Terrain Mapping, Glacial History and Drift Prospecting in the Northwest Corner of McLeod Lake Map Area (Part of NTS 093J), Central British Columbia

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Introduction

Central British Columbia has highly prospective bedrock geology, but mineral exploration activity has been limited in some areas due to the thick cover of surficial deposits. Economic growth in this region has been severely affected by the spread of the mountain pine beetle, therefore funding bodies, such as Geoscience BC, with their QUEST Project, and the federal and provincial governments, are providing financial support for geological projects that will help spur mineral exploration in the impacted areas. Significant knowledge gaps exist in the glacial history of the QUEST Project area and thus pose a considerable hindrance to mineral exploration, in particular when sampling transported sediments for geochemical analysis. Knowledge of the glacial history, specifically the ice-flow history and dominant transport direction, is vital to the interpretation of geochemical survey data from the area. This project is designed to address this knowledge gap by providing a Quaternary framework for a portion of the QUEST Project area, along with data from both regional and detailed till geochemical surveys from which inferences on local, covered, bedrock units can be made.

This ambitious three-year project is currently in year two. The study area comprises NTS map sheets 093G, H (west half) and J. The overall objectives of this three-year program are to provide

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

This work will help to stimulate mineral exploration activity in beetle-kill–affected areas through the release of new surficial geology and geochemical survey data. It is hoped these data will provide new exploration targets but also provide some geological context for companies to interpret their own geochemical and geological datasets.

The focus of this report is the detailed work carried out in the western half of NTS map area 093J. Fieldwork began in 2008, late June to early July, with the majority of it being completed in 2009, July and August. The 2008 field season concentrated on the collection of striation data for the reconstruction of ice-flow history and assessing the accuracy of the existing soil and landform and surficial geology mapping to be used for drift thickness mapping throughout the project area. Also, detailed-scale till geochemistry sampling occurred in areas down-ice from two geophysical anomalies (described in Ward et al., 2009). The 2009 field season concentrated on the terrain mapping of the six 1:50 000 map areas in NTS 093J, while collecting ice-flow

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

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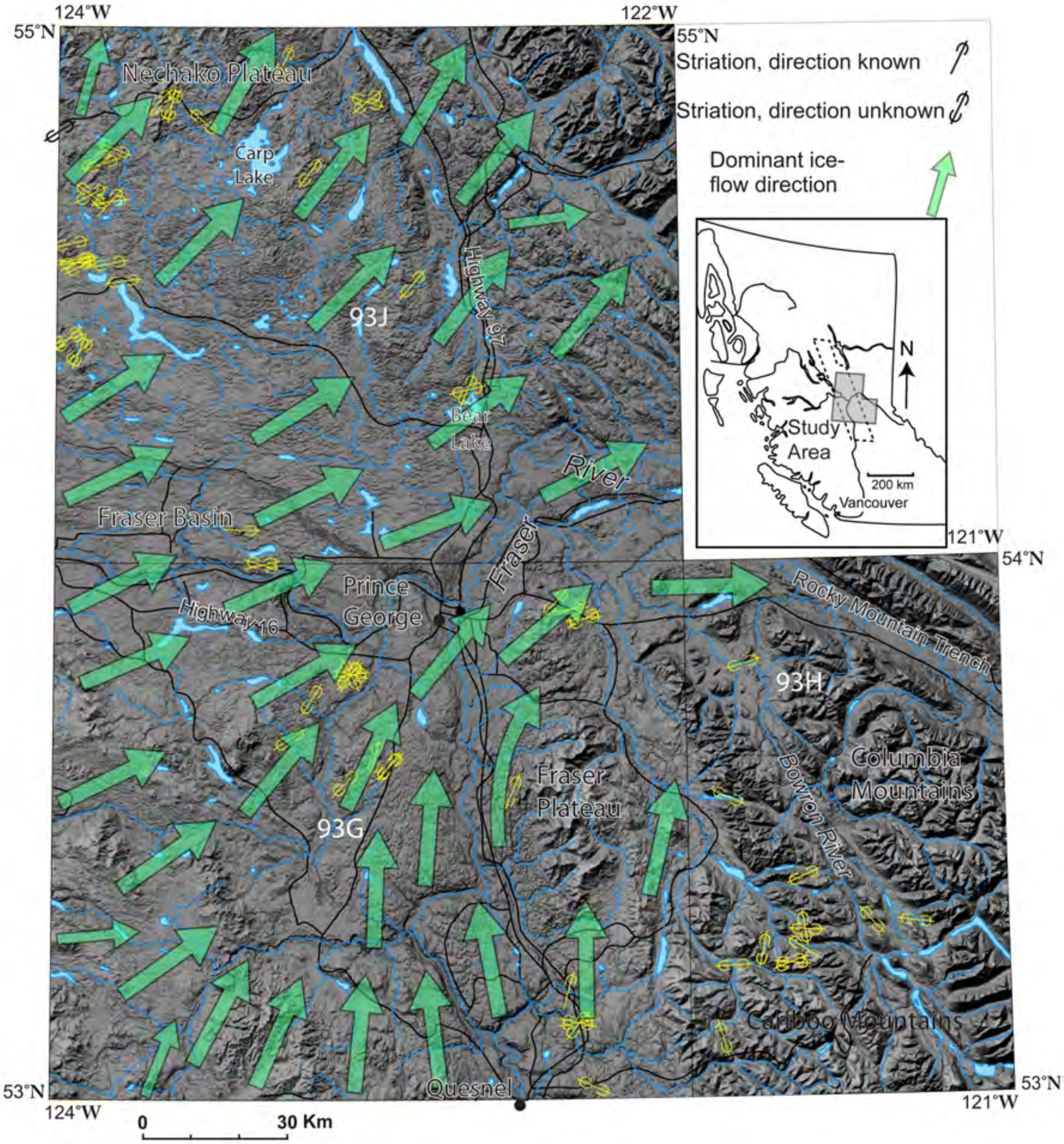

Figure 1. Digital elevation model (DEM) of the study area with ice-flow information. Drumlinized drift is evident throughout most of the study area and is used to interpret dominant ice flow. Striation data is compiled from field observations and existing maps (Tipper, 1971a; Clague, 1998a, b; Paulen, 2000; Blais-Stevens and Clague, 2007). 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).

data and conducting regional-scale till geochemical sampling for the map areas.

Study Area and Physiography

The study area is situated at the heart of the QUEST Project area (Figure 1). The majority of the study area lies in the relatively low relief area of the Interior Plateau (Holland, 1976; 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. The Cariboo Mountains, located in the southeastern corner, occupy the rest of the area.

Regional Quaternary History

The Cordilleran Ice Sheet has repeatedly covered British Columbia and portions of Yukon, Alaska and Washington over the last two million years (Armstrong et al., 1965; Clague, 1989). At its maximum extent, the Cordilleran Ice Sheet was up to 900 km wide and up to 2000–3000 m thick over the Interior Plateau, closely resembling the present-day Greenland Ice Sheet (Clague, 1989). A more comprehensive history of the Cordilleran Ice Sheet can be found in Jackson and Clague (1991).

The major sources of regional ice that covered the study area advanced from accumulation centres in the Coast, Skeena and Cariboo mountains (Tipper, 1971a, b; Levson and Giles, 1997; Plouffe, 1997, 2000). The study area occurs near the convergence of these three advancing ice fronts, making it difficult to determine which ice centre(s) had the most influence on the study area in the early parts of the Late Wisconsinan. Previously reported ice-flow indicators (Tipper, 1971a; Paulen, 2000), in combination with data from this study, suggest that it was mainly ice from the Coast Mountains to the west and south, and to a lesser extent ice from the Cariboo Mountains, that covered the area. Chronological information on the movement and/or confluence of ice fronts through the study area is limited. Although it is known that ice was advancing out of the Coast Mountains by 28 800 ±740 BP (sample GSC-95, Clague, 1989), it is not clear when this advance reached the central Interior Plateau. Ice, possibly sourced from the Cariboo Mountains (Paulen, 2000), covered the Bowron Valley sometime after 19.9 Ka (sample AA44045, Ward et al., 2008). According to Bobrowsky and Rutter (1992), ice advancing from the Skeena Mountains into what is now the north arm of Williston Lake occurred sometime after 15 180 ±100 BP (sample TO-708, Bobrowsky and Rutter, 1992).

Throughout the Interior Plateau, stratigraphic exposures of advance-phase glaciolacustrine, advance-phase glaciofluvial and till deposits suggest that regional ice advances were not necessarily continuous, nor uniform, but were instead interrupted by standstills and possible retreats (Clague, 1989). Evidence of this has been reported in exposures to the south (Tipper, 1971a, b; Clague, 1989; Eyles and Clague, 1991) and west (Plouffe, 1997, 2000) of the study area. Eventually, these ice fronts did coalesce sometime during the Fraser glaciation maximum, forming the Cordilleran Ice Sheet.

Deglaciation is thought to have occurred by downwasting, followed by widespread stagnation throughout much of the interior (Fulton, 1967; Clague, 1989). Initially, ice continued to flow at a subdued rate and eventually downwasting of ice exposed the uplands. Ice was then restricted to the valleys and as it retreated downslope it locally produced ice-dammed lakes, culminating with glacial Lake Fraser around Prince George. Thick deposits of glaciolacustrine silt and clay over large areas are a product of these ice-dammed lakes, such as glacial Lake Fraser. Eventually ice became stagnant and melted in place resulting in hummocky and kame-and-kettle topography. The deglacial history of the study area will be discussed further in a later section of this paper.

Methods and Results

Terrain Mapping

Terrain mapping for the six 1:50 000 scale map areas in the western half of NTS 093J (093J/05, /06, /11, /12, /13, /14) began this year using standardized mapping methods (Resources Inventory Committee, 1996; Howes and Kenk, 1997). High resolution, 1:40 000 scale, aerial photographs provided 3-D imagery of the entire area upon which the mapping was based. In addition, field checking was carried out to assist in identifying and delimiting the surficial materials occurring within the study area. Good ground access was available throughout most of the map areas enabling detailed fieldwork to be conducted through much of the study area. In addition, GIS software and a variety of digital spatial data were used to create a digital elevation model (DEM) for the map areas from which landforms could be identified and spatial relationships could be observed (Figure 2). Although useful, these models were limited by the resolution of the available elevation data. Map units have been stereoscopically delimited, subdividing the land surface according to the origin and texture of surficial materials and landforms (surface expression) that occur there. Geomorphological processes that have modified the landscape were included on the map and on-site map symbols were used to identify specific landscape features, such as small terrace scarps and meltwater channels.

The final maps, to be completed in early 2011, will use a hybrid surficial geology and terrain map legend. Polygons will be placed into a coloured closed legend, similar to that of a surficial geology map but will include additional terrain information, such as additional surficial materials and

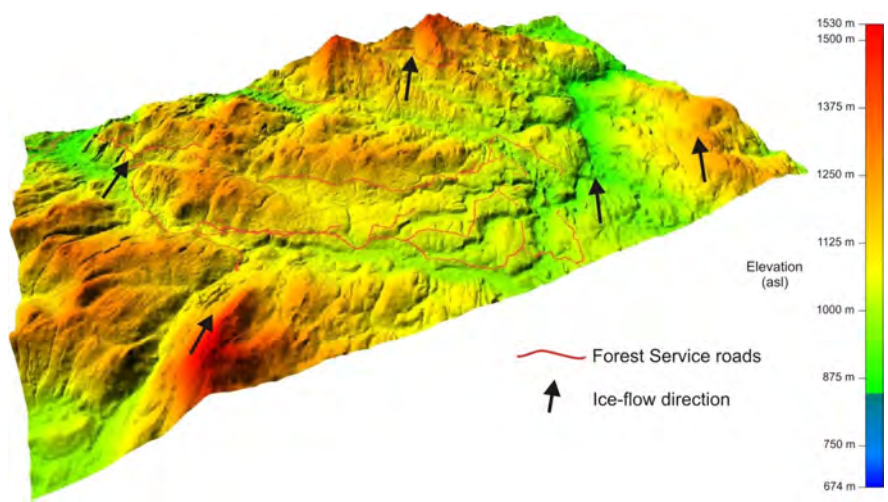

Figure 2. Digital 3-D model for a portion of the northern uplands in NTS 093J/14, central British Columbia, created using GIS software. Model is oriented in the direction of ice flow, illustrated by streamlined rock and drift.

any active geomorphological processes. This will make these maps easier to read yet still retain a more detailed description of the surficial materials and geomorphological processes occurring within individual polygons.

Nature of Surficial Materials

Surficial material of the study area is dominantly composed of till, glaciofluvial and glaciolacustrine sediments. Postglacial materials are also present, including fluvial, eolian, colluvial and organic deposits. Similar surficial units have been described to the west and south of the study area (Tipper, 1971a; Howes, 1977; Paulen, 2000; Plouffe, 2000).

Most of the till in the area is a dense, dark grey, matrix-supported diamicton, characteristics typical of a basal till. Subangular to well rounded, gravel-sized clasts comprise 10–40% of the diamicton and are supported by a sandy silt to silty clay matrix (Figure 3A). In several locations, the till was less dense, more gravelly and supported by a dominantly sand matrix. This facies of till was commonly observed within the top metre of an exposure and is interpreted as ablation till. The surface expression of tills range from fields of ridged, streamlined features (e.g., drumlins) to near-level plains with little or no vertical expression.

Glaciofluvial deposits varied greatly from well sorted sand to poorly sorted gravel that locally was composed of cobble-sized clasts (Figure 3B). These deposits most commonly consist of moderately sorted sandy pebble to pebbly sand granular material and form hummocky or kame-and-kettle topography, esker complexes and systems of terraces and plains. Numerous meltwater channels were observed throughout the study area, often, although not always, spatially associated with glaciofluvial deposits. In the northern portion of the study area, some of these channels crosscut topographic highs and incised valleys while others exist as areally extensive plains, generally draining northward. Farther south, roughly to the southwest of Carp Lake, the main meltwater channels formed in conformance to the southwesterly retreating ice sheet and thus drained somewhat laterally along the northwest-southeast oriented ice front. Present-day underfit streams occupy some of these meltwater channels, and their associated fluvial deposits partially infill the channels.

Glaciolacustrine deposits are generally composed of laminated silt and fine sand with some clay (Figure 3C). They are expressed as plains if they are thick deposits, and blankets or veneers where the material is thinner and the underlying unit controls its surface expression. These sediments cover extensive regions in the southern map sheets (NTS 093J/05, /06) and are less widespread in the north.

Eolian deposits, consisting of dominantly well sorted, fine to medium, wind-blown sand (Figure 3D), occur only locally but are worthy of mention. These deposits were commonly located near glaciofluvial, and to a lesser extent, glaciolacustrine sediments; the source material for these eolian sediments. The surficial expression of these deposits ranged from veneers to ridges (sand dunes). It is likely that the size of the sediment source correlates with the surface expression of the adjacent eolian deposit (i.e., small sources yield veneers and larger sources yield dunes). Further analysis of the spatial distribution of eolian and glaciofluvial deposits may reveal characteristics of deglacial wind regimes.

Bedrock is prevalent on the uplands in the northern portions of NTS 093J/13 and /14. In the southern map sheets, drift is much thicker and bedrock outcrops occur mainly on isolated topographic highs such as Merton Hill and Mount Prince. Thin mantles of bedrock-derived colluvium and discontinuous till occur in association with the bedrock-dominated terrain.

Ice-Flow History

The ice-flow history of the study area was determined by compiling ice-flow information from existing maps (Tipper, 1971a; Clague, 1998a, b; Paulen, 2000; Blais-Stevens and Clague, 2007), combined with newly conducted aerial photograph interpretation and observations made during the 2008 and 2009 field seasons (Figure 1). In this study area, ice-flow indicators generally consist of macroforms such as drumlins, flutings, crag-and-tail forms and streamlined bedrock ridges. Indicators measured in the field were mainly microflow indicators, such as grooves, striations and rat tails. Further information on these ice-flow indicators and the processes by which they form can be found in Ward et al. (2009).

The ice-flow–indicator data collected in 2009 provides further support to previous interpretations of the dominant ice flow. In most areas, the dominant flow is indicated by macroforms visible in the DEM. In portions of NTS 093H where these macroforms are rare, these data were substituted with the observed microflow indicators. Striations, rat tails and grooves were recorded at 33 sites in 2008 and an additional 23 sites in 2009. Finding microflow indicators was problematic due to the lack of bedrock exposures in the majority of the study area, and the weathered nature of some of the outcrops present. In most cases, striations were only found after sediment, usually till, was scraped, brushed or washed off bedrock surfaces. Where more than one orientation was observed at a site, it was sometimes possible to determine a relative age or timing of ice-flow events by locating crosscutting relationships or by the relative locations of the striated surfaces (Figure 4). For example, if a large groove is present and there are striations within the groove, the groove must be older than the striations. Similarly, by noting the dominant flow of ice

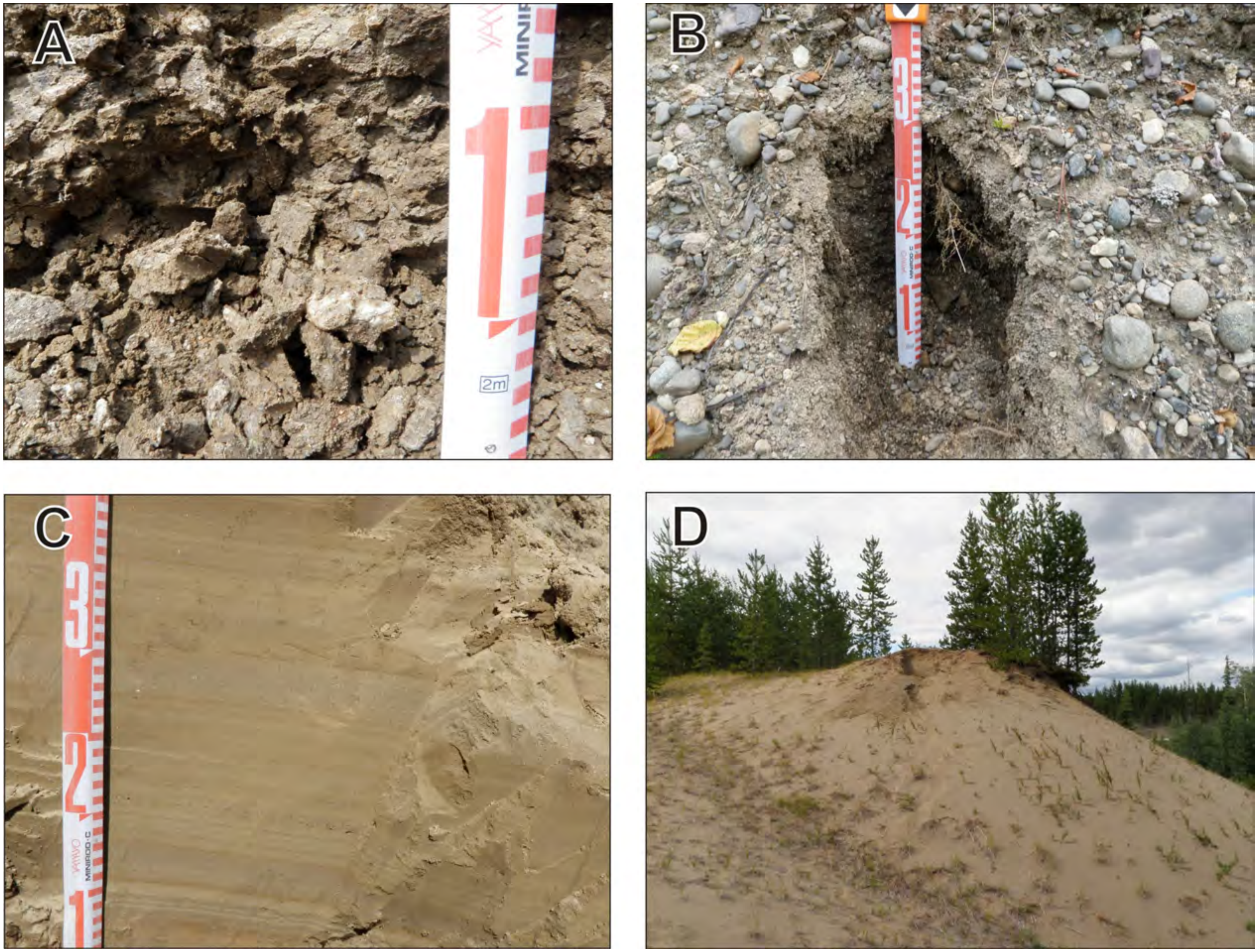

Figure 3. Surficial materials commonly found in the mapped regions of NTS 093J, central British Columbia: **A)** typical dense basal till from sample pit in NTS 093J/13; **B)** moderately sorted gravel from a glaciofluvial terrace; **C)** glaciolacustrine beds of laminated silt, clay and fine sand with some faulting; **D)** eolian dune cut by road construction.

over a bedrock outcrop, striations located on protected surfaces on the lee side (down-ice) of the feature, are likely older. Relative age control, or timing of different ice-flow events, was only possible at a few sites. At most of these sites, orientations of microflow indicators were within ~035° of each other, reflecting only minor changes in ice-flow direction, which likely occurred during deglaciation.

Some sites, however, showed dramatic differences in microflow indicator orientations. For example, southwest of Prince George three sets of striations were observed at one field station. The oldest was oriented at 150°, the second oldest at 100° and the youngest at 080°. Based on this chronology, it is possible to infer that ice flowing east from the Coast Mountains reached the area first and produced the oldest striations. The younger striations likely reflect a sequential northerly shift in dominant ice flow as ice from the Cariboo Mountains in the south interacted with ice from the Coast Mountains.

These data are in agreement with existing ice-flow data that suggest easterly flowing ice from the Coast Mountains entered the area first (Plouffe, 2000; Ward et al., 2009). To the south, ice constrained by topographic highs flowed west and northwest from the Cariboo Mountains as well as up the Bowron River valley (Paulen, 2000). The orientations of macroflow and microflow features suggest these two sources interacted south of Quesnel, with ice flow from the west appearing to be dominant. This interaction caused ice from the Cariboo Mountains to be deflected eastward to the southeast of Prince George, along the Fraser Plateau and then into the Rocky Mountain Trench. In the northern section of the study area, the dominant flow changes from east-northeast to northeast, possibly due to the same interaction. Exceptions to this occur locally where flow direction changes are the result of ice thinning sufficiently enough to be influenced by topography.

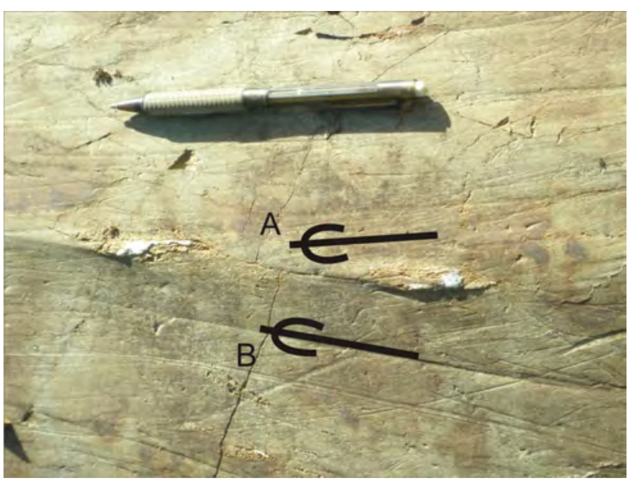

Figure 4. Glacially smoothed bedrock along Highway 16 (central British Columbia) illustrating microflow indicators of two different-aged ice flows. The older flow formed the rat tails (**A**) that are truncated by the younger flow. Rat tails show unidirectional flow and striations (**B**) generally indicate bidirectional flow. Due to the cross-cutting relationship between these two microforms, these striations suggest unidirectional flow.

Deglaciation

The timing and style of deglaciation in the study area is poorly understood. Based on the distribution of surficial deposits and glacial landforms associated with deglaciation, Fulton (1967) put forth a model of deglaciation for south-central BC. This model can be divided into the following four phases: 1) active ice phase; 2) transitional upland phase; 3) stagnant ice phase; and 4) dead ice phase. This model is the generally accepted model for deglaciation of areas in BC with low to moderate relief, and is a good framework for understanding the deglaciation of the study area. Some physiographic differences in this study area may, however, cause deviations from the general model.

The distribution of glaciofluvial and glaciolacustrine sediments and glacial features, such as meltwater channels and lateral moraines, can be critical to unravelling the deglacial history of an area. Glacial lake sediments in the higher valleys and meltwater channels subparallel to the topography delineate the locations of the ice fronts of the retreating glaciers. In the study area, this retreat appears to have been from east to west. As with many other areas in central BC that have subdued to moderate topography, glaciers in the study area first abandoned the higher elevations and then retreated to the lower areas. Ice-marginal channels were cut along irregular ice fronts as they progressively retreated downslope (a combined result of ice front retreat and downwasting of the ice mass; Figure 5). Hummocky melt-out till, and kettle-and-kame topography associated with deformed glaciofluvial sediments, is limited in the study area. This could indicate that during deglaciation the glaciers that were constrained to valleys remained active longer than Fulton's model would suggest. Further evidence that thinning ice was still active can be seen in striation data from topographically constrained areas. For example, north of Bear Lake, on Highway 97, striations in the valley indicate a north-northeast ice flow that is parallel to the valley walls. This is contrary to the surrounding streamlined features that indicate northeast was the dominant flow direction during times of unconstrained ice flow. The last glacial lake in the area, glacial Lake Fraser, left thick packages of silt and clay sediments in the Prince George region. This lake was the result of ice retreating across the Fraser Valley, but still damming the Fraser River further south. A large esker complex, occupying the Hart Highway area, north of Prince George, indicates the location of a glaciofluvial system that once fed water and sediment into this lake.

Plouffe (2000) offers evidence that similar processes occurred west of the study area with ice retreating east to west with irregular margins that were controlled by topography.

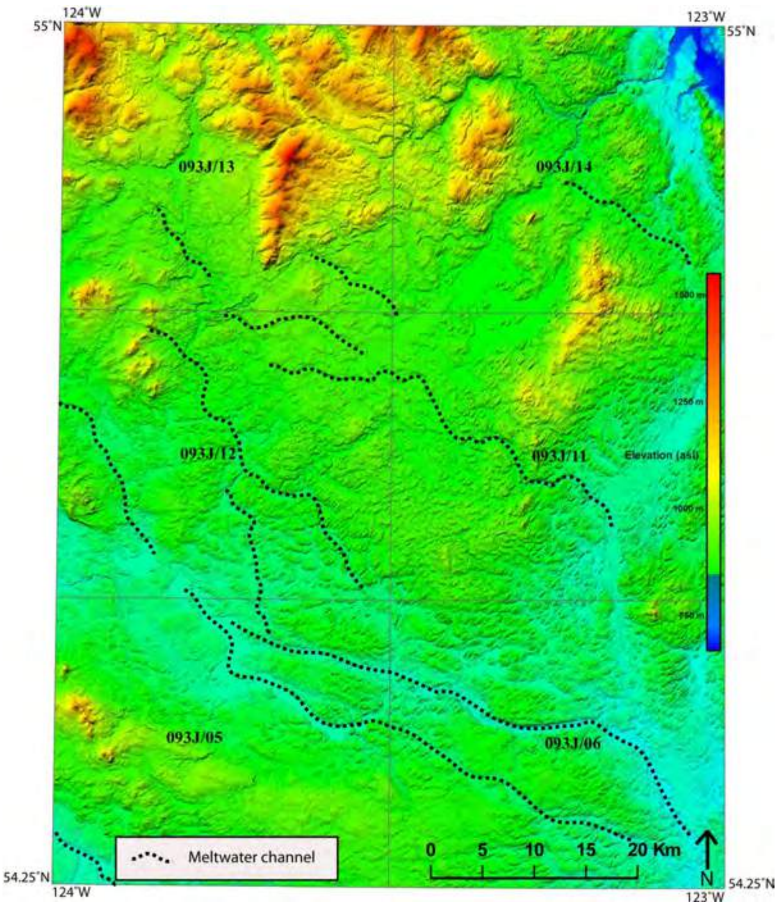

Figure 5. Ice marginal meltwater channels, which crosscut topographic highs, illustrate that ice retreated in a southwesterly direction along an irregular ice front during deglaciation in areas of subdued to moderate topography, central British Columbia.

Plouffe also suggests significant movement during the stagnation phase and a less influential dead ice phase during deglaciation. These differences from Fulton's original model are likely a result of the increased topography in the north compared to the more subdued southern regions (where the model was developed) where deglaciation was characterized by downwasting, followed by widespread dead ice stagnation.

Postglacial deposits, in particular organic and eolian, can be useful for creating a timeline for, or chronology of, deglaciation. Basal peat, directly overlying glacial sediments, can provide a minimum age of deglaciation. Attempts have been made to find such organic deposits east of the study area, but they appear to be absent, possibly due to the warm dry climate of the early Holocene retarding paludification (Plouffe, 2000). Sand dunes, last active between ice retreat and vegetative colonization, can also provide a minimum age for deglaciation. Six sites were sampled during the 2009 field season for optically stimulated luminescence dating. If successful, these samples will provide an approximate age for when the sand was last exposed to sunlight (i.e., the last time the dunes were active).

Till Geochemistry

Regional-scale till sampling can be carried out to assess the mineral potential of areas covered with drift (Paulen, 2000; Levson 2001). Detailed investigations, when possible, of regional-scale till samples with elevated or anomalous values can help define potentially mineralized zones within covered bedrock units. The preferred sampling medium for till geochemical surveys is basal till, as it is commonly considered a first derivative of bedrock (Dreimanis, 1989; Levson, 2001).

In 2008 and 2009, detailed- and regional-scale till geochemical surveys were conducted respectively. The sampling regime for both included collecting three separate 900 g samples at each sample site for: 1) analysis of the clay-sized fraction by aqua-regia digestion followed by ICP-MS at Acme Analytical Laboratories Ltd. (Vancouver, BC); 2) analysis of the silt- plus clay-sized fraction by INAA at Becquerel Laboratories Inc. (Mississauga, ON); and 3) archiving. In addition, at every 4–5 sites, a >10 kg sample was collected for heavy mineral separation and gold grain counts. These separations and counts are conducted at Overburden Drilling Management Limited (Nepean, ON). The <0.25 mm fraction heavy mineral concentration is sent for INAA determinations. Results from the INAA are used to identify samples with elevated element values and it is from these samples that heavy minerals are picked and identified.

To quantify the accuracy and precision of these analytical data, a combination of field duplicates, analytical duplicates and reference standards are used. For every 20 samples collected in the field, one field duplicate is collected, one analytical duplicate is split and inserted into the sample sequence at the lab, and one reference standard (either an in-house BCGS standard or a certified Canada Centre for Mineral and Energy Technology [CANMET] standard) is inserted.

In 2008, till samples were collected from a total of 123 sites around two anomalies interpreted from airborne gravity survey data (Saxton Lake and 200 Road anomalies; Figure 6). Geochemical determinations around the Saxton Lake anomaly delineated a potential mineralized zone. Elements related to mineralization, such as Cu, Au, As, Cr and Ni, tend to have higher concentrations in samples down-ice of the anomaly. These results imply that there may be volcanogenic massive sulphide (VMS) mineralization associated with the transition from the high to low magnetic

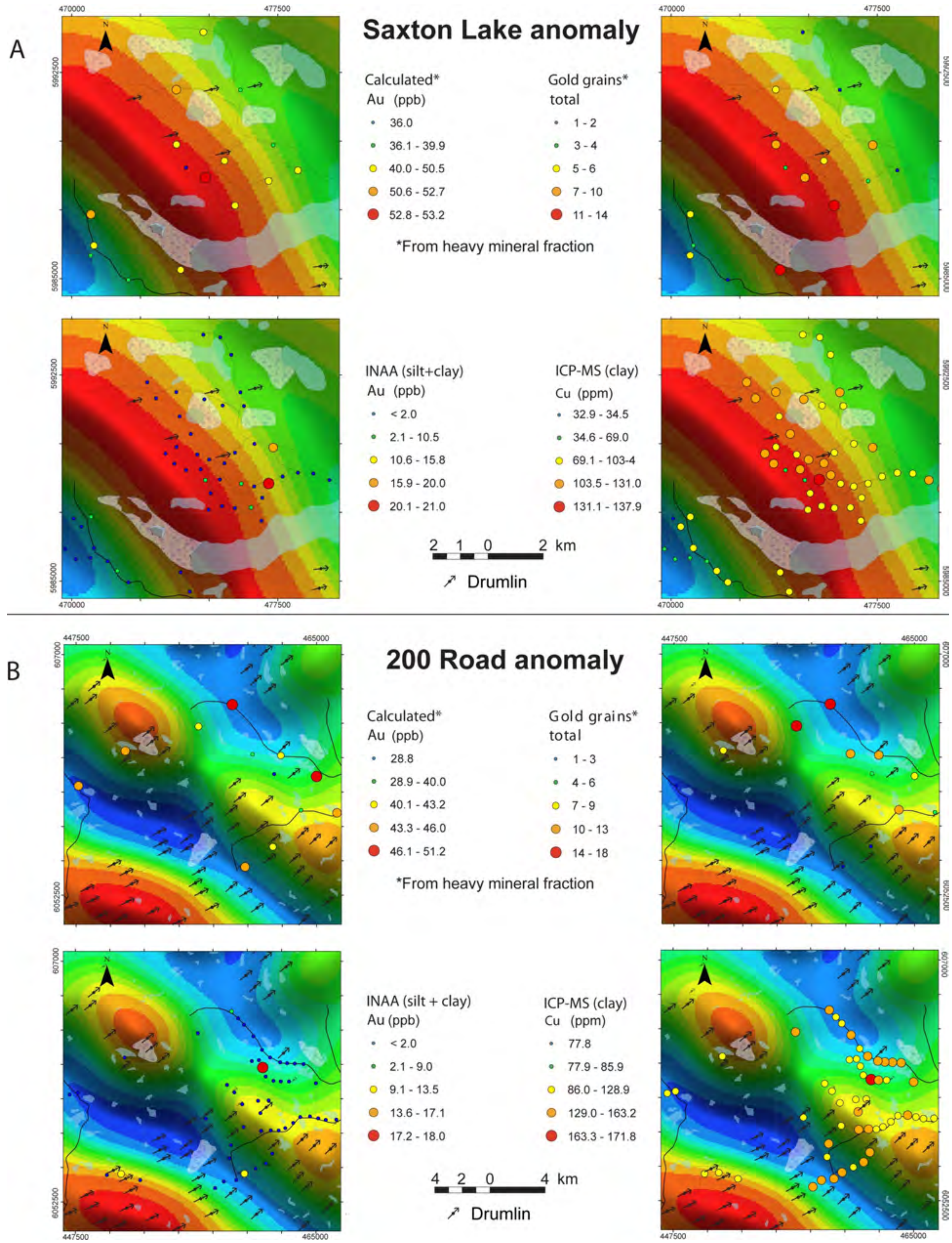

Figure 6. Copper (Cu) and gold (Au) distributions, associated with Saxton Lake (A) and 200 Road (B) linear magnetic anomalies, derived from till geochemical survey analysis. The Saxton Lake example shows elevated Cu values down-ice compared to up-ice of the anomaly. Absolute Cu values are actually higher in the 200 Road area but up-ice values are also high, reducing the contrast of the dispersal plume to the background values. In both examples, instrumental neutron activation analysis (INAA) of Au indicated low values, but gold grain counts and resultant calculated concentrations in the smaller suite of heavy mineral analysis indicate gold is present down-ice of both anomalies. Abbreviation: ICP-MS, inductively coupled plasma–mass spectrometry.

values (Figure 6). Element concentrations in the 200 Road anomaly are more subdued making it more difficult to define any mineralized zones (Figure 6). It should be noted, however, that increases in Cr and Ni are evident on the down-ice side of the geophysical anomaly. More samples were taken in the vicinity of the 200 Road anomaly in 2009 so that background values could be better defined. Road deactivation combined with large areas of eolian deposits limited where sampling could take place. In general, initial geochemical results from till samples collected in 2008 suggest that a detailed till geochemical survey conducted around geophysical anomalies, in areas where there is very little rock outcrop, is an effective way of assessing potential relationships between the geophysical anomalies and metallic mineralization.

In 2009, 670 new till samples were collected at a density of about one sample per 8 km^2 from NTS 093J/05, /06, /11, /12, /13 and /14 (Figure 7), using the same sampling regime described above. The geochemical analysis of these samples should be available in late 2010. Due to sampling restrictions in Carp Lake Provincial Park, thick surficial deposits (i.e., not basal till) and areas without road access, there were several large regions that could not be sampled thus decreasing the average sampling density. Detailed sampling of any geochemical anomalies may be carried out in 2010 to more accurately delineate new zones of elevated trace-element concentrations.

Future Work

Six 1:50 000 scale terrain maps will be completed in early 2011. These maps will be useful to explorationists following up on till geochemical data conducted as part of this study but also for other geochemical surveys (including their own) conducted within this portion of the QUEST Project area. Also in 2010, regions of the study area that proved difficult to access will be sampled using all-terrain vehicles and foot traverses.

Conclusion

Further progress has been made in the understanding of the glacial geological framework for a portion of the QUEST Project area. This understanding is integral to the interpretation of data from geochemical surveys that use glacially transported sediments as a sample medium. The initial stages of terrain mapping have been completed for six 1:50 000 scale map sheets. These maps will delineate and describe surficial deposits and landforms occurring within the study area and will be useful for planning and implementing media-specific geochemical surveys. These data, combined with the compilation and collection of ice-flow data, have provided the basis for a more comprehensive understanding of the study area's ice-flow history. This improved understanding can only improve the effectiveness of drift-prospecting programs in the region.

Trace-element geochemistry of till samples collected in the vicinity of two geophysical anomalies suggest that these anomalies may be associated with metallic mineralization. This suggests that detailed till geochemical sampling, combined with an understanding of an area's glacial history, is an effective way to test geophysical anomalies within areas of thick drift and determine if they are in fact related to me-

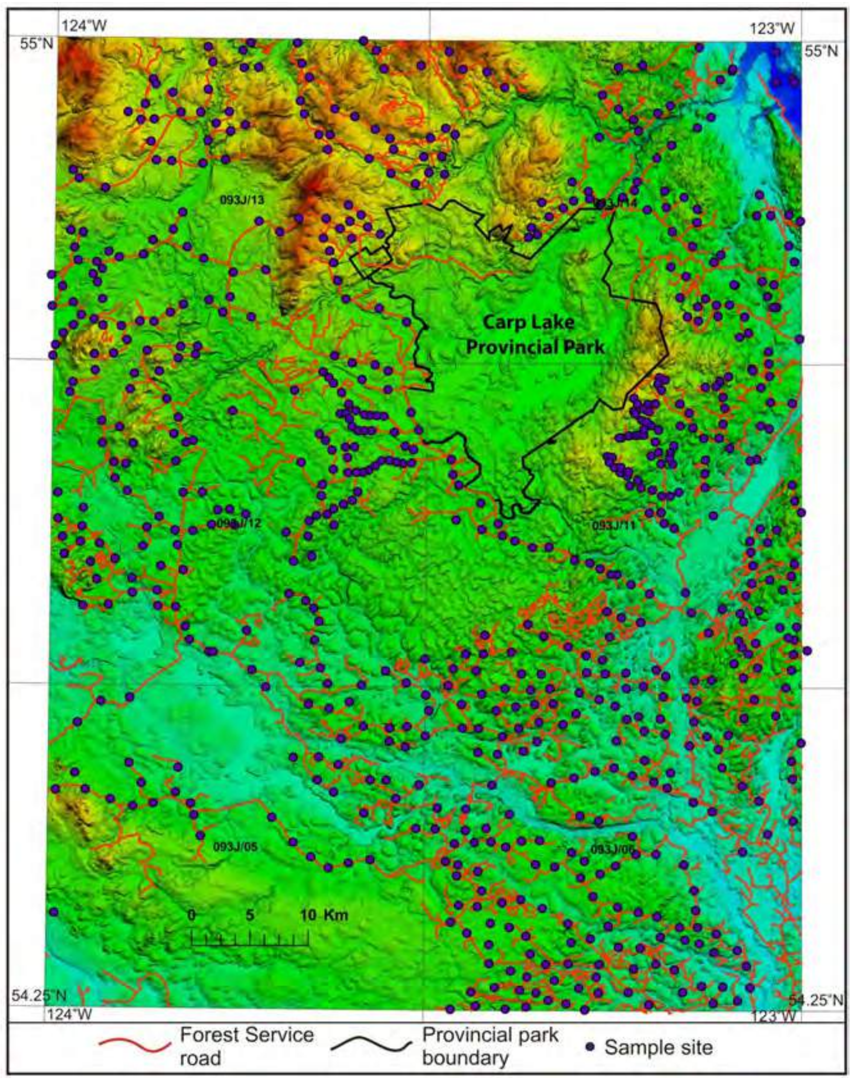

Figure 7. Till geochemical survey sample site distribution in NTS map areas 093J/05, /06, /11, /12, /13 and /14, central British Columbia.

tallic mineralization. Geochemical determinations for 670 new sites are pending for a larger portion of the study area.

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