Ice-Flow History, Drift Thickness and Drift Prospecting for a Portion of the QUEST Project Area, Central British Columbia (NTS 093G, H [west half], J)

B. Ward, Department of Earth Sciences, Simon Fraser University, Burnaby, BC, bcward@sfu.ca

D. Maynard, Denny Maynard & Associates Ltd., North Vancouver, BC

M. Geertsema, British Columbia Ministry of Forests, Northern Interior Forest Region, Prince George, BC

T. Rabb, Department of Earth Sciences, Simon Fraser University, Burnaby, BC

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Introduction

Central British Columbia has areas of highly prospective bedrock geology but mineral exploration has been limited due to the thick cover of surficial deposits. To help spur economic growth in this region, which has been severely affected by the mountain pine beetle, the federal and provincial governments are funding geological projects such as QUEST. Significant knowledge gaps exist in the glacial history of the QUEST Project area and thus pose a significant hindrance to mineral exploration. Knowledge of the glacial history, specifically the ice-flow history and dominant transport direction, is vital to interpret data from geochemical surveys of the area. This project is designed to address this knowledge gap by providing a Quaternary framework along with both regional and detailed till geochemical surveys. The study area comprises NTS map sheets 093G, H (west half) and J (Figure 1).

This ambitious project will occur over three years and provide

1) the regional glacial geological framework for map areas NTS 093G, H (west half) and J (i.e., the central portion of the QUEST area);
2) a map of approximate drift cover for areas within NTS 093 G, H (west half) and J based on existing surficial geology, soils and landform mapping augmented with reconnaissance field observations;
3) terrain mapping of six 1:50 000 scale sheets (NTS 093J/05, /06, /11, /12, /13, /14);
4) till geochemical data (inductively coupled plasma mass spectrometry [ICP-MS] with aqua regia digestion and instrumental neutron activation analysis [INAA] for trace, minor and major elements), gold grain counts and heavy mineral separates for samples collected within these new sheets; and
5) detailed geochemical surveys down-ice of two geophysical anomalies (interpreted from geophysical data [Barnett and Kowalczyk, 2008]).

This work will help to stimulate mineral exploration in beetle-kill–affected areas by releasing new surficial geology and geochemical survey data and providing a framework for companies to interpret their own datasets. This project will also provide invaluable training for at least two graduate students and numerous undergraduate students.

Fieldwork occurred in late June and early July 2008. The initial two weeks concentrated on collecting striation data for the ice-flow history and checking the validity of existing soil and landform and surficial geology mapping to be used for drift thickness mapping. The second half of the fieldwork season concentrated on till geochemistry sampling in areas down-ice from two geophysical anomalies. The results of the first field season are given below.

Study Area and Physiography

The study area occurs in the heart of the QUEST project area (Figure 1). The majority of this area lies in the relatively low relief area of the Interior Plateau (Mathews, 1986), including its subdivisions, the Fraser Basin and Nechako Plateau. It is characterized by glacial lake deposits, drumlinized drift and glaciofluvial outwash and esker deposits (Holland, 1976).

Regional Quaternary History

The Cordilleran Ice Sheet has repeatedly covered BC and portions of Yukon, Alaska and Washington over the last two million years (Armstrong et al., 1965; Clague, 1989). Growth of the Cordilleran Ice Sheet is thought to have followed four phases as defined by Davis and Mathews (1944): alpine phase, intense alpine phase, mountain ice

Keywords: *ice-flow history, drift prospecting, geochemical survey, terrain mapping, drift thickness, striations, heavy minerals*

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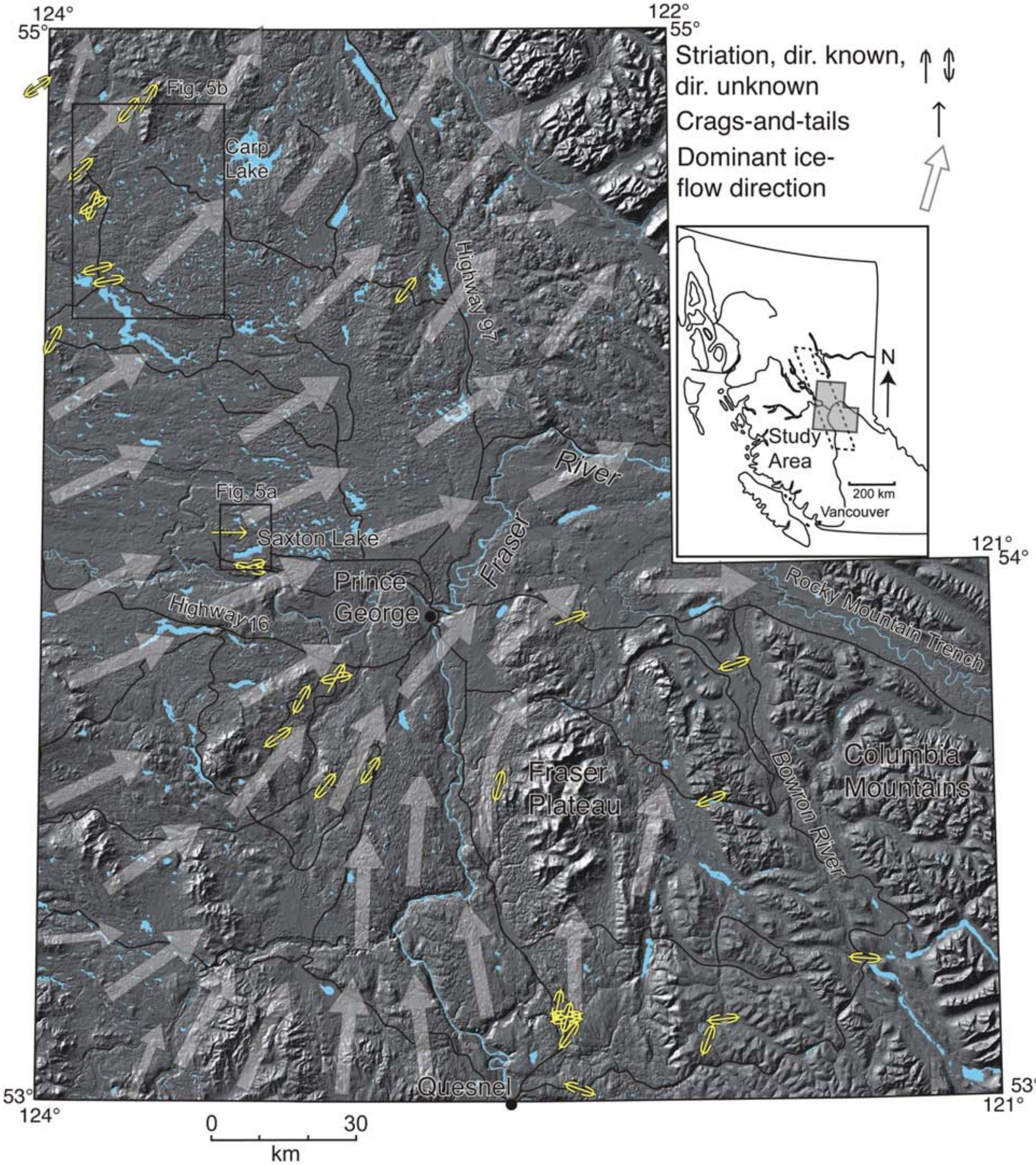

Figure 1. Digital elevation model of the study area with ice flow information. Drumlinized drift is evident throughout most of the study area. Striation data is from field observations in summer 2008. Some striation sites were simplified to avoid cluttering. Inset map indicates the location of the study area (shaded area) in relation to British Columbia and the QUEST Project geophysical survey area (dashed line). D. Turner (Simon Fraser University) compiled the digital elevation model. Abbreviation: dir, direction.

sheet phase and continental ice sheet phase (Fulton, 1991; Figure 2). In short, ice originated in alpine areas as valley glaciers. Over time, these valley glaciers extended out from mountain fronts as piedmont glaciers and eventually grew into mountain ice sheets. Eventually, the ice sheet would have grown into a continental ice sheet. Throughout this sequence, topography has less and less control over ice flow, until the continental ice sheet phase when ice flows independent of topography. At its maximum extent, the Cordilleran Ice Sheet was up to 900 km wide and up to 2000–3000 m thick over much of the Interior Plateau, closely resembling the present-day Greenland Ice Sheet.

During the Late Wisconsinan, the last glaciation to affect BC, ice was advancing out of the Coast Mountains by 28 000 BP. In the study area, it is unclear how extensive the

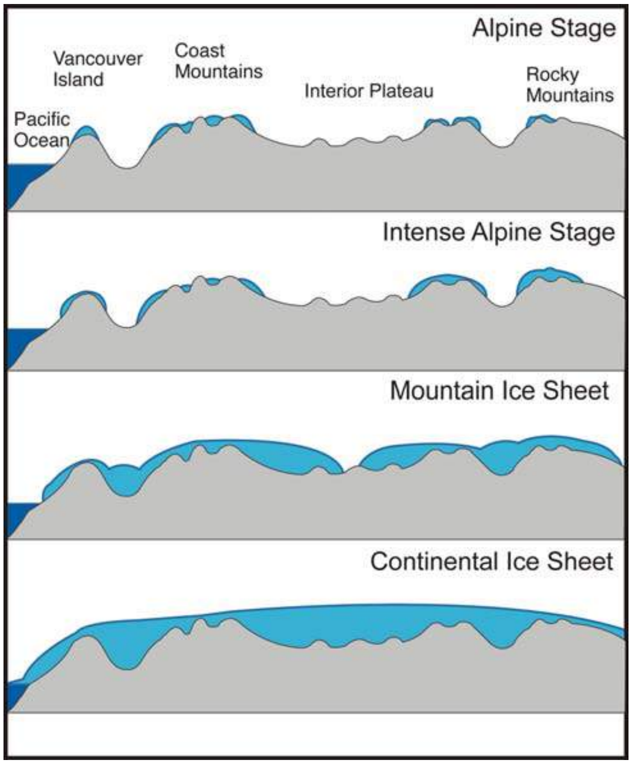

Figure 2. Hypothesized sequence of ice growth for the Cordilleran Ice Sheet (*modified after* Fulton, 1991).

glaciers in the cirques of the Caribou Mountains were. Paleoenvironmental reconstructions from this time indicate conditions were very arid, not conducive to growing large local glaciers (Ward et al., 2005). However, it is clear that a large glacial lake existed in the Bowron Valley indicating that ice in the Rocky Mountain Trench blocked the mouth before local ice extended out of the valley. Radiocarbon ages indicate that ice covered the Bowron Valley sometime after 20 000 BP. Maximum extent also occurred after this but there is no chronological control. Evidence that the Cordilleran Ice Sheet attained continental ice sheet status is provided in a study by Stumpf et al. (2000), which shows that the ice divide shifted eastward from the Coast Mountains to over the Interior Plateau, just to the west of the study area.

In contrast, deglaciation was characterized by downwasting, followed by widespread stagnation throughout much of the interior (Fulton, 1967); the ice sheet melted from the top down. It appears that the equilibrium line either rose very close to or above the top of the glacier. Initially, regional ice flow continued but was less vigorous. As uplands became exposed, significant flow was restricted to valleys. Eventually, as the ice sheet continued to thin, ice tongues in the valleys became stagnant and ceased to move. This style of deglaciation is characterized by flights of lake levels starting in the highest valleys and ending in the lowest valleys. This is caused by the highest elevations becoming ice-free first and lakes being ponded by ice in the lower valleys. It is also characterized by extensive ice stagnation topography (e.g., hummocky or kame-and-kettle topography and the presence of eskers). Deglacial lakes dammed by ice in the larger valleys are common in the Bowron Valley and on the east side of the Rocky Mountain Trench. The last lake in the area, Glacial Lake Fraser, occupied the Fraser River valley.

Results

Ice Flow

The ice-flow history of the study area was determined by compiling ice-flow information from existing maps (Tipper, 1971; Clague, 1998a, b; Blais-Stevens and Clague, 2007) and combining it with observations made in the field. The ice-flow indicators on the pre-existing maps generally consist of macroforms such as drumlins, flutings, crags-and-tails and streamlined bedrock ridges. Drumlins generally comprise thick (>3 m), ridged till (Figure 3a) that is commonly described as an inverted teaspoon shape. These ridges are oriented parallel to ice flow and are asymmetric in long profile, with a steeper up-ice side and a gentler down-ice side. Flutings are more elongate till ridges, without the asymmetric long profile. Crags-and-tails have an up-ice outcrop of glacially smoothed, resistant bedrock and a down-ice tail of till (Figure 3b). Streamlined bedrock ridges are similar in shape to flutings. Drumlins are common throughout the study area and were not measured in the field as they are evident on digital elevation models (DEM; Figure 1), topographic maps and Google™ Earth images.

Ice-flow indicators measured in the field were mainly microflow indicators, such as grooves, striations and rat tails. Striations and grooves are glacial erosion features that form by debris in the base of the ice being dragged along the bedrock surface (Figure 3c, e, f). They are usually considered to be bidirectional, meaning that a flow direction is not evident from examination of the striation or groove itself, however, examination of the outcrop upon which the striations are measured can give a sense of direction by the presence of a plucked surface on one of the outcrop edges. Plucked surfaces are evidenced by a steep vertical edge caused by the overriding ice freezing onto the bedrock and removing blocks, usually along joints. Rat tails form where there are more resistant portions with a rock unit (i.e., clasts in a conglomerate, porphyroblasts, phenocrysts, etc). These resistant portions also protect the rock immediately down-ice, forming a small protuberance that has a tail pointing down-ice (Figure 3d, f). These features are considered to be unidirectional, giving flow direction. The Telkwa volcanic rocks have more resistant clasts that commonly form rat tails (Figure 3f).

Striations were measured at a total of 33 sites. At some of these sites, numerous directions were recorded (Figure 3d–

f), at others only one dominant direction was recorded. Finding striations was challenging due to the lack of bedrock exposures in parts of the field area, and the weathered nature of some of the outcrops present. In most cases, except for some fresh roadcuts, striations were only found after sediment, usually till, was scraped, brushed or washed off bedrock surfaces. Where more than one orientation was observed, it was sometimes possible to determine a relative

Figure 3. a) Roadcut through a drumlin, central portion of NTS 093J. A till sample was taken for geochemical analysis. **b)** Crag-and-tail, Saxton Lake area. The glacially smoothed crag and tail are indicated. **c)** Example of a glacially smoothed striated outcrop, along Highway 16 east of Prince George. **d)** Rat tails on a glacially smoothed outcrop, along Highway 16 east of Prince George. Two ages of ice flow are indicated, the older flow (1) formed the rat tails and the younger flow (2) truncated the tails. **e)** Two striation directions are present on this outcrop near Saxton Lake but no age relationship could be determined. **f)** Striated faceted surface (1) is older than the striations and rat tails (2), along Highway 16 west of Prince George.

age or timing by looking for crosscutting relationships or the relative location of the different striated surfaces. For example, if large grooves are present and there are striations in the groove, the groove must be older than the striations. Similarly, by noting the dominant direction of ice movement on an outcrop, striations found on protected surfaces in the lee (down-ice) of this direction are likely older (Figure 3f). Relative age control was only possible at a few sites, and most of these were within 20° of each other. These slight differences likely reflect minor changes during deglaciation.

The dominant ice-flow direction in the area is relatively easy to demonstrate using the orientations of numerous drumlins (Figure 1), except for portions of NTS 093H where drumlins are rare. These data were supplemented by observations on the striations, rat tails and grooves. The drumlin data indicate the dominant ice divides, to the south and west of the study area, controlled the drumlin-forming ice flow. These two flow sources interacted, with ice flow from the west appearing to be dominant, causing ice flow to be deflected eastward. This deflection is evident on the DEM to the southeast of Prince George along the margin of the uplands of the Fraser Plateau. This ice continued to flow to the east along the Rocky Mountain Trench. In the north part of the study area, the dominant flow changes from east-northeast to northeast.

Striation data in general correspond with ice flow indicated by the drumlins, however, some exceptions occur. For example, in the vicinity of Saxton Lake (Figure 1) striations and a crag-and-tail indicate ice flow to the east. This likely represents a readvance over the area during deglaciation, something confirmed by examination of sections in the area. There are several sites in the southeast part of the study area where valley-parallel striations were recorded. These likely reflect valley-parallel flow during deglaciation, when ice had thinned enough that topography exerted more of an influence.

Drift Thickness

A relative drift thickness map is currently being constructed. This map will prove useful to companies planning till-sampling programs and locating areas where bedrock outcrop or near surface subcrop are most likely to occur. This map is being constructed from a mix of existing Geological Survey of Canada (GSC) surficial geology mapping, soil and landform mapping and some airphoto interpretation. Surficial geology maps at a scale of 1:100 000 exist in the northwest, southwest and southeast portions of NTS 093G. Soil and landform mapping at a scale of 1:50 000 exists for the west half of NTS 093H, all of NTS 093G but only the south half of NTS 093J. As terrain mapping will occur in the northwest portion of NTS 093J, reconnaissance mapping will be undertaken to provide drift thickness information. Unfortunately, there is no terrain mapping for the Quest area. The limited, existing, mainly reconnaissance-scale, terrain stability mapping is inappropriate for this map. Reconnaissance field observations carried out in the summer of 2008 will be incorporated. This and existing map information will be merged to the generalized map units outlined below:

1) Shallow to bedrock terrain. Rock outcrops are common and/or at shallow depth (usually at <1 m). Surficial deposits are dominantly derived from local bedrock (e.g., colluvium and weathered rock) but thin mantles of till can also occur.
2) Variable thickness of till, usually <3 m thick. Some discontinuous bedrock outcrops occur and bedrock can be expected in relatively shallow excavations such as roadcuts. Isolated areas of low-lying and depressional terrain may have second- and third-order derivative sediments at the surface, covering the till.
3) Mainly a continuous cover of thick till, usually 3 to >10 m thick. Bedrock outcrops are rare and usually the underlying rock surface will only be exposed in deep excavations (e.g., pits). Surface mantles of second- and third-order derivative sediments are probable in isolated areas of low-lying and depressional terrain.
4) Thicker and continuous surface cover of second- and third-order derivative sediments, including glaciofluvial, glaciolacustrine, fluvial, lacustrine, organic and anthropogenic (e.g., mine waste). Surface exposures of till and/or bedrock are rare and may only be encountered in deep excavations.

Isolated bedrock outcrops in units of thicker drift will be identified with an onsite symbol. Generalized ice-flow information will be included on these maps to assist with the planning of drift prospecting programs. Because of the generalized and simplified nature of the units, however, training of samplers on the identification of till is essential to ensure a consistent sample medium.

Till Geochemistry

Till samples were collected in the vicinity of two geophysical anomalies, which were identified by the authors in collaboration with P.L. Kowalczyk, PK Geophysics Inc. (personal communication, 2008). Both sites occur on NTS 093J, one in the south around Saxton Lake and one in the central-west area of the map sheet (site locations [labelled as Figure 5a, b] are shown on Figure 1). Initially, a total of four anomalies were identified by the integration of existing geophysical data and recently acquired geophysical data, released by Geoscience BC (Sander Geophysics Limited, 2008), with regional lake- and stream-sediment geochemical data. Based on the lack of till occurring at the surface and their proximity to populated areas (sampling is difficult on private land), two of these areas were found to be unsuitable.

Figure 4. Typical dense, massive basal till found throughout the study area.

Basal till in the study area is a dense, dark grey, matrix-supported diamicton. This basal till is composed of 25–40% gravel-sized material (clasts) and the matrix is usually sandy silt (Figure 4). Sampling proved difficult because of access problems and lack of suitable sample media. For both anomalies, many of the mapped roads had been deactivated and were undriveable with a four-wheel–drive truck. The Saxton Lake geophysical anomaly occurs in the transition between glaciolacustrine deposits associated with Glacial Lake Fraser and areas of till. Thus, glaciolacustrine deposits covering till deposits limited sampling. In the vicinity of the northern geophysical anomaly, there were extensive areas of sand, which are likely postglacial eolian deposits, and some areas of glaciofluvial deposits.

Basal till samples were collected at a total of 123 sites within and adjacent to the two study areas (Figure 5). At each sample site, three separate samples were collected for 1) clay separation at Saskatchewan Research Council followed by ICP-MS (Package 1-DX) at Acme Analytical Laboratories Ltd.; 2) silt plus clay separation and INAA (Package 1D EnH) at Activation Laboratories Ltd.; and 3) archiving at the BC Geological Survey (BCGS). As well, at 30 of these sites >10 kg till samples were collected for heavy mineral separation and gold grain counts, which are to be carried out at Overburden Drilling Management Services. The <0.25 mm fraction of the heavy mineral concentration will be sent for INAA. These analytical data will be used to identify anomalous samples which will then have the heavy minerals picked and identified. Initial results will be released at Roundup 2009. Funding obtained from the federal government's Mountain Pine Beetle (MPB) Program, under the direction of C. Hutton (GSC, NRCan), will cover the costs for the majority of these analyses, allowing more Geoscience BC funds to be used for analysis of samples next year. This funding will also allow for additional analysis by ICP-MS of the silt- plus clay-sized fraction samples already analyzed by INAA. Analytical variability

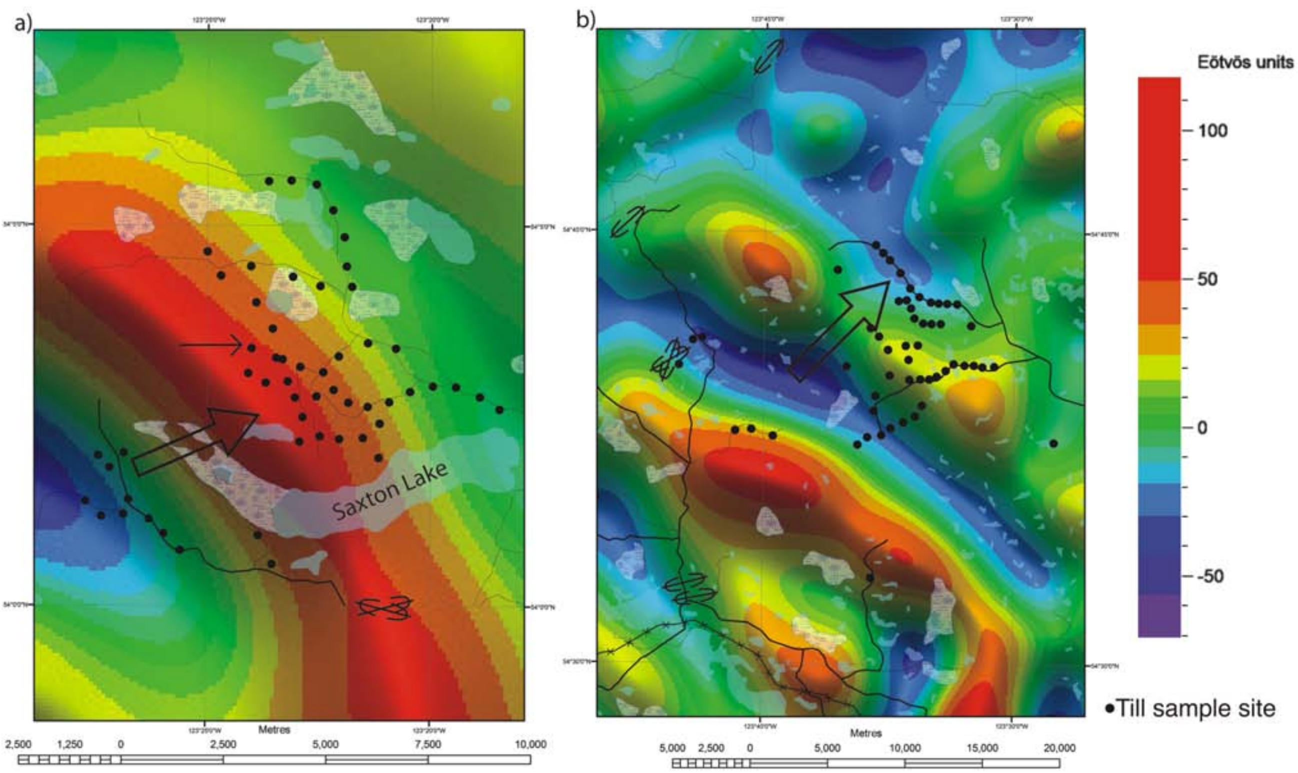

Figure 5. Sample locations for the detailed till geochemical surveys associated with linear magnetic geophysical anomalies (*modified after* Sander Geophysics Limited, 2008). Striations and dominant ice flow indicated with same symbols from Figure 1. Note the difference in scale between the two images: **a)** Saxton Lake; and **b)** North 200 road. Location of images shown on Figure 1.

between the ICP-MS datasets for the two size fractions will be assessed. If results warrant, this type of analysis may be continued for samples collected next summer.

To quantify the accuracy and precision of these analytical data a combination of field duplicates, analytical duplicates and standards are being utilized. For the 143 samples submitted for analysis, six were field duplicates, seven were analytical duplicates and six were standards obtained from R. Lett at the BCGS for use in this study.

Depending on these initial results, areas sampled in the summer of 2008 may be revisited in the summer of 2009 to collect more samples and therefore increase sample density. Next summer, all-terrain vehicles will be rented to allow further access and more foot traverses will be planned.

Future Work

Terrain Mapping and Associated Till Geochemistry

In the summer of 2009, two graduate students will carry out terrain mapping on four to five 1:50 000 scale sheets in the northwest portion of NTS 093J. The senior authors will map another one to two map sheets in the same vicinity. Terrain mapping will utilize the BC classification system (Howes and Kenk, 1997). Associated with this mapping, till samples will be taken for geochemical analysis. The same sampling strategy and analytical control used in the detailed surveys described above will be utilized.

Conclusion

Progress has been made on the glacial geological framework and drift prospecting for a portion of the QUEST Project area. Ice-flow history and drift thickness data has been collected. Till samples associated with two geophysical anomalies have been collected and will be analyzed. These studies will continue next year with the addition of two graduate students who will undertake terrain mapping and more till sampling.

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