Glacial history of Howard's Pass and applications to drift prospecting

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ABSTRACT

Four stages of ice-flow occurred in Howard's Pass during the late Wisconsinan McConnell glaciation. The first stage is marked by ice growth from local cirques. During the second stage, an ice divide developed east of the Nahanni River, with ice flowing southwest across Howard's Pass. Ice sheet growth continued during stage 3 and the ice divide migrated southwest into the Logan Mountains. At this time ice flowed northward across the study area. Stage 4 is marked by deglaciation and more topographically influenced ice-flow. This last phase of ice-flow is the most important for drift prospecting in the valley bottoms. Conversely, drift transport directions at higher elevation are likely remnant from earlier stages of ice-flow. A mobile-metal-ion survey over a known deposit returned promising results, supporting the potential of this geochemical technique in other drift-covered areas of Howard's Pass.

RÉSUMÉ

Pendant la glaciation de McConnell, au cours du Wisconsinien tardif, quatre phases d'écoulement glaciaire se sont opérées à Howard's Pass. La première a été marquée par la formation de glace depuis les cirques environnants. Durant la deuxième, une ligne de partage glaciaire s'est formée à l'est de la rivière Nahanni et de la glace s'est écoulée vers le sud-ouest, en passant par Howard's Pass. Au cours de la troisième phase, la formation de l'inlandsis s'est poursuivie, et la ligne de partage glaciaire s'est déplacée vers le sud ouest jusque dans les monts Logan; c'est alors que la glace s'est dirigée vers le nord et qu'elle a traversé la zone d'étude. La quatrième phase a été marquée par une déglaciation et un écoulement glaciaire circonscrit par la topographie et représente la phase d'écoulement glaciaire la plus importante en matière de prospection glaciosédimentaire des fonds de vallée. Par contre les directions dans lesquelles les sédiments glaciaires ont été charriés à des altitudes plus élevées correspondent probablement aux premières phases d'écoulement glaciaire. Un levé d'ions métalliques mobiles exécuté au-dessus d'un gisement connu a donné des résultats encourageants montrant que cette technique géochimique pourrait être utilisée avec succès dans d'autres zones glaciosédimentaires d'Howard's Pass.

INTRODUCTION

The late Wisconsinan glacial history of Howard's Pass is important because of ongoing resource exploration and development in the area, and its proximity to the ice divide for the Selwyn lobe (Fig. 1). This lobe is one of several source areas for the northern Cordilleran Ice Sheet (Fig. 2). The sequence of ice-flow and the style of deglaciation remain enigmatic as do the location and potential migration of the ice divide in relation to Howard's Pass.

Ice-flow directions and the pattern of deglaciation were reconstructed in conjunction with investigations into the distribution of surficial sediments (Fig. 3). This information allows interpretation of soil geochemistry and helps locate materials needed for further infrastructure development in Howard's Pass. These applications are essential for the current drift-prospecting programs aimed at extending mineralized zones in the study area.

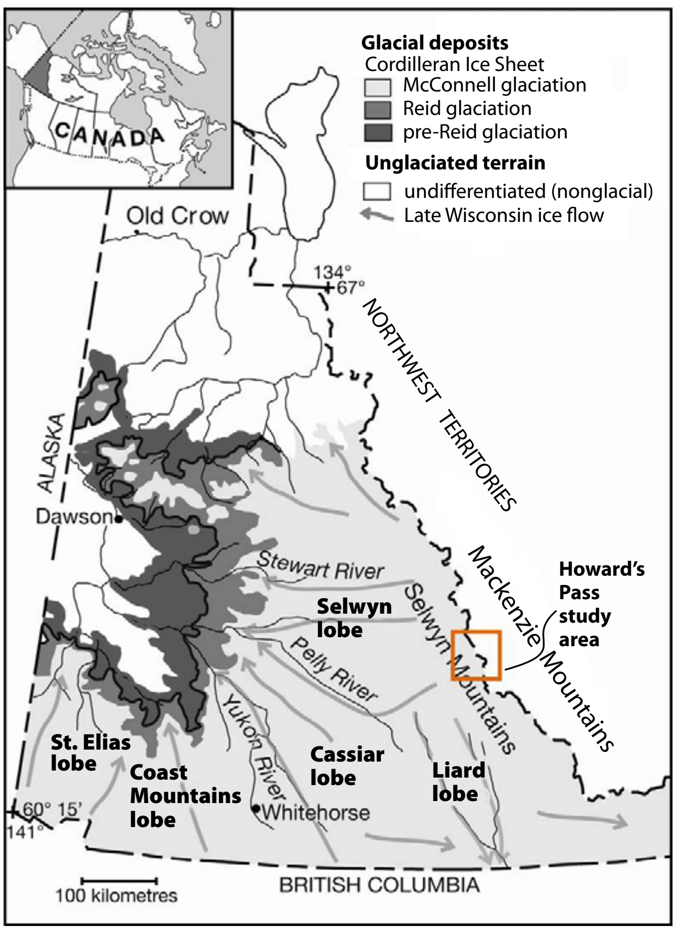


Figure 1. *Location map of the Howard's Pass study area (see square) in context with late Wisconsinan ice lobes and glacial extents of Yukon Territory (modified from Ward et al., 2007; Duk-Rodkin, 1999).*

In 2007, a 1:50 000-scale terrain map and an ice-flow history were constructed for Howard's Pass. In addition, a mobile-metal-ion (MMI) geochemistry case study was completed over a known deposit to test this technique's ability to detect anomalies directly over mineralized bedrock in glaciated terrain. These will be tools for future drift prospecting in Howard's Pass. The purpose of this paper is to summarize the late Wisconsinan glacial history of Howard's Pass, outline implications this history has for drift prospecting and discuss the applicability of the MMI technique in the area.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

Howard's Pass straddles the continental divide with the Pelly River flowing west to the Yukon River, and the Nahanni River flowing east to the Mackenzie River (Figs. 1 and 3). In the Pelly River drainage, broad river valleys oriented east-west contrast with the narrower valleys running north-south in the Nahanni watershed. The steep, sediment-filled valleys in Howard's Pass have relief of over 800 m. Cirques are common throughout the study area and those facing north typically contain rock glaciers.

Howard's Pass lies within the central part of the Selwyn basin, a Paleozoic fault-controlled basin at the continental margin of the Mackenzie and Cassiar platforms (Gordey, 1981; Goodfellow, 2007). The basin formed during rifting of the western margin of North America during the Late Proterozoic. Ordovician and Cambrian limestone, and Devonian and Mississippian Earn Group sedimentary rocks dominate the bedrock in the study area. The nearest sizable intrusive bodies are the Central Nahanni pluton and the O'Grady batholith (Fig. 4), members of the Tungsten and Tombstone plutonic suites, respectively, part of the Selwyn Magmatic Province (Hart *et al.*, 2004). They are located approximately 20 km east of Howard's Pass, across the Nahanni River. The closest large pluton to the west is located over 100 km away.

The Late Proterozoic rifting made the Selwyn basin ideal for metalliferous fluids to exit onto the seafloor creating sedimentary-exhalative zinc-lead-silver deposits (SEDEX) (Morganti, 1979). The resulting sulphide minerals, composed predominantly of zinc and lead bound in sphalerite and galena, occur interlaminated with chert, cherty mudstone and limestone of the Lower Silurian Road River Group (Gordey, 1981; Goodfellow *et al.*, 1983). The Howards Pass SEDEX deposit is estimated to

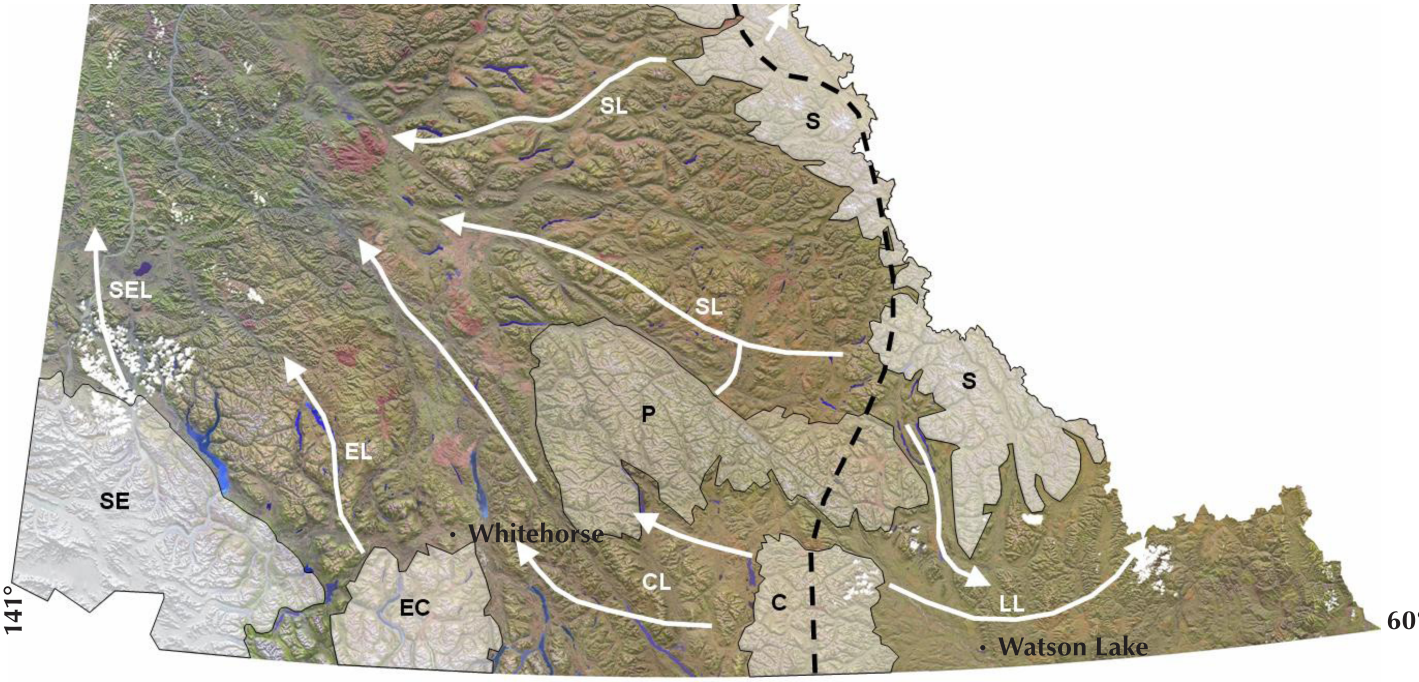


Figure 2. *Ice-flow in the northern Cordillera during the late Wisconsinan (modified from Jackson et al., 1991). EC = Eastern Coast Mountains, P = Pelly Mountains, C = Cassiar Mountains, S = Selwyn Moutains, SE = St. Elias Mountains, EL = Eastern Coast Mountain lobe, CL = Cassiar lobe, SL = Selwyn lobe, SEL = St. Elias lobe, LL = Liard Lowlands. The dotted line is the position of an inferred ice divide.*

have 86.6 millions tonnes of Indicated mineral resources, with an additional 215.46 million tonnes of Inferred resources (C. Pearson, 2007).

REGIONAL LATE WISCONSINAN GLACIATION

The northern Cordilleran Ice Sheet (CIS) comprised several distinct ice lobes centred in the St. Elias, Coast, Cassiar and Selwyn mountains (Fig. 2). These lobes extended into the surrounding lowlands from a major ice divide that extended from the Cassiar Mountains to the Pelly and Selwyn mountains (Jackson *et al.*, 1991; Bond, 2007). The Selwyn Mountains were the largest centre of ice accumulation in the northern CIS during the late Wisconsinan (Klassen, 1987; Dyke, 1990). Ice flowed from the Selwyn divide southeast into the Liard Lowlands, where it was deflected east by ice from the Cassiar Mountains (Dyke, 1990). Ice also extended east from this divide into the Mackenzie Mountains, but was far more limited than ice spreading west (Ford, 1976; Jackson, 1989). The westward-flowing Selwyn lobe spread across more than 300 km (Fig. 2; Jackson, 1989; Jackson *et al.*, 1991).

The Selwyn lobe grew in stages, likely similar to those proposed by Kerr (1934) and Davis and Matthews (1944) for the southern CIS. Ice thickness likely exceeded 2000 m near the divide and topped most mountain peaks (Jackson, 1989). Despite the thickness of the Selwyn lobe, ice-flow was thought to be dominantly topographically controlled (Jackson, 1987; Jackson *et al.*, 1991). However, aligned landforms below 1700 m in the Big Salmon Range (southwest of Pelly Mountains) suggest Cassiar lobe flow over these mountains was topographically unconstrained (Bond, 2007). This indicates that glacial flow dynamics varied across the northern CIS and were more complex than previously thought.

METHODS

TERRAIN MAPPING

A 1:50 000-scale terrain map was constructed for Howard's Pass utilizing 1:40 000-scale air photos (2004), combined with helicopter and foot traverses during the 2006 and 2007 field seasons. Mapping criteria followed a modified version of the Terrain Classification System for BC (Howes and Kenk, 1997). Some common processes,

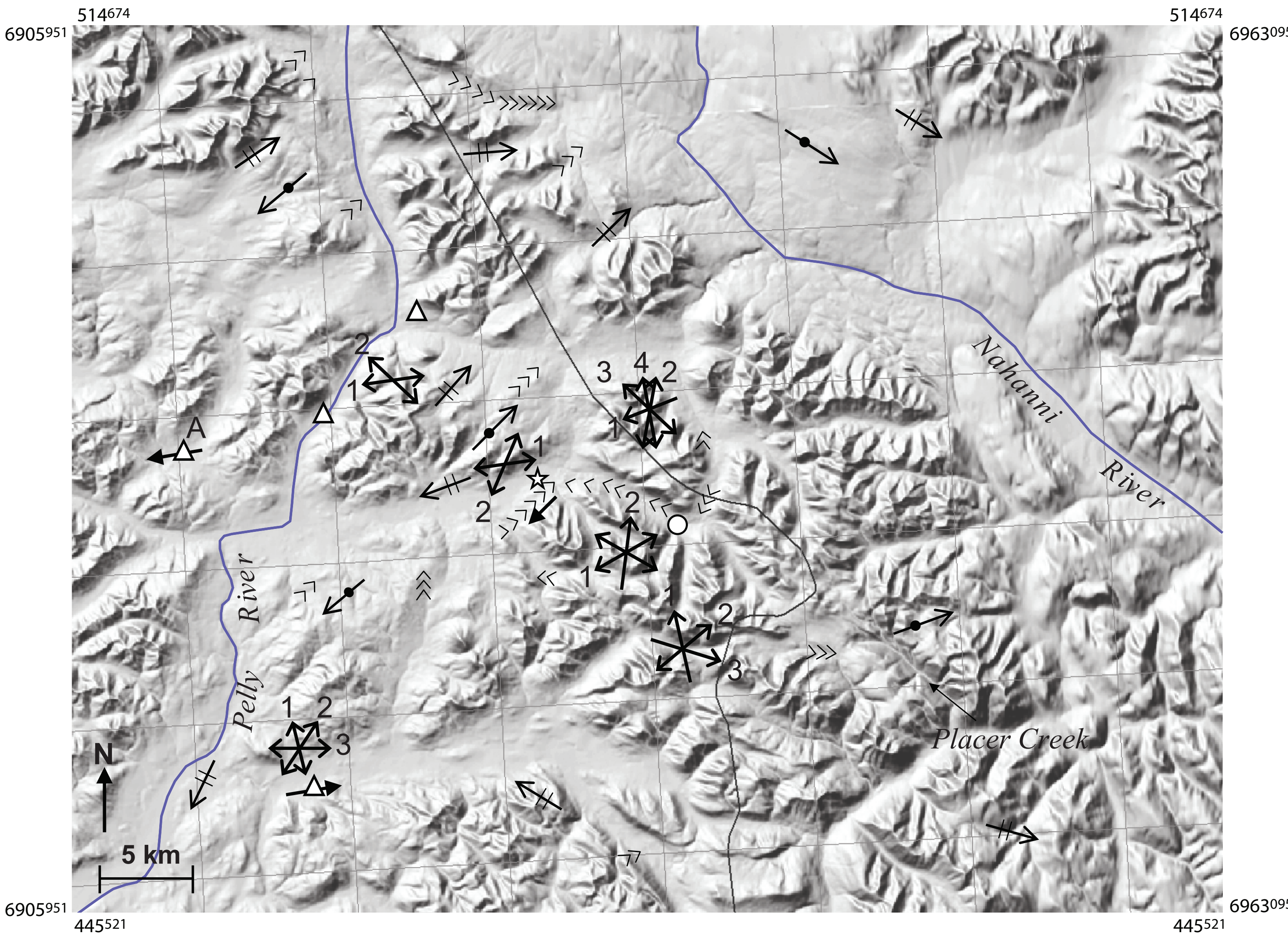
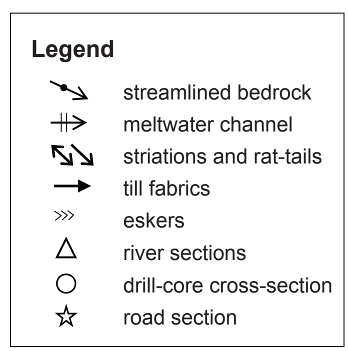


Figure 3. *Map of ice-flow indicators in Howard's Pass. Numbers by striations denote age relations. The section in Figure 5 is indicated with an A. The road section denoted by a star is at Don camp.*



such as permafrost and creep, were only indicated where they were unusually prevalent or hazardous.

ICE-FLOW

The ice-flow history of Howard's Pass was investigated during the 2007 field season in order to create a terrain map. In addition to investigating the distribution of surficial sediments, detailed descriptions were made of stratified sections exposed by streams and roads, and Quaternary sediments in drill core. These data provide important information on the timing and dynamics of the various ice-flows and the sedimentology of surficial units.

Other methods allowed quantification of late Wisconsinan ice-flow in Howard's Pass. One such technique used was tracing erratic boulders of distinctive lithology throughout the study area. Direct ice-flow indicators such as striations, rat-tails, till fabrics, crag and tails, and roches moutonnées were measured throughout the area. Indirect indicators such as the distribution of meltwater channels, moraines and eskers were also noted during mapping.

GEOCHEMISTRY

Previous analysis of glacially dispersed geochemical anomalies in Howard's Pass has been impeded by a lack of documented ice-flow history, combined with a sample

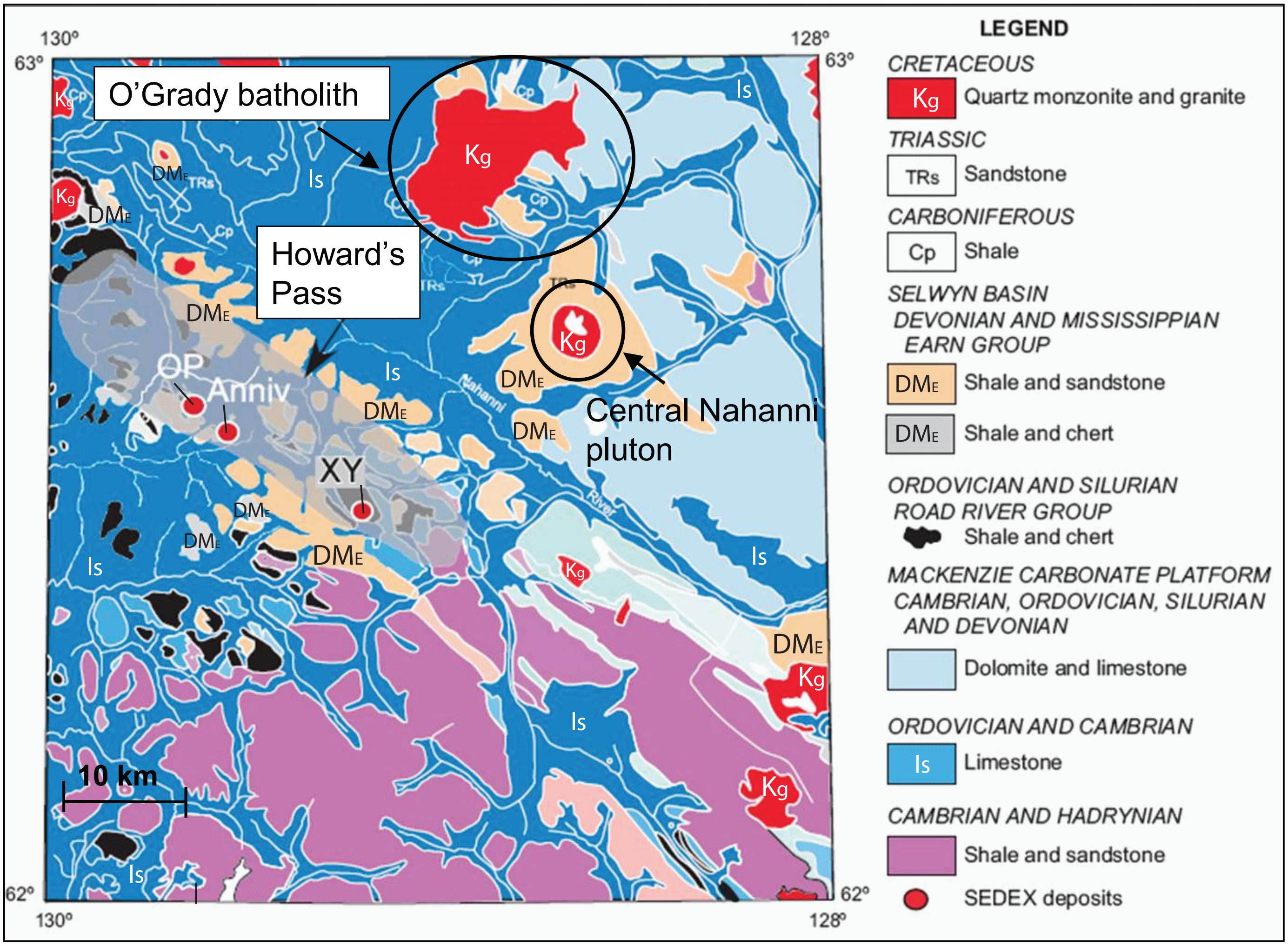


Figure 4. *Bedrock map of Howard's Pass. Granodiorite erratics found in Howard's Pass are likely sourced in either the O'Grady batholith or the Central Nahanni pluton (modified from Gordey, 1981).*

collecting procedure that did not take into account the source of surficial materials. In order to test the applicability of MMI geochemistry versus till geochemistry, a case study was conducted over the known Anniv Central deposit, part of the Howards Pass property (105I 012, Yukon MINFILE 2007[1]).

MMI geochemistry is a controversial method that utilizes the loose attachment of mobile ions to soil particles as they migrate from oxidizing mineral deposits to the surface. Diffusion, convection and capillary rise are all suggested mechanisms for this transportation. Mobile ions are converted at the surface to insoluble compounds or particles occluded to, or strongly adsorbed onto, soil materials (Mann *et al.*, 1998). This conversion occurs during pedogenic development. MMI anomalies are found directly above underlying mineralized bedrock (Harris *et al.*, 1988).

The purported benefits of using MMI geochemistry in mountainous terrain include sharp and precise anomalies, minimal nugget effects and the ability to detect deeply buried mineralization (Mann *et al.*, 1998). In addition, because the mobile ions migrate upwards to the same depth regardless of material type, samples are taken at a fixed depth, simplifying the sampling process.

In the summer of 2006, MMI and till geochemistry samples were collected at 39 locations over the known Anniv Central deposit in Howard's Pass. MMI samples were collected using four 10-cm increments at each location to evaluate which interval contained the highest element concentrations. MMI samples were analysed for 45 elements by the MMI Multi-Element Leach (MMI-M)

[1]http://www.geology.gov.yk.ca/databases_gis.html

complimentary of SGS Minerals. Aqua-regia digestion and multi-element analyses of the silt and clay fraction of the till samples, with sieving down to the 180-micron (80 mesh) size, was done at ALS Chemex Labs Ltd.

RESULTS

TERRAIN MAPPING

A terrain map of Howard's Pass is being completed as part of this thesis study and will be released as an open file map soon. The map will be useful for reconstructing the glacial history by indicating the location of meltwater channels, eskers, streamlined bed-forms and potential stratigraphic sections. This map will also assist resource development in the area, as it will portray the character and distribution of surficial materials. Six types of surficial material were identified in Howard's Pass: till, glaciofluvial, glaciolacustrine, colluvium, organic and fluvial.

Till: Till is ubiquitous throughout the study area, occurring as thick deposits on valley bottoms, and blankets and veneers on gentle to moderate slopes. It is composed of clayey silt diamicton with 10 to 40 % clasts of variable lithology. Till locally contains segregated ice lenses, so development on northern or organic-material-mantled slopes should proceed with caution. It is suitable as a bulk fill and, because of its fine-grained matrix, as an impermeable liner for tailing ponds.

Glaciofluvial: Glaciofluvial deposits are concentrated in the valley sides and bottoms where they comprise terraces, kames and eskers. These sediments are typically massive to weakly stratified sand and gravel. Their quality as an aggregate resource varies, with some gravel consisting of poorly indurated shales that break down easily. The excellent drainage of these deposits results in few segregated ice lenses. Glaciofluvial deposits therefore make good locations for roads and other infrastructure development.

Glaciolacustrine: Glaciolacustrine sediments are uncommon in Howard's Pass. They are mostly restricted to small tributary valleys or are adjacent to glaciofluvial ridges and hummocks. Northeast of the study area,

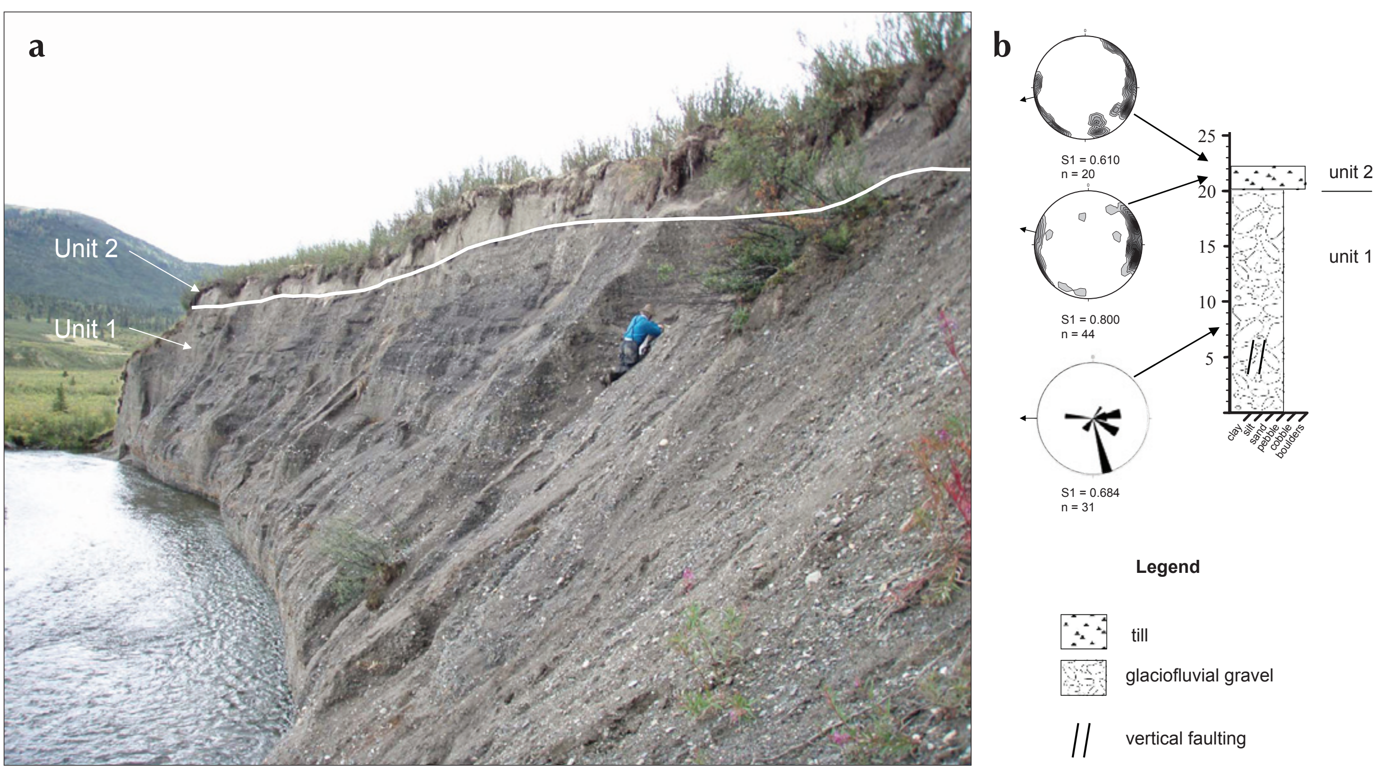


***Figure 5. (a)** Section exposed by a river west of the Pelly River. **(b)** Stratigraphic log of the exposure. Unit 1 is coarsening-upwards pebble-cobble glaciofluvial gravel. Unit 2 is a basal lodgement till. The primary eiganvalue (S1) is a statistical analysis of the orientation of elongate clasts. The higher the S1, the more representative the distribution plot is for ice-flow. Little arrows indicate the interpreted westward ice-flow direction.*

Jackson (1987) mapped a large glaciolacustrine deposit in the Nahanni valley that formed during ice retreat. Glaciolacustrine sediments consist of stratified sand, silt and clay. Their low permeability, poor drainage and high *in-situ* moisture content can result in ice lenses that melt and cause large slumps, but this permeability also makes them excellent liner material for mine construction.

Fluvial: Fluvial deposits consisting of stratified sand and gravel found in, and adjacent to, modern streams running through Howard's Pass occur as floodplains, terraces and fans. Most of these deposits are limited to narrow channels and fans, but in the larger rivers, such as the Pelly and the Nahanni, these materials can be substantial. Floodplains are generally poor sites for development despite favourable foundation conditions. This is due to potential flooding, especially from ice jams during break-up. Many smaller streams transporting sediment down mountain-sides develop fans in valley bottoms. These features may contain useful construction materials, but they are also prone to hazards such as debris flows, debris floods and rapid channel avulsions.

Organic: Organic deposits are accumulations of vegetative matter thicker than 1 m. They are commonly found in floodplains, areas of shallow permafrost, and other locations with poor drainage. Their susceptibility to freeze-thaw processes, compressibility and the common presence of permafrost makes them a poor foundation for roads. In zinc-rich areas in Howard's Pass, organic deposits are highlighted by bright green zinc accumulation in mosses fed by spring water (Jackson, 1987).

Colluvial: Colluvium is material that was transported by direct, gravity-driven processes. This includes rapid processes such as rock falls, debris flows and avalanches, as well as slow processes like solifluction and creep. The texture and composition of colluvium varies more than any other material in Howard's Pass due to the range of these processes; angular boulders occur at high elevations, and finer grained sediments are on gentle slopes. Thus, its utility as aggregate material also varies across the study area. However, due to the hazards commonly associated with this material, sites with colluvium are not recommended for infrastructure development.

QUATERNARY STRATIGRAPHY

River sections

Four river-cuts in valleys oriented both west and south expose similar stratigraphy. One section in a valley west of the Pelly River reveals two units (Fig. 5). Although the upper unit is exposed at the surface, glaciofluvial hummocks and terraces lie adjacent to, and stratigraphically above, the exposure. This relation is similar to the stratigraphy preserved in drill core and described below.

Unit 1 is a 20-m-thick deposit of coarsening-upward, horizontally bedded pebble and cobble gravel with a fine to coarse sand matrix. Paleocurrent measurements in this unit suggest it was deposited by a river flowing down-valley to the west (Fig. 5b). Extensive post-depositional faulting crosscuts bedding. This faulting was caused by glacial compression after deposition and indicates that unit 1 is a glaciofluvial deposit that pre-dates the last glaciation.

Unit 2 is a consolidated grey diamicton with a clayey silt matrix approximately 1.8 m thick. It is interpreted as a till lying unconformably over unit 1. Mean clast measurements of two fabrics between 50 and 75 cm above the lower contact are plunging east and only vary by 10°. These fabric measurements indicate ice was flowing west down this valley since till clasts are deposited plunging 180° to the direction of ice-flow. Unit 2 is a late Wisconsinan till deposited during valley-parallel flow.

Road sections

A recent road cut through a 17-km-long, 10-m-high system of eskers near Don camp was examined (Figs. 3, 6). The best exposure contained three units (Fig. 6). Unit 1 is a consolidated, grey, jointed diamict with a strong clast fabric indicating it is a till deposited by a glacier flowing to the southwest (Fig. 6b). In addition, a 3-m-diameter boulder exposed near Don camp that likely originated from this unit has rat-tails and striations on it, supporting a southwest flow direction.

Unit 2 is a 1 m, loosely consolidated, black diamict. It has a weak fabric and abundant interlaminated silt and sand rip-ups. Its upper contact undulates and the unit pinches out to the southeast. Unit 2 is interpreted as a meltout till that deposited into a subglacial channel. The associated silt and sand rip-ups were deposited as unit 2 was remobilized during deposition of unit 3.

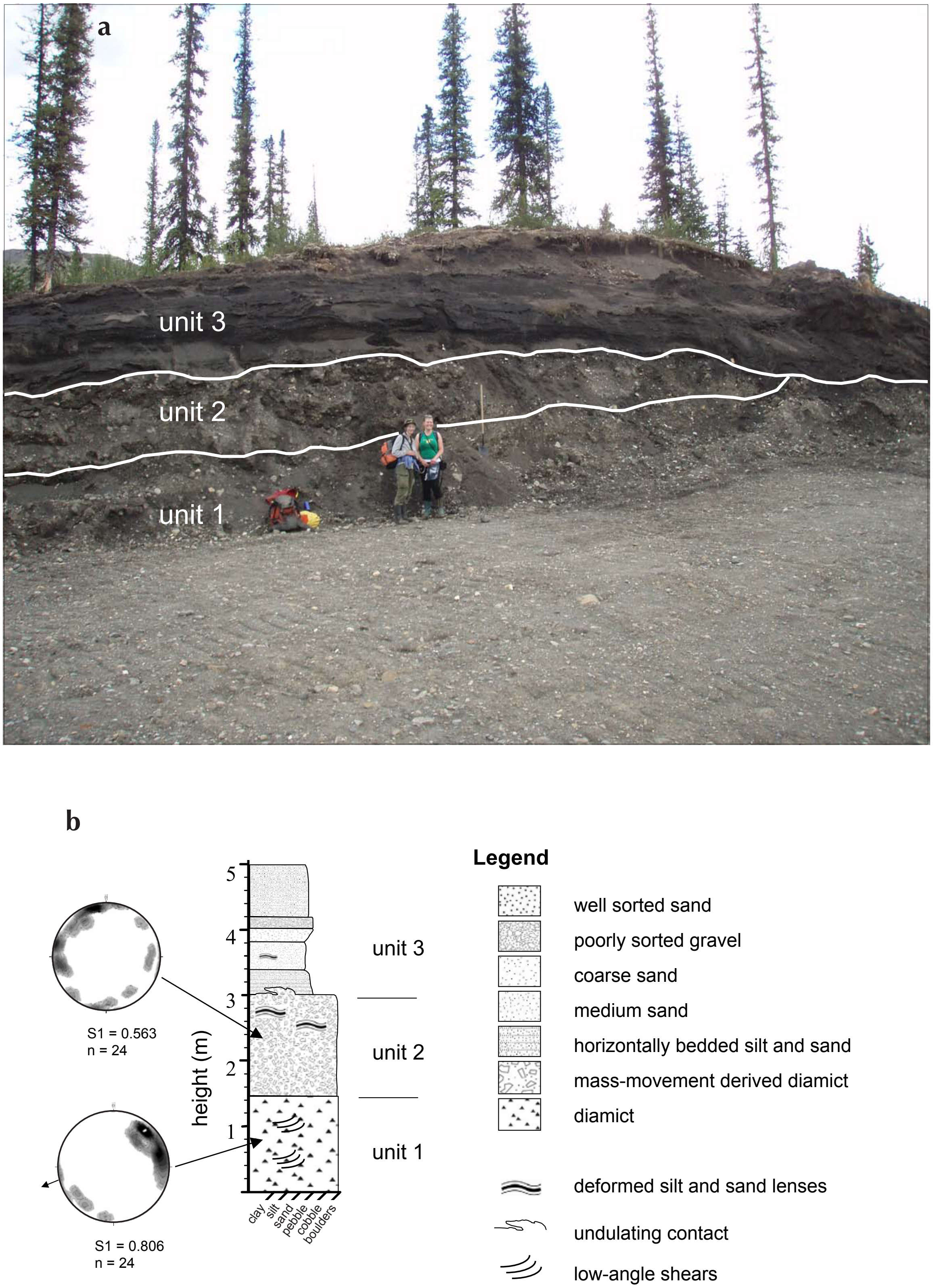


Figure 6. (a) *Road cut through an esker at Don camp.* ***(b)*** *Stratigraphic log of the section. Unit 1 is interpreted as a basal till, unit 2 is a meltout till that was subsequently remobilized, and unit 3 is the base of an esker. The difference between the S1 of the basal and meltout till supports their formation through different processes.*

Unit 3 is a 60-cm-thick, horizontally interbedded sand and silt layer that was exposed by road cuts throughout the esker system. These sand and silt layers are reversely graded with parallel to sub-parallel stratification and contain large diapirs that crosscut bedding. However, in this exposure and others, the unit becomes finer grained outward from the ridge crest, and contains climbing ripples. This sedimentology, combined with the morphology of the ridges, suggests unit 3 is a subglacially deposited esker flowing to the northeast (Saunderson, 1975; Brennand, 1994).

Drill core

Drill core from 18 holes in the Don valley provides otherwise inaccessible stratigraphic information. Eight of these holes contain multiple units that correlate across the valley and reveal both advance- and retreat-phase glacial deposition (Fig. 7). Holes Don-87, 104, 111 and 112 contain thick glaciofluvial deposits overlying a diamict interpreted as a till. Don-104 and 111 also have a thin glaciofluvial unit lying stratigraphically below the till. This sequence suggests advance glaciofluvial accumulation, followed by till deposition during glaciation, and subsequent deglacial glaciofluvial deposition. The pre-glacial floodplain illustrated in Figure 7 is inferred from the position of unit 1 exposed in the river cuts, below till.

ICE-FLOW

The most reliable and direct ice-flow indicators in Howard's Pass are striations and rat-tails. Crosscutting, bidirectional striations were observed in six areas (Fig. 3). These striations show either minor changes in ice-flow or multiple ice-flows in different directions. Striations in Earn Group conglomerates are typically accompanied by rat-tails that indicate unidirectional flow and confirm all the major flow directions. Supporting the striation data are large-scale streamlined bedrock features. These ridges observed on aerial photographs are prominent west of the Pelly River and in the Nahanni River valley (Fig. 3).

Erratics, meltwater channels and glaciofluvial deposits are indirect indicators of ice-flow in Howard's Pass (Fig. 3). Approximately 35 granodiorite erratics were observed at elevations ranging from 1100-1650 m. These erratics likely originated from either the Central Nahanni pluton or the O'Grady batholith to the east, indicating ice-flow to the west (Fig. 4). Abundant meltwater channels formed either as lateral channels beside a glacier, or proglacially, in front of a glacier during deglaciation. In the study area, meltwater channels at high elevations trend towards the northeast, whereas at lower elevations, they tend to be oriented valley-parallel. As these form during deglaciation, they indicate that the ice sheet was initially sloping toward the northeast and then became more topographically controlled. Eskers and kame deltas indicate the direction of flow during late deglaciation.

GEOCHEMISTRY

MMI surveys require sampling at the same depth regardless of material type. The case study was therefore designed to test which interval would be best for future

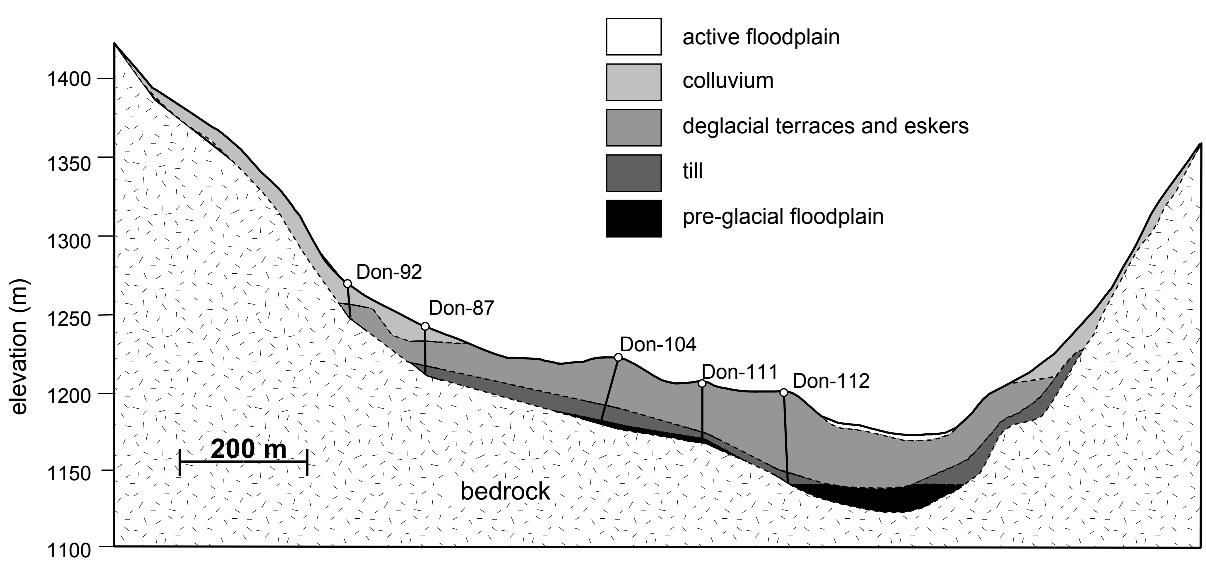


Figure 7. *Cross-section of the surficial materials in the Don valley. Depths of materials are inferred from Quaternary sediments in drill holes.*

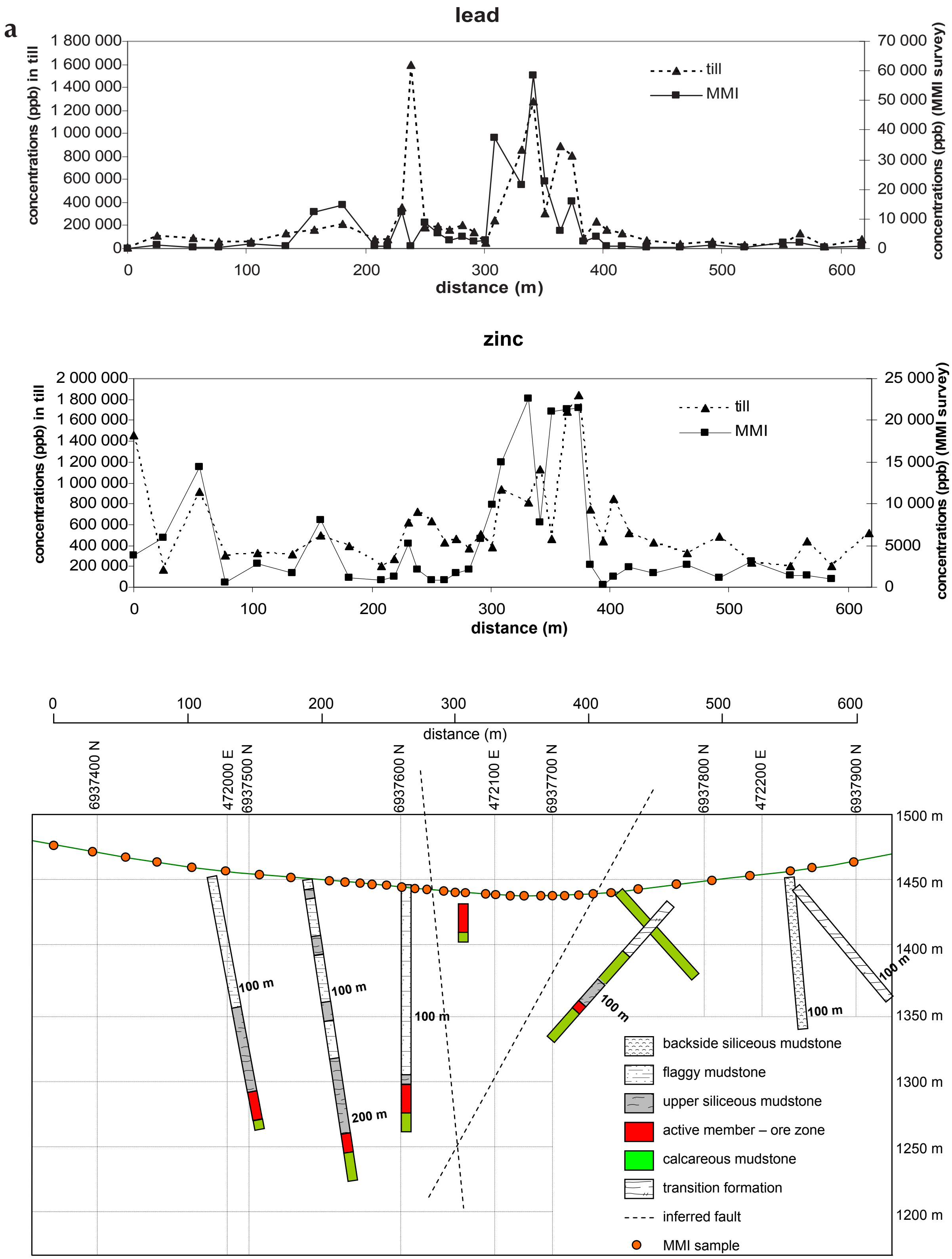


Figure 8. (a) *MMI vs till geochemistry profiles for lead and zinc from the 0-10 cm increment of an orientation survey completed in 2006 over the Anniv Central deposit, compared with drill hole logs. Till metal concentrations are significantly higher than those done with MMI. The ore zone is bounded by two inferred faults.* ***(b)*** *Profiles for potential pathfinders silver, nickel and cobalt over the same ore zone.*

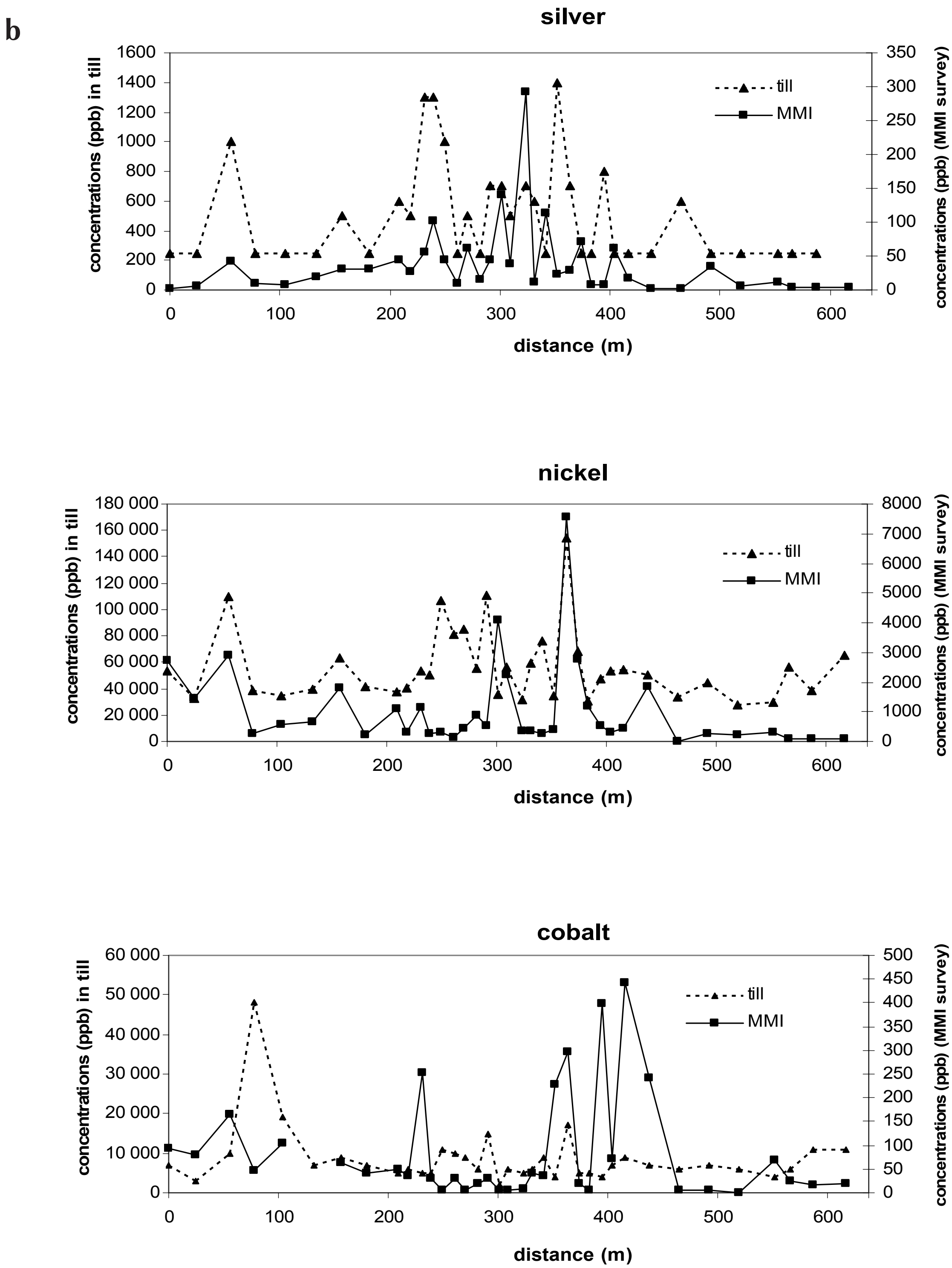


Figure 8. (b) *caption on previous page*

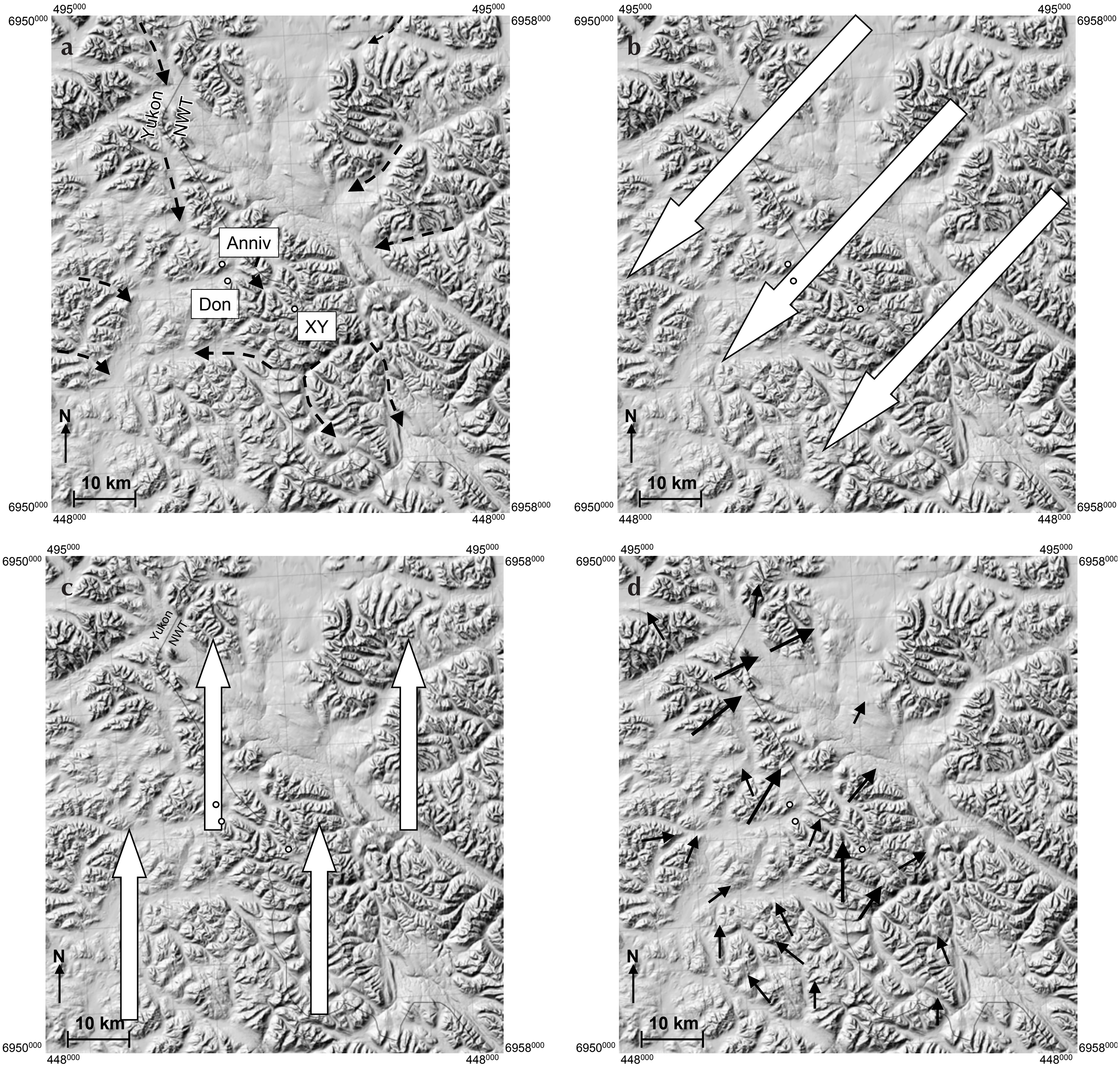


Figure 9. ***(a)*** *Alpine stage – topographically controlled ice-flow from local cirques. The only evidence for this is a groove found west of Anniv. Arrow size indicates strength of flow.* ***(b)*** *Nahanni stage – ice-flow originating east of the Nahanni River flowing southwest across Howard's Pass.* ***(c)*** *Logan stage – following an ice-divide migration across the study area, ice-flow was directed north across Howard's Pass.* ***(d)*** *Don stage I – as the ice thinned it became more topographically controlled. Ice-flow was still generally north-northeast across the study area.* ***(e)*** *Don stage II – When the ice thinned below topographic highs, it oriented parallel to the major valleys in Howard's Pass. It was during this phase that the till exposed in river sections (white triangles) was deposited.*

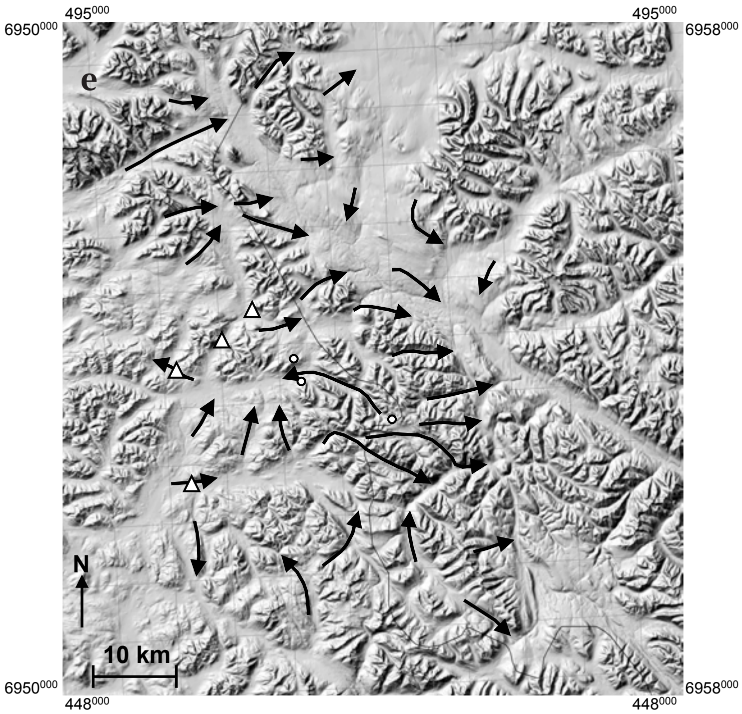


Figure 9. *continued from previous page*

surveys in addition to what the concentration ranges of various elements of interest were. For most elements, the most reactive interval was 30-40 cm. However, lead was more reactive between 0-10 cm. Both zinc and lead show significant peaks above the ore zone (Fig. 8). Other elements such as nickel, silver and cobalt also showed small anomalies over the ore zone. The average concentration of lead over the ore zone was 20 060 ppb, compared to 2880 ppb outside the ore zone. Zinc ranged from 17 260 ppb over the ore zone to 4580 ppb outside the ore zone (Fig. 8a). The trends from the till samples for lead, zinc and to a lesser extent, silver mimic those from the MMI survey. The concentrations of the till samples were significantly higher than the MMI samples, likely due to the different digestion techniques used.

DISCUSSION

ICE-FLOW STAGES

At least four stages of ice-flow occurred during the last glaciation. These stages corroborate Fulton's (1991) model of growth and decay for the Cordilleran Ice Sheet (CIS). The earliest of these (Alpine stage, Fig. 9a) involved alpine ice extending out of local cirques. While this stage is largely inferred, evidence was documented at one site where a glacial groove was crosscut by striations from a subsequent phase.

When the Selwyn lobe initially attained maximum thickness, the ice divide was positioned east of the Nahanni River, causing a southwestward flow across the study area (Nahanni stage, Fig. 9b). Multiple granodioritic boulders of various textures located at different elevations throughout Howard's Pass indicate that this flow covered the highest peaks in the study area. There are also streamlined bedrock ridges and striations that corroborate the Nahanni stage.

Following the Nahanni stage, the ice divide migrated to the southwest causing ice-flow to shift to the north (Logan stage; Fig 9c). This migration was likely due to increased accumulation on the windward side of the Selwyn lobe. Evidence for the subsequent northward flow from this stage are crag and tails near the Anniv camp airstrip, multiple sets of striations and rat-tails, and abundant meltwater channels at high elevations across Howard's Pass. The deflection of some striations and crag and tails around topographic highs indicate that this flow was at least somewhat topographically controlled.

During initial deglaciation, ice thinned until topography had a significant effect on ice-flow (Don stage, Fig. 9d, and 9e). Initially, ice flowed across the Nahanni River to the northeast. However, with increasing ablation, the ice eventually flowed down the Nahanni Valley to the southeast.

In the Don Valley, meltwater channels above ~1400 m above sea level (a.s.l.) indicate the ice sloped towards the northeast, which contrasts with westerly dipping channels below 1400 m a.s.l. As ice thinned further, it was unable to flow over the ridge adjacent to Anniv camp and instead flowed valley-parallel (Fig. 9e). In the latest stages, ice began to stagnate; eskers formed according to localized controls on subglacial hydraulics, mainly ice thickness, and likely do not represent significant ice-flow.

Several data indicate that Howard's Pass deglaciated by stagnation and downwasting before approximately 9000 ka BP (McDonald, 1983), rather than by frontal retreat into source areas. The only end moraines observed in the study area are located in cirques and are likely due to a small, local readvance following regional deglaciation. The lack of large, recessional moraines in the valley bottoms suggests linear retreat did not occur in these valleys. Instead, thick kame and kettle deposits in many valley bottoms indicate that ice melted in place. These deposits imply an uneven ice surface during melt, causing pockets of coarser sediments to collect and form local topographic highs bounding lower energy deposition in lakes. These landforms are more likely to form with stagnant ice rather than flowing ice.

IMPLICATIONS FOR DRIFT PROSPECTING

The ice-flow history of Howard's Pass is significant for drift prospecting. Typically, the last phase of ice-flow is the most important for tracing anomalous geochemical signatures (Plouffe and Bond, 2004; Bond, 2007). However, the direction and distance that sampled material has been transported changes with elevation across the study area.

At lower elevations in the study area, the Don stage was the last phase of ice-flow. This stage was highly topographically dependant and likely remobilized material that had been previously transported by earlier ice-flows. Anomalies at low elevations are therefore more likely to be valley-parallel and may be more difficult to interpret as they contain sediment that could reflect transport during multiple stages of ice-flow. Conversely, at higher elevations, the ice-flow history is simplified and the Nahanni and Logan stages of ice-flow controlled drift transport. These flows would result in more fan- or amoeba-shaped anomalies. Unfortunately, the elevation at which the change occurs, from simple to complex ice-flow history, varies across Howard's Pass.

Locally, variations in ice-flow can affect drift prospecting. Ice-flow during the Don stages was simpler at XY camp than at Don camp. At the XY camp, ice emanated from cirques to the south and southwest and was directed by topography to the northwest across XY camp, and east down Placer Creek. As this ice melted, a small lake developed on the plateau where XY camp is currently located. This lake was ponded against ice in the valley to the northwest and fed by ice to the north and east.

The MMI survey over Anniv Central shows anomalous values of lead and zinc directly over near-surface mineralized bedrock (Fig. 8a). However, samples taken at the edge of the survey that overlie more deeply buried mineralization, are also unusually high for background concentrations (W. Grondin, pers. comm., 2007). These high background values suggest either that the MMI technique can recognize mineralization through approximately 200 m of non-mineralized bedrock and drift, or that background levels are unusually high because of abundant black shales in the area. If the survey edges are detecting deeply buried mineralization, then this geochemical cross-section provides important data into the concentration change with depth. The central lead and zinc anomaly would then be reflecting the near-surface mineralization, with the inferred faults possibly acting as conduits for ion transmission. Another MMI survey extending further off an ore zone is necessary to reveal the true background concentrations in the area and to test the penetration depth of MMI geochemistry through bedrock.

Other elements, such as nickel and cobalt, were anomalous over the ore zone only in MMI samples (Fig. 8b). Conversely, elements like silver were detected by both MMI and till geochemistry, but had more contrast in the MMI samples. The similarity between the anomalies found with these elements, and the anomalies found for lead and zinc, indicates that silver, nickel and cobalt are potential pathfinders in Howard's Pass.

CONCLUSIONS

A better understanding of the glacial history is vital to interpreting geochemical data in Howard's Pass. The earliest stage of ice-flow involved valley glaciers originating in local cirques. As these glaciers coalesced and developed into an ice sheet, the ice divide was centred east of the Nahanni River. The flow during this stage was southwest across Howard's Pass and completely covered the landscape.

Prior to deglaciation, the ice divide migrated across the study area and ice flowed dominantly north across Howard's Pass. As the ice sheet melted, increased topographic control channeled flow parallel to the major valleys. Deglaciation in Howard's Pass commenced through rapid starvation and widespread stagnation of the ice sheet.

The complicated glacial history of Howard's Pass makes tracing geochemical anomalies difficult. A MMI geochemistry case study completed directly over a known deposit resulted in anomalous values of lead, zinc, silver, nickel and cobalt. This result possibly indicates that MMI geochemistry can penetrate through at least 200 m of bedrock, and potentially reveals multiple elements that are potential pathfinders for lead and zinc in Howard's Pass.

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