, -15, and -16) at 1:50 000 scale (Campbell, 2003a, 2003b, 2004a, 2004b). In addition, surficial geological mapping, at a scale of 1:250 000 was completed east of NTS map sheet 64L in Manitoba by Dredge *et al*. (1985). In the southwest corner of the map sheet, Schreiner (1983) mapped the surficial sediments at 1:100 000 scale in the IAEA test area (part of NTS map sheets 64L-4 and -5; 74I-1 and -8) 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.

In northeastern Saskatchewan, Swanson (1996) conducted a regional reconnaissance sampling program of eskers for diamond indicator minerals. Only one sample (FS-95-28) however, was collected within the Cochrane River–Charcoal Lake study area. No silicate, chromite or gold grains were identified from that sample, 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 the Cochrane River–Charcoal 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 as a way of ground truthing 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).

Glacial ice-flow history was determined by measuring the orientation of striae, chattermarks, roches moutonées and large scale features such as drumlins. Typically, the median orientation of seven striae measurements was recorded at each site. Direction and relative age(s) of multiple directions were determined by stoss/lee relationships, cross-cutting 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 2070 km^2 was mapped this summer. Over 330 sites were visited by boat, traverse crews or float plane. Recently burned areas were more extensively field checked. Sample spacing ranged from one sample per 2 km^2 along lakeshore areas to one sample per 5 to 7 km^2 in floatplane accessible areas. Samples collected for geochemical analysis weighed approximately 1 kg and were placed in plastic bags. In addition, 9 to 10 kg bulk-till samples were collected at half of the sites (115 samples). Duplicate 1 kg and bulk samples were collected every 20 sample sites. Duplicate samples will be used as control samples for geochemical analyses. Samples were collected from hand-dug pits that had an average depth of 97 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 of the samples were collected near the bedrock-till interface. Despite some problematic sampling sites, more than 89.4% of samples were taken from the C horizon. Two hundred and seventeen till samples have been submitted to SRC Geoanalytical Laboratories for fine fraction (<63 µm) major and trace element geochemistry and textural analysis. Bulk samples analyses will be conducted at a later date.

Wetlands and organic deposits are common within the study area. At two lakeshore sites, thick peat sections were exposed. The bases of the peat sections were sampled using a handheld auger. Peat samples were placed in a plastic ziplock bag and kept cool to prevent bacterial growth until samples could be dried. The dried samples will be sent to Beta Analytical Inc. for radiocarbon analysis. The dates from the basal peats will provide a minimum date for ice margin retreat from the region.

KIMS were collected from 17 esker sites throughout the study area. Approximately 25 kg of sand-sized sediment was collected from 1 m deep hand-dug pits at the crest of the eskers. These samples will be analyzed at a later date.

a) Ice-flow Record

The extensive drift cover in the Cochrane River–Charcoal Lake area has decreased the potential for finding glacial striae. The majority of ice-flow indicators were identified along the shoreline and in areas were glacial drift was thin and interspersed with outcrop. In total, 131 measurements were recorded from 106 sites (Figure 2). The main ice-flow direction ranged between 200º and 215º, with an average direction toward 207º (south-southwest). This is similar to the range of 201º to 214º measured by Scott (1972). In addition to the main south-southwest direction (207º), southerly (190º), and southwesterly to west-southwesterly (220º to 258º) directions were also recorded throughout the study area with a variance of ±5º. A rare south-southeast (163º) direction was recorded preserved in the lee of the main direction (207º) in the eastern side of the field area. As well, a rare orientation of west-northwest–east-southeast (295º to 115º) was recorded along the western side of the field area. The southwest direction (220º) was not only recorded by striae, but was also the average direction of measured roches moutonées. Drumlins recorded south-southwesterly ice flow ranging from 193º to 207º.

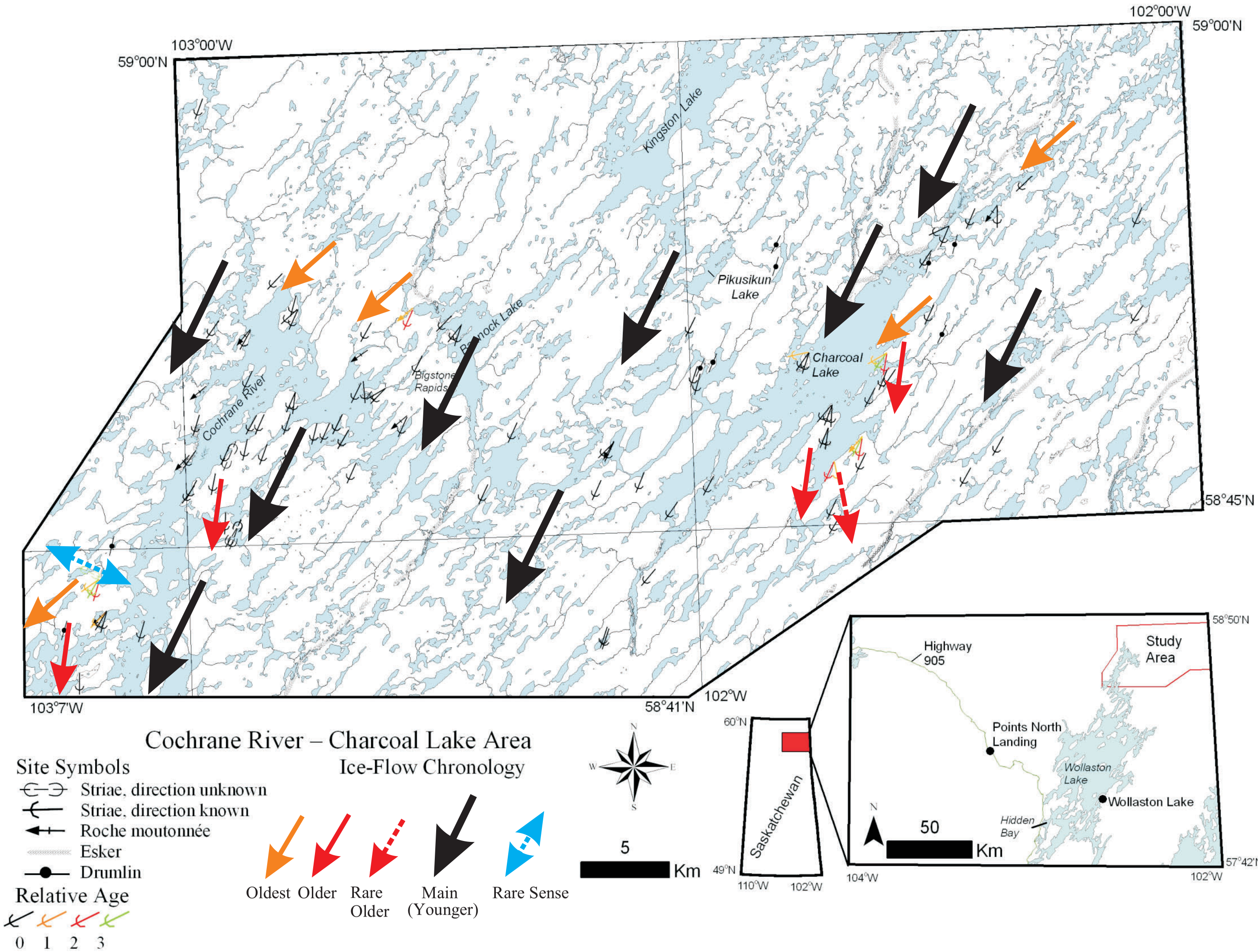

Figure 2 - Distribution and relationship of ice-flow indicators measured in the Cochrane River–Charcoal Lake study area. Ice-flow indicators at multiple directional sites are given relative ages with zero being unknown, one being the oldest and three being the youngest. Larger arrows denote the preliminary ice-flow history of the area. The main flow (207°) is marked by large black arrows while older flows are noted by smaller red and orange arrows. Rare ice flow events are denoted by dashed arrows. The age relationship between the main direction and the rare orientation 295° to 115° (blue doubled ended arrow) is unknown, it is therefore not given the youngest age designation.

Despite having 25 multiple directional sites, the age relationship could only be determined at five of them. The following is a very preliminary interpretation of the ice-flow chronology as it is based on limited field data.

The oldest ice-flow direction ranges from west-southwest to southwest, however the median direction was toward 235º. It was identified at three of the five sites. The southward ice-flow direction (190º) was also identified, at three of the sites, as being younger than the southwest flow (235º). The dominant south-southwest ice flow (207º) was recorded as the youngest flow at four of the five sites studied. The only occurrence of the south-southeast flow (163º) was determined to be older that the main south-southwest flow (207º). The rare west-northwest–east-southeast (295º to 115º) was determined to be younger than both the southwest flow (235º) and the southerly (190º) flow. No relationship was observed between the west-northwest–east-southeast (295º to 115º) flow and the main south-southwest flow (207º).

These observations about the ice-flow history are similar to those reported by Campbell (2001b, 2002b, 2003b, 2004b) and Dredge *et al*. (1986). In the Bonokoski and Keseechewun areas to the north, Campbell (2001b, 2002b) recorded a south-southwest (210º) ice-flow direction. Over two hundred kilometres to the south, in the northwest Reindeer Lake area, the same south-southwest (210º) ice flow was documented (Campbell, 2003b, 2004b). Older southwest (230º) and southward (190º) directions were also recorded in these regions (Campbell, 2001b, 2003b, 2004b). Campbell (2003b) has also recorded rare striae that have a west-northwest–east-southeast (295º to 115º) orientation in the Patterson Island, Reindeer Lake area. The relationship of this west-northwest–east-southeast (295º to 115º) flow with the main south-southwest (210º) is unknown. Both the northwesterly and south-southwest ice-flow directions were recorded further south at the southern end of Reindeer Lake by Johnston (1978), where age relationships suggested the northwesterly flow was older than the south-southwest ice-flow event.

To the east, Dredge *et al*. (1986) recorded south, south-southwest, and southwest ice-flow events. Cross-cutting relationships and the regional pattern of glacial landforms indicate that the southward-trending striae predated the south-westward trending striae (Dredge *et al*., 1986). This is consistent with the age relationship between the south (190º) flow and the main south-southwest (207º) flow documented in this study. Dredge *et al*. (1986) interpreted the south direction as the main ice-flow during the glacial maximum and the southwest flow and the main ice flow occurring during deglaciation.

b) Exotic Clasts

Exotic clasts were identified in both till and glaciofluvial sediments and are commonly pebble-size in glaciofluvial sediments and up to boulder size in till. Slightly altered blue-grey sandstones to argillite rocks and unaltered conglomerates as well as red felsic volcanic rocks were identified as being from the upper Hurwitz Group and Pitz Formation rhyolites of the Wharton Group volcanics, respectively (Harper, pers. comm., 2006; Figure 3). Sources of the Hurwitz Group sediments are to the northeast in Nunavut (Aspler, and Chiarenzelli, 1995). Sources for the Pitz Formation rhyolites are found to the north in the Baker Lake area, Nunavut (Peterson *et al*., 2002). Erratics of Pitz Formation rhyolites have been found in the Keseechewun Lake (Campbell, 2002b) and Points North Landing (Campbell *et al*., 2002) areas. Similar Hurwitz Group clasts have been found in the Keseechewun and northwest Reindeer Lakes 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 250 km in a northeast direction to 500 km in a northerly direction (Campbell, 2002b).

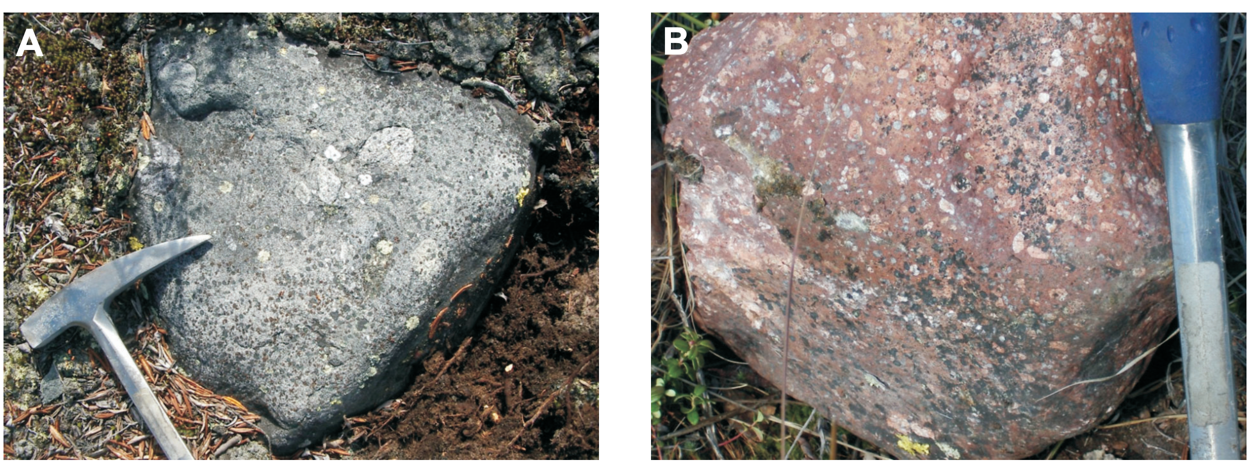

Figure 3 - Glacial erratics from Nunavut. A) Undeformed conglomerate of the Hurwitz Group; B) Red Pitz Formation rhyolite boulder, from the Wharton Group (photos courtesy of C.T. Harper).

c) Quaternary Geology

Aerial photographic interpretation and ground truthing identified extensive surficial deposits within the Cochrane River–Charcoal Lake area. The surficial material is dominated by till, organics, and glaciofluvial deposits, with rarer occurrences of boulder fields. These units are similar to those on Schreiner's (1984b) 1:250 000 scale surficial map of Wollaston Lake (NTS map sheet 64L). In the field, thickness of till is difficult to determine due to a lack of exposed sections. Based on limited drill hole data, the thickness of the overburden ranges from 2 to 41 m (Saskatchewan Industry and Resources assessment files 64L16-0005, 64L16-NW-0020, 64L15-003, and 64L15-004). Till deposits appear to be thick over much of the study area, except on topographic highs or within valleys that have been scoured by meltwater. Such areas are mantled by a thin till veneer. Organic deposits are common along the edges of ponds and lakes, and within topographic lows. Glaciofluvial sediments commonly form veneers and large esker systems in subglacial valleys.

Till

Till deposits include blankets, plains, stagnate ice moraine, veneers, and streamlined features. Despite the variation in morphological expression of the till, only one stratigraphic unit was identified. The till is generally massive, moderately compact, matrix supported, and poorly sorted. Clast content ranges between 10 and 40%, but is commonly around 20%. Within sample pits, clast sizes ranged from 0.02 to 0.6 m in diameter. Boulder-sized clasts were found within the upper 50 cm as well as on the surface, commonly creating an obstacle for obtaining good samples. In general, clast content was more cobble- to boulder-rich in the Charcoal Lake area and more pebble-rich towards the Cochrane River area (Figure 4A). The shape of clasts range from angular to subangular; however, subrounded clasts are not uncommon. Although local bedrock clasts predominate, exotic clasts are also present. Till surfaces are typically mantled with high concentrations of cobbles and boulders, which are more noticeable in

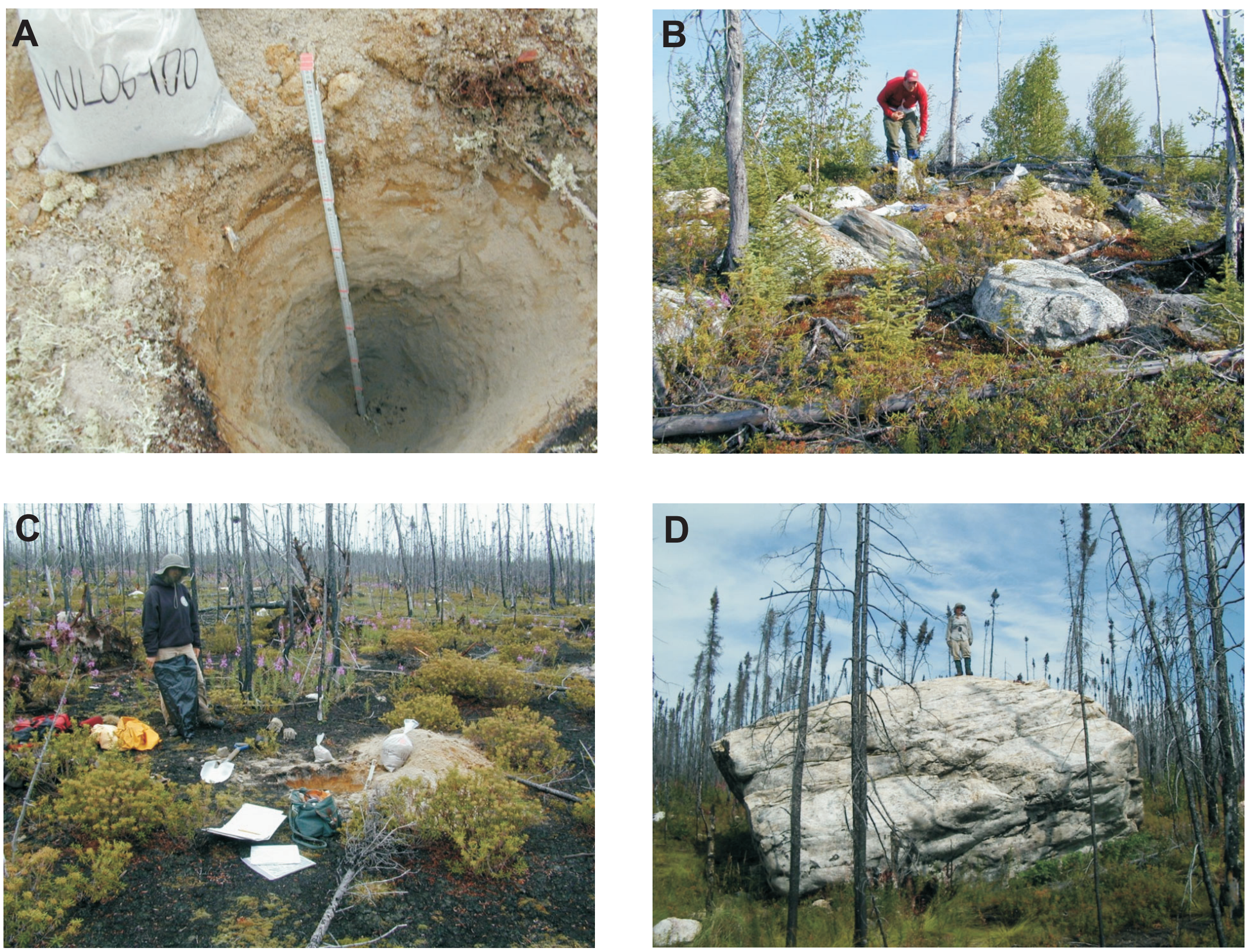

Figure 4 - Morphology and composition of till deposits. A) Grey, silt-rich, pebble till. Clast content is usually around 15% with clasts ranging from sub-angular to sub-rounded. B) Clast-rich bouldery till is associated with abundant clasts on the surface. C) In contrast to boulder-rich till, pebble till, generally have fewer clasts on the surface. D) In areas where till is classified as stagnant ice-contact moraine, boulders may be blocky and reach a size of 10 x 10 x 5 m (width x length x height).

burned areas (Figure 4B). There is a discernable decrease in the amount of surface boulders associated with the pebble-rich till (Figure 4C). Boulders commonly range from 1 to 2 m in diameter, however, larger blocks exceeding 5 m in diameter are present (Figure 4D). These huge boulders are typically angular to very angular and of the same composition as local bedrock, suggesting short glacial transport distances. The matrix of the till ranges from grey silt to grey fine- to medium-grained sand. Four till facies were identified based on matrix grain size: 1) silty sand, 2) sandy, 3) sandy silt, and 4) silty. Over 78% of the tills examined had a silty sand or sandy matrix. There are no obvious trends in the spatial distribution of these four till facies.

Boulder Fields

The location and distribution of boulder fields are hard to assess from aerial photographs and on the ground. They are easily recognizable from a float plane however, and are common in low-lying areas, along the edges of small lakes and streams, and at the base of slopes between streamlined forms and till plains (Figure 5A). The boulder fields that were field checked were clast-supported, composed of angular to sub-angular boulders ranging in size from 0.5 to 2 m in diameter. Most boulder fields were composed predominantly of a single locally derived lithology, however exotic clasts were present occasionally (Figure 5B). Individual boulder fields ranged from 10 to 1000 m^2 and thus, were commonly too small to map at a scale of 1:50 000.

Geomorphic Features Developed in Till

The majority of till is stagnant ice-contact moraine: eroded till, streamlined forms, and minor ridged moraine are less prevalent. Stagnant ice-contact moraine comprises approximately 50% of the till consisting of rounded mounds of sediment that form steep-sided hummocks with an undulating surface (Figure 6A). Hummocks range from 2 to 5 m in height, with diameters up to tens of meters (Figure 6B). The surfaces of the hummocks are typically covered with sub-angular to angular clasts ranging in size from 0.1 to 1 m in diameter. Other common features within the stagnant ice-contact moraine include scarps, kettles, and boulder lags. Stagnate ice-contact moraine also forms a veneer over other till morphologies.

Stagnant ice-contact moraine is formed when ice blocks detach from the retreating ice margin and become buried (Benn and Evans, 1998). A high proportion of stagnant ice-moraine suggests that the ice sheet retreated slowly and underwent a prolonged period of downwasting.

The term 'eroded till' has been used to describe low-lying areas that have been uniformly eroded leaving large steep-sided 'uplands' and 'islands' of till. The low-lying areas are generally composed of a 30 to 40 cm thick veneer of clast-rich material containing little to no fines, which overlies undisturbed till. This eroded till is commonly overlain by organic deposits. The adjacent till 'islands' and 'uplands' commonly have steep, sculpted, boulder-covered slopes, and are often flat topped. Boulder lags are common between till 'uplands' and 'islands' as well as along shorelines and in low-lying areas. The areas of eroded till and overlying organic deposits surrounding till 'islands' or 'uplands' are most noticeable along the Cochrane River where they form 50 to 120 m wide spans from the shoreline to the slope of the till 'uplands' and 'islands' (Figure 7).

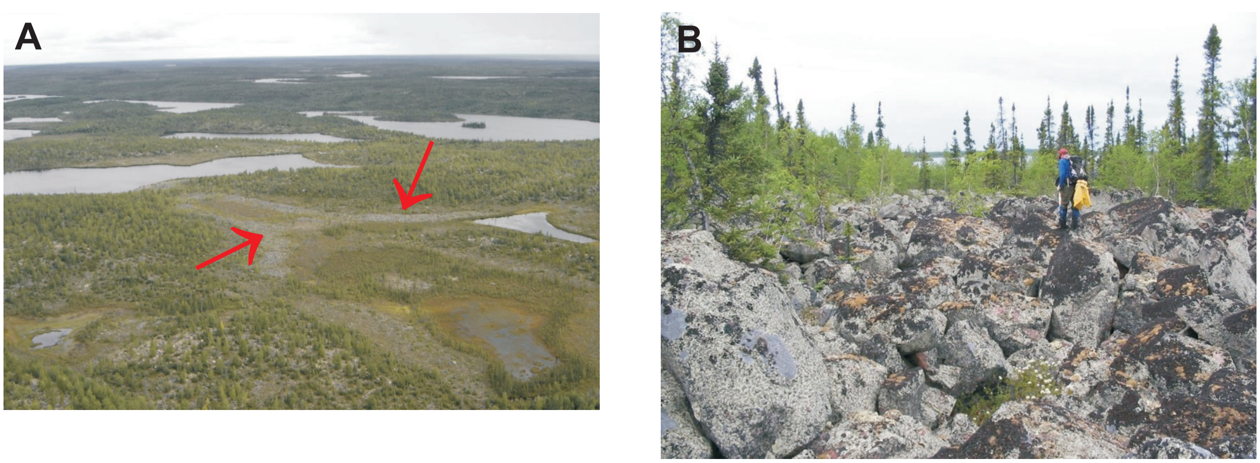

Figure 5 - Boulder fields as seen from the air and ground. A) High concentrations of boulders (arrowed) are found at the base of sculpted slopes of till plains and adjacent to organic deposits. B) On the ground, boulder fields are clast supported, free of matrix, and consist of large angular to sub-angular monolithologic clasts.

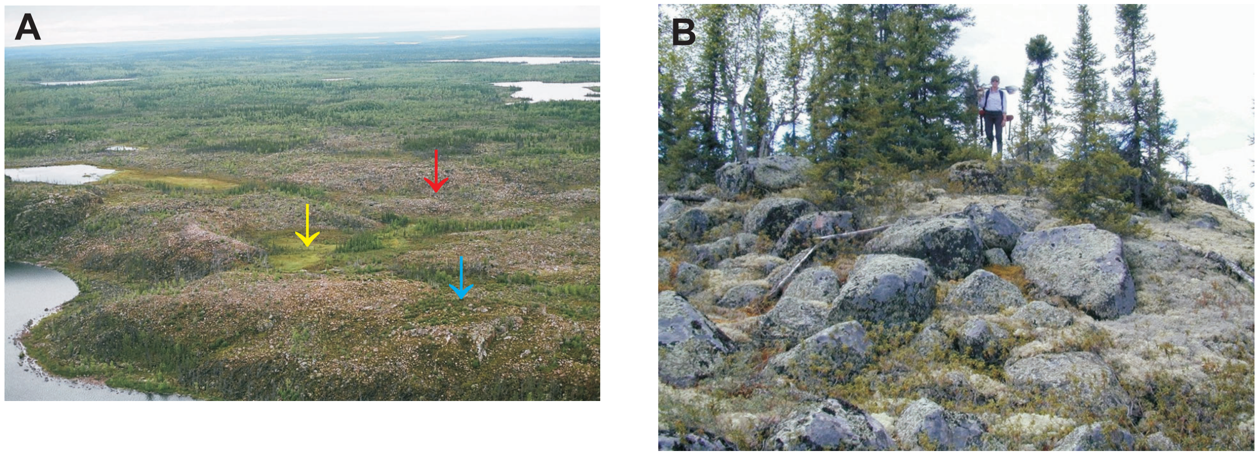

Figure 6 - Stagnant ice-contact moraine as see from the air and ground. A) Stagnant ice-contact moraine is generally associated with a high concentration of boulders. It usually forms hummocks (red arrow) that may be surrounded by organics (yellow arrow) and a veneer over bedrock (blue arrow). B) Boulder covered hummock on ground. Note the angularity of the clasts.

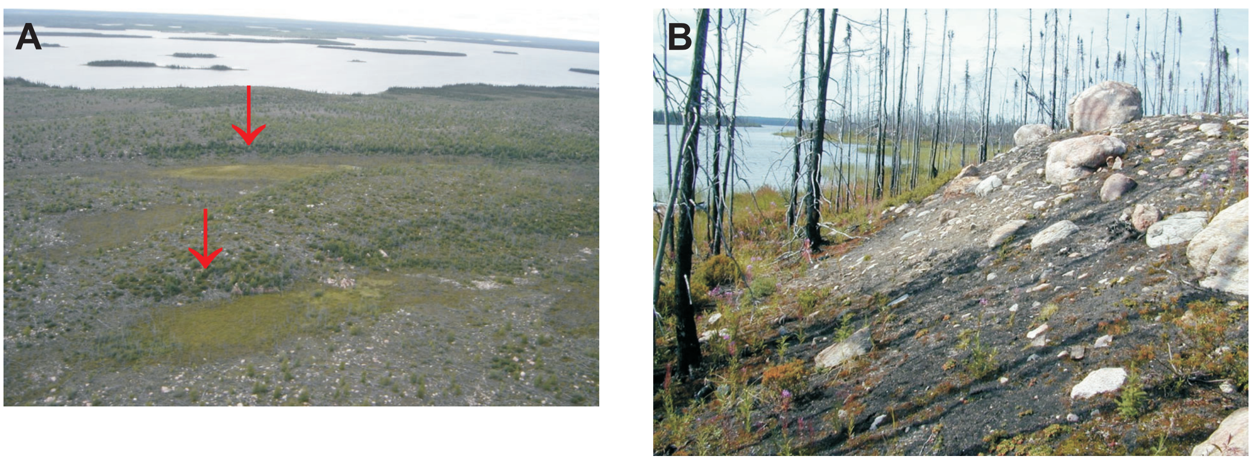

Figure 7 - Eroded slopes of till deposits from the air (A) and from the ground (B).

A preliminary interpretation for the formation of this terrain involves broad meltwater sheet flow eroding through a thick till plain and leaving steep, sculpted slopes on till 'uplands' and 'islands'. The removal of such vast amounts of fine material would form boulder lags in the low-lying areas at the base of these slopes. The number of large esker systems indicates that high volumes of meltwater were present, and thus supports this hypothesis. Large meltwater corridors and associated boulder lags and sculpted slopes were described by Rampton (2002) in the Slave Province, NWT, and by Campbell (2001b, 2002b) in the north Phelps Lake and Reindeer Lake (Campbell 2003b, 2004b) areas. Further work is needed in order to test this hypothesis.

Streamlined forms consist primarily of drumlinoid features. Their morphology is variable; some have the classic drumlin shape, whereas others have flat tops. They have steep, sculpted sides and bouldery surfaces, although boulders are typically concentrated in the low-lying areas between these forms. The drumlins are 360 to 650 m long, 155 to 200 m wide, and 10 to 20 m high. A few of the streamlined forms were composed of boulder-rich till. Detailed stratigraphic and compositional work is required to determine if the drumlinoid features in the Cochrane River–Charcoal Lake area formed as a result of subglacial ice processes or meltwater erosion.

Recessional ridged moraine makes up less than 5% of the till unit. It typically occurs as a single ridge or series of ridges. These ridges are commonly 400 to 500 m long and 100 to 200 m wide and are less than 10 m high. They are commonly associated with stagnant ice-contact moraine. Their spatial distribution will be analyzed to determine if they form a regional ice margin.

Glaciofluvial Deposits

Glaciofluvial deposits represent approximately 20% of the surficial deposits. They are generally associated with ice-contact deposits including esker complexes, subglacial channels, and stagnant-ice moraine.

Glaciofluvial sediments associated with subglacial channels and stagnant-ice moraine are discontinuous and commonly overlie, or are adjacent to, till deposits. Glaciofluvial sediments typically form a veneer up to 40 cm thick (Figure 8), comprising fine- to coarse-grained, massive brown sand that is matrix supported, loosely compact, and variably sorted. Approximately 40% of sites contain no clasts, whereas the remainder have a clast content ranging from 15 to 40%. Clasts range from pebble- to cobble-size and from angular to sub-rounded in shape. Surface boulders are not uncommon and, in places, form a completely armoured surface.

Eskers and Subglacial Channels

Within the study area, both small eskers and large esker systems were identified. Small eskers have a subtle expression on the landscape, forming single discrete ridges 0.5 to 3 km long, 5 m high, that are typically less than 10 m wide. They are commonly sharp crested with abundant cobbles and boulders on the surface. These small eskers are not confined to valleys and generally conform to the underlying topography.

Four large esker systems were identified: three in the Charcoal Lake area (NTS map sheets 64L-9 and -16) and one in the Cochrane River area (NTS map sheets 64L-10 and -15). Those in the Charcoal Lake area are approximately 8 to 10 km apart, relatively straight, and trend southwest. The two eskers found in the southeast corner of the Charcoal Lake map area are in shallow valleys associated with a system of elongate lakes that also trend southwest. In the Cochrane River area, northwest of Bannock Lake, the esker trends south; along Bannock Lake it trends southeast, changing to southwest further south. These changes reflect changes in the trends of structures in the underlying bedrock.

All four eskers are discontinuous, with segments ranging from 8 to 35 km long. Despite being discontinuous, they can be traced further north in Saskatchewan, as well as, to the northeast into Manitoba and Nunavut. These eskers 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 clasts in the eskers from the Hurwitz and Wharton Groups in Nunavut.

Figure 8 - Morphology and composition of glaciofluvial veneer. A) A veneer, 30 cm thick, of fine to coarse sand overlying grey till. Note the concentration of granules at the contact between the sand and the till. The contact (arrowed) is irregular and erosive in nature. B) Site of glaciofluvial veneer. Note the flatness and the lack of large clasts.

The morphology of these eskers is quite variable. They commonly have steep sides and crests, but may also contain segments that are flat topped. Heights range from 10 to 20 m and widths from tens of meters to hundreds of meters. The widest parts of the esker system are where secondary channels merged, the main channel bifurcated, or where small outwash plains formed.

The composition of sediments associated with esker complexes is also quite variable, commonly changing multiple times over the length of a single esker. They are typically brown in colour, loosely compact, and variably sorted. Of the seventeen samples taken from esker deposits, there were equal numbers of sandy matrix and sandy to granule gravel, with one granule gravel matrix containing no fines. Clast content was also variable with slightly more than half of the samples having a clast content of less than 15%, with the remaining samples composed of 35 to 50% clasts. Clasts range from sub-rounded to sub-angular, and contain a greater proportion of exotic clasts than in any of the other sediment types in the area. Harper (pers. comm., 2006) identified clasts of sedimentary rocks of the upper Hurwitz Group and volcanic rocks from the Wharton Group. The concentration of boulders on the surface of eskers was typically low; however, at several sites, both the slopes and tops are armoured with cobbles and boulders (Figure 9).

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 have typically followed pre-existing valleys. Boundaries between eskers and adjacent glacial deposits are sharp and 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 that the presence of gravel dunes, transverse gravel ridges, and scoured bedrock are also indicative of meltwater channels. A number of narrow channels have been identified through airphoto 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 float plane.

The aerial extent and relationship of these narrow channels and corridors to larger subglacial esker systems is not yet known. Similar large esker systems, subglacial channels and corridors, and areas of meltwater erosion were noted in the Bonokoski Lake area to the north (Campbell, 2001b). The presence of large esker systems and subglacial channels indicate that meltwater played a large role in sculpting the landscape in northern eastern Saskatchewan.

Organic Deposits

Organic deposits, including bogs and fens, are commonly found bordering lakes and streams in areas below 390 m elevation. They are found in surface depressions, valleys, or between outcrops of bedrock, till and drumlins where drainage is poor, and are locally flanked by boulder fields (Figure 5A). Flat to gently sloping, thicker deposits mask the underlying morphology forming plains or blankets. These areas are locally dotted with rounded depressions that are interpreted to be thermokarst features, which develop in areas of melting permafrost. Other features associated with these deposits include lineations and poorly developed solifluction lobes, which are easily identified on the airphotos, but are very subtle and inconspicuous on the ground.

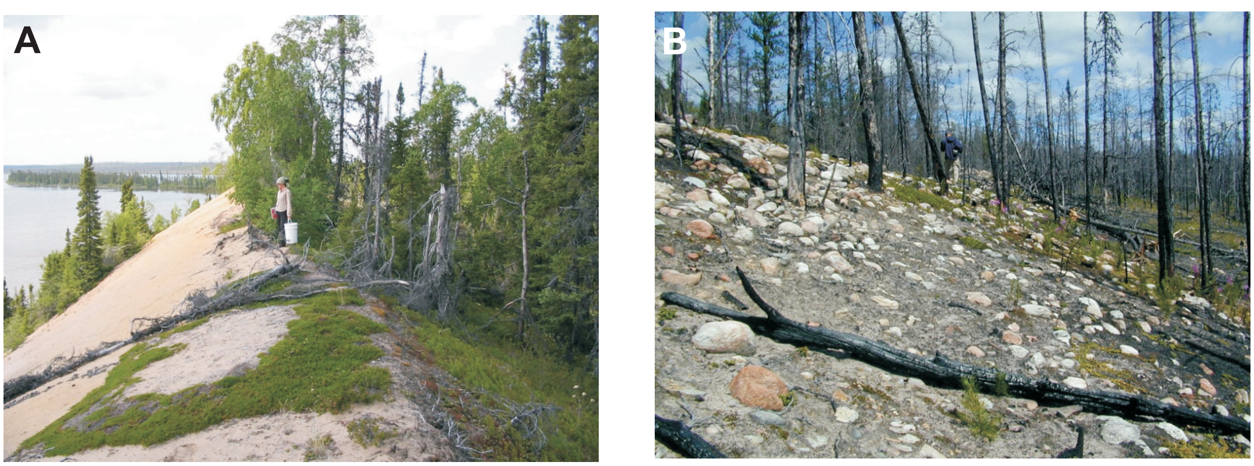

Figure 9 - Morphology and composition of esker systems. A) Sharp crested sandy esker on the west side of Charcoal Lake. Note the lack of clasts on the surface. Matrix is fine to coarse sand with less than 1% clasts. B) Armoured surface of large esker south of Bannock Lake. Note the high concentration of sub-rounded to rounded clasts.

The thickness of organic deposits in three exposures studied range from 2 to 4 m (Figure 10A). In all of these locations, the peat is believed to overlie till. Generally, the peat is fine to medium textured, although some coarse peat with preserved woody fragments was also observed (Figure 10B).Woody fragments extracted from just above the peat/till interface in the exposure on the western side of Charcoal Lake will be radiocarbon dated to provide a minimum date for ice-free conditions in this area.

d) Implications for Drift Prospecting

Although till geochemical, textural, and indicator mineral analyses are not yet available, some preliminary comments can be made with respect to drift prospecting in the Cochrane River–Charcoal Lake area.

1) The Cochrane River–Charcoal Lake area has a complex ice-flow history, reflecting a number of glaciations and fluctuations in ice flow during the last glacial advance and retreat. Therefore, care must be taken when inferring the direction of mineralized dispersal trains.
2) Areas of thin veneer with local boulders are more favourable for conducting drift prospecting studies as the till was likely deposited by the last ice-flow event. 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) Areas of meltwater erosion, *i.e.*, meltwater channels and corridors, have significant impact for exploration and, as a result, the role of meltwater must be taken into account when interpreting till geochemical surveys. The following are important points to keep in mind when drift prospecting in these areas:
   - Bedrock outcrops are often associated with corridors of meltwater erosion.
   - 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. This may include reworked surface sediments in which the fine fraction has been redistributed. It is therefore important when sampling tills in areas of meltwater erosion that the sample is taken below the reworked horizon from undisturbed till. The reworking and/or truncation of the upper till surfaces may result in the exposure of till of different provenances.
   - The distribution pattern of these sediments 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, 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.
4) A large proportion of the Cochrane River–Charcoal Lake area has been mapped as being composed of stagnant ice-contact moraine. This type of sediment is less suitable for drift prospecting programs as there is often a high proportion of distally derived material and due to varying amounts of associated meltwater, sediments tend to contain less fines (*i.e.*, sandier, less silt) and be better sorted.

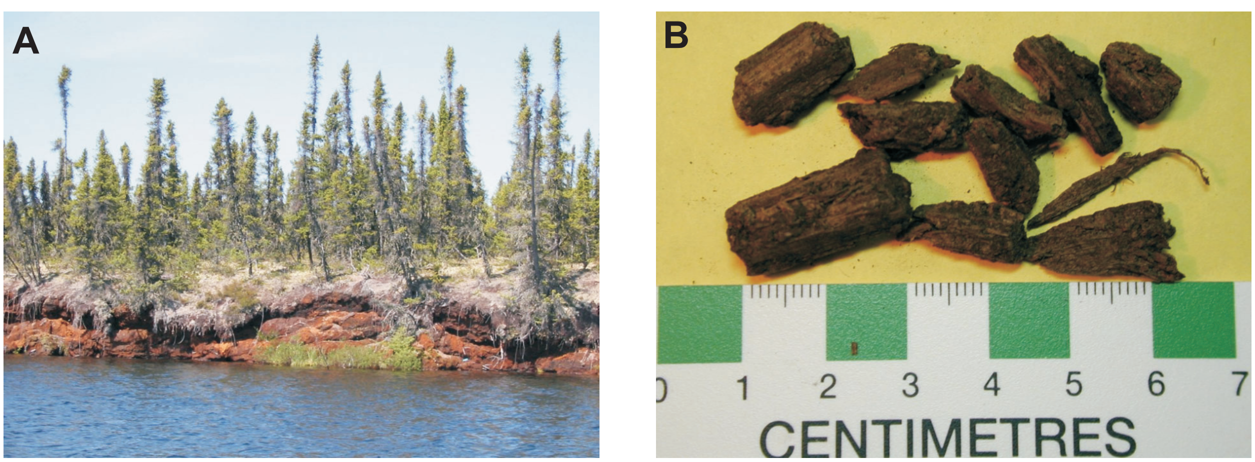

Figure 10 - A) Thick peat section (2 m) overlying till, located along the west side of Charcoal Lake. Sections identified within the study area can be up to 4 m thick. B) Peat contains wood, charcoal, and macrofossils.

6. Summary

The Quaternary geology of the Cochrane River–Charcoal Lake area is complex. Despite having been glaciated multiple times, the landscape seen today is a result of deglaciation and ice retreat during the Late Wisconsinan glaciation. A slowly retreating ice margin that deposited ice blocks covered with subglacial debris formed the stagnant ice-contact moraine. A well developed system of eskers is indicative of abundant meltwater produced during downwasting of the ice margin. The sharp erosional scarps on streamlined forms and till plains, with associated exposed bedrock and well developed boulders lags, suggest that broad turbulent meltwater sheet flows also played a significant role in the development of this landscape. The presence of this type of terrain north of Phelps Lake, northern Saskatchewan (Campbell, 2001b, 2002b) as well in adjacent parts of the NWT (Rampton, 2000) indicate that a phenomenal amount of meltwater was released from the ice sheet and affected a huge area.

7. Future Work

Further insight into the glacial history of northeastern Saskatchewan, will be gained by completing the following:

1) An interpretation of textural, chemical, and lithological data.
2) Additional aerial photograph interpretation focusing on:
   - The spatial distribution of ridged moraine in order to determine if these features are a part of a regional ice marginal moraine.
   - Identifying erosional features that characterize meltwater flow in the Cochrane River–Charcoal Lake area.
3) Determining the relationships between areas of meltwater erosion to the north and south of the field area.
4) Further analysis of the preliminary ice-flow history including additional field research. This is warranted in order to better understand the relationships between each of the ice-flow events and how this history corresponds with the regional ice-flow history.

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