# QUATERNARY GEOLOGY AND TILL GEOCHEMISTRY STUDIES IN THE NECHAKO AND FRASER PLATEAUS, CENTRAL BRITISH COLUMBIA (NTS 93 C/1, 8, 9, 10; F/2, 3, 7; L/16; M/1)

By Victor M. Levson
British Columbia Geological Survey
and Timothy R. Giles
Ministry of Forests

*KEYWORDS:* Surficial geology, Quaternary stratigraphy, drift exploration, till geochemistry, ice-flow history, glaciation, soil geochemistry

## INTRODUCTION

Mineral exploration programs in the Interior Plateau physiographic region in central British Columbia have been hindered as a result of a widespread and often thick mantle of glacial drift including till, glaciofluvial sediments and glaciolacustrine sediments. In order to address this problem, 1:50 000-scale surficial geology mapping, regional till geochemical surveys (Table 1) and case study investigations were conducted in the region by the British Columbia Geological Survey as part of the Canada/British Columbia Mineral Development Agreement (1991-1995). Stratigraphic and sedimentologic studies of Quaternary deposits were also conducted in order to define the glacial history and aid in interpreting till geochemical data. The program focused on areas of perceived high mineral potential in the northern Fraser Plateau (1992/3), the southern Nechako Plateau (1993/4 and 1994/5) and the northern Nechako Plateau (1995/6) regions (Figure 1). The main objectives of the program were to:

- understand and map the distribution of Quaternary deposits;
- decipher the glacial history and ice-flow patterns;
- locate areas most suitable for conducting drift exploration programs;
- identify geochemically anomalous sites for follow-up by the mineral exploration industry;
- evaluate the effects of surficial processes on geochemical distribution patterns;
- refine models of glacial dispersal in montane and plateau areas; and
- develop methods of drift exploration applicable to the Interior Plateau.

A number of publications relating to this program have been released, including surficial geology and till geochem-

TABLE 1
REGIONAL TILL GEOCHEMISTRY SURVEYS CONDUCTED IN THE NECHAKO PLATEAU AREA: 1992-1995

| Survey Date | 1:50,000 Survey Area | NTS | Area ($km^2$) | Sites | Sampling Density ($\#/km^2$) |
|---|---|---|---|---|---|
| 1992 | Chilanko Forks | 93C/01 | 952.6 | 71 | 13.4 |
| | Chezacut | 93C/08 | 947.3 | 83 | 11.4 |
| | Clusko River | 93C/09 | 942 | 86 | 11.0 |
| | Toil Mountain | 93C/16 | 936.7 | 91 | 10.3 |
| 1993 | Fawnie Creek | 93F/03 | 931.3 | 171 | 5.4 |
| 1994 | Tsacha Lake | 93F/02 | 931.3 | 195 | 4.8 |
| | Chedakuz Creek | 93F/07 | 925.9 | 143 | 6.5 |
| 1995 | Fulton Lake | 93L/16 | 893.3 | 304 | 2.9 |
| | Old Fort Mountain | 93M/01 | 887.8 | 293 | 3.0 |
| | *Totals:* | | **8348.2** | **1437** | **5.8** |

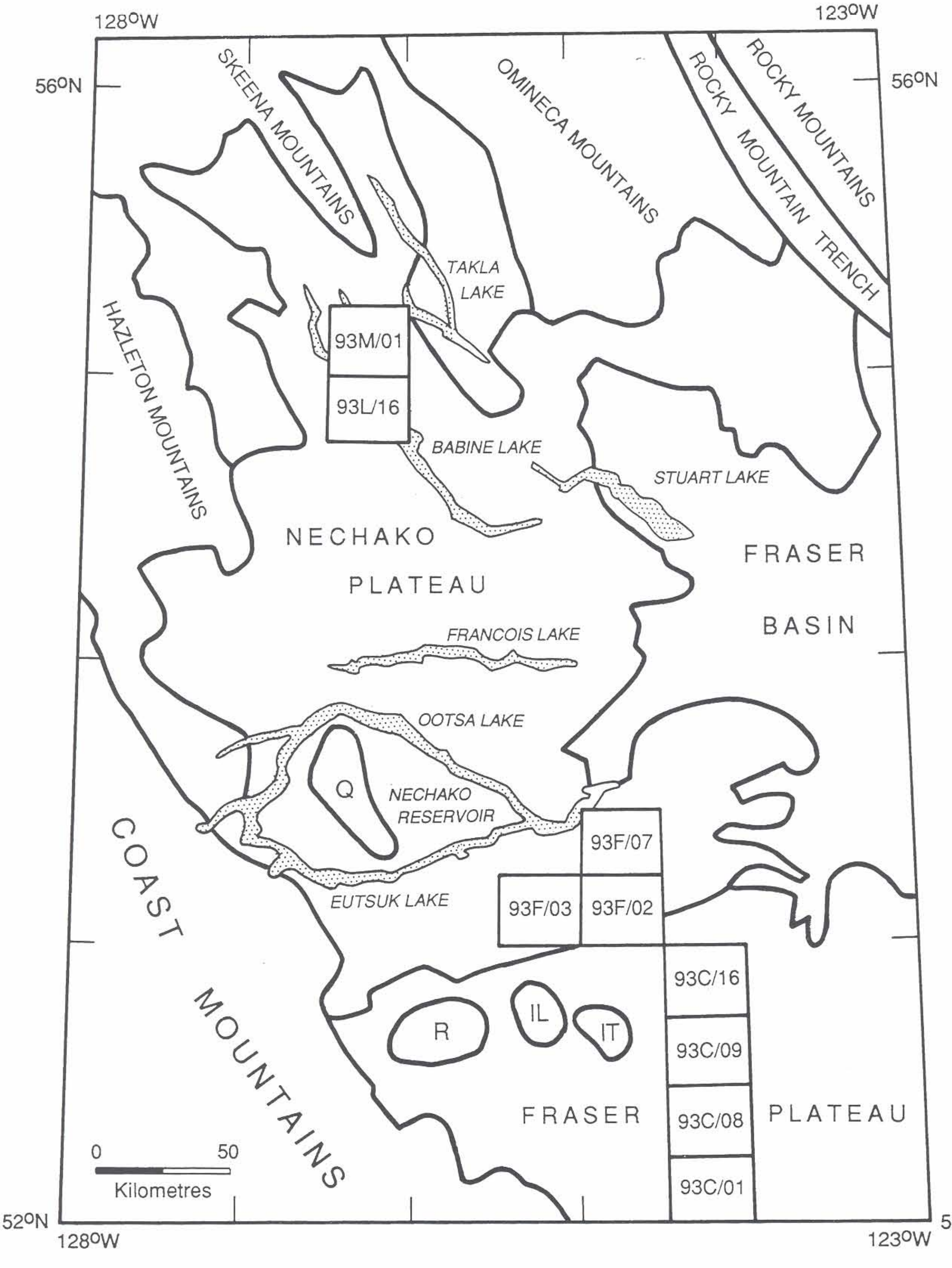

Figure 1. Physiography of the study region (after Holland, 1976); location map of areas studied in 1992 (93C/1, 8, 9, 16), 1993 (93F/3), 1994 (93F/2 and F/7) and 1995 (93L/16, M/1); R-Rainbow Range, IL-Ilgachuz Range, IT- Itcha Range, Q- Quanchus Range.

istry data for the Fawnie Creek map area (93F/3; Giles and Levson, 1994a, b; Levson and Giles, 1994; Levson *et al.*, 1994) and surficial geology data for the Chilanko Forks - Chezacut map areas (93C/1 and 8, respectively; Giles and Kerr, 1993, Kerr and Giles, 1993a, b), Clusko River - Toil Mountain map areas (93C/9 and 16, respectively; Proudfoot, 1993, Proudfoot and Allison, 1993a, b), Tsacha Lake - Chedakuz Creek map areas (93F/2 and 7, respectively; Giles and Levson, 1995, Giles *et al.*, 1995; Weary *et al.*, 1995), and Fulton Lake - Old Fort Mountain map areas (93L/16 and M/1, respectively; Huntley *et al.*, 1996). Detailed investigations around areas of known mineralization have also been conducted as part of this program (Levson and Giles, 1995; O'Brien *et al.*, 1995; Stumpf *et al.*, 1996). This paper provides an overview of these studies. This work is part of a multidisciplinary program in the Interior Plateau that includes bedrock geology mapping, lake sediment geochemical sampling and mineral deposit studies (see Diakow *et al.*, Cook, and Lane and Schroeter, respectively, 1996, this volume).

## RELATED STUDIES

Reconnaissance (1:250 000-scale) mapping of Quaternary deposits in the Interior Plateau was conducted by Tipper (1971). Howes (1977) completed 1:50 000-scale terrain mapping in the southern part of the Nechako Plateau. Most recently, Plouffe (1994a, b) completed 1:100 000-scale surficial geology mapping in the central part of the Nechako Plateau. Nine regional (1:50 000 scale) surficial geology maps have been published as part of this program throughout the study area (Figure 1). An annotated bibliography of published studies dealing with glacial dispersal processes in British Columbia was provided by Kerr and Levson (1995). An overview of drift prospecting methods and research of particular relevance to the Interior Plateau region is provided by Kerr and Levson (1996). A wealth of information is also contained in unpublished assessment reports filed with the B.C. Ministry of Employment and Investment (Kerr, 1995). A review of these reports, filed for the southern Nechako Plateau area, was conducted by Levson and Giles (1995) and examples were used to illustrate current methods of exploration in the region, identify typical problems encountered and present information that can be used to develop and refine drift exploration methods. Reconnaissance till geochemical sampling programs in the Interior Plateau have been conducted in the Manson River - Fort Fraser area (93K, N; Plouffe and Ballantyne, 1993; Plouffe, 1995) and the Mount Tatlow - Elkin Creek area (93O/5, 12; Plouffe and Ballantyne, 1994). More detailed till geochemical studies have also been completed around mineral properties in the region such as the Wolf property (MINFILE 93F 045; Delaney and Fletcher, 1994; Levson and Giles, 1995), Mount Milligan (Sibbick and Kerr, 1995), Arrow Lake (Bohme, 1988; Levson and Giles, 1995) and the CH mineral claims (Edwards and Campbell, 1992; Levson and Giles, 1995; O'Brien *et al.*, 1995).

## PHYSIOGRAPHY AND LANDFORMS

The study area includes parts of the Nechako Plateau and the northern Fraser Plateau, in the west-central part of the Interior Plateau (Holland, 1976). These plateaus are areas of low relief compared to the Coast and Hazelton Mountains to the west and the Skeena Mountains to the north (Figure 1). Surface elevations generally range from about 1200 to 1500 metres. Topographic relief in the southern part of the Nechako Plateau is provided mainly by the Quanchus, Fawnie and Nechako ranges (Figures 1 and 2). The highest peaks in each are Michel Peak at 2255 metres (7396 ft), Fawnie Nose at 1925 metres (6319 ft) and Kayakuz Mountain at 1780 metres (5842 ft), respectively. The boundary between the Nechako and Fraser Plateaus occurs at the Blackwater (or West Road) River. The dominant physiographic features in the northern Fraser plateau are a series of Tertiary volcanic centres forming, from oldest to youngest, the Rainbow, Ilgachuz and Itcha ranges (Figure 1).

Flat lying or gently dipping Tertiary lava flows, locally forming steep escarpments, cover older rocks throughout much of the Nechako and, especially, the Fraser plateaus. Glacial drift is extensive and often as little as 5 or 10% of the bedrock is exposed. During Late Wisconsinan glaciation, ice moved into the Nechako and Fraser plateaus from the Coast Mountains to the west and southwest and from the Skeena Mountains to the northwest, before flowing easterly and northeasterly towards the Rocky Mountains (Tipper, 1963, 1971). Well developed flutings and drumlinoid ridges, oriented parallel to the regional ice-flow direction, are dominant features on the plateaus. During deglaciation, stagnant ice topography, large esker complexes, glaciofluvial deposits and meltwater channels, developed in many areas. Much of the variation in topography and surficial geology in the plateau areas is due to these features. In low-lying regions, such as the valleys now occupied by Nechako River, Babine Lake, Nechako Reservoir and Fraser River, large glacial lakes formed and deposited extensive belts of glaciolacustrine sediments, generally below 950 metres elevation. Topography in these areas is subdued and older glacial landforms are often difficult to recognize.

## PROCEDURES

The following field and laboratory procedures have been developed and refined over the course of this four-year study. The methods outlined below are those used during the more recent regional surficial geology mapping and till geochemical sampling programs in the Interior Plateau.

### *FIELD METHODS*

Surficial geology mapping was completed by compilation of existing terrain-mapping data, interpretation of air photographs, field checking and stratigraphic and sedimentologic investigations of Quaternary exposures in the study areas. Ice-flow history was largely deciphered from the measurement of the orientation of crag-and-tail features, flutings, drumlins and striae.

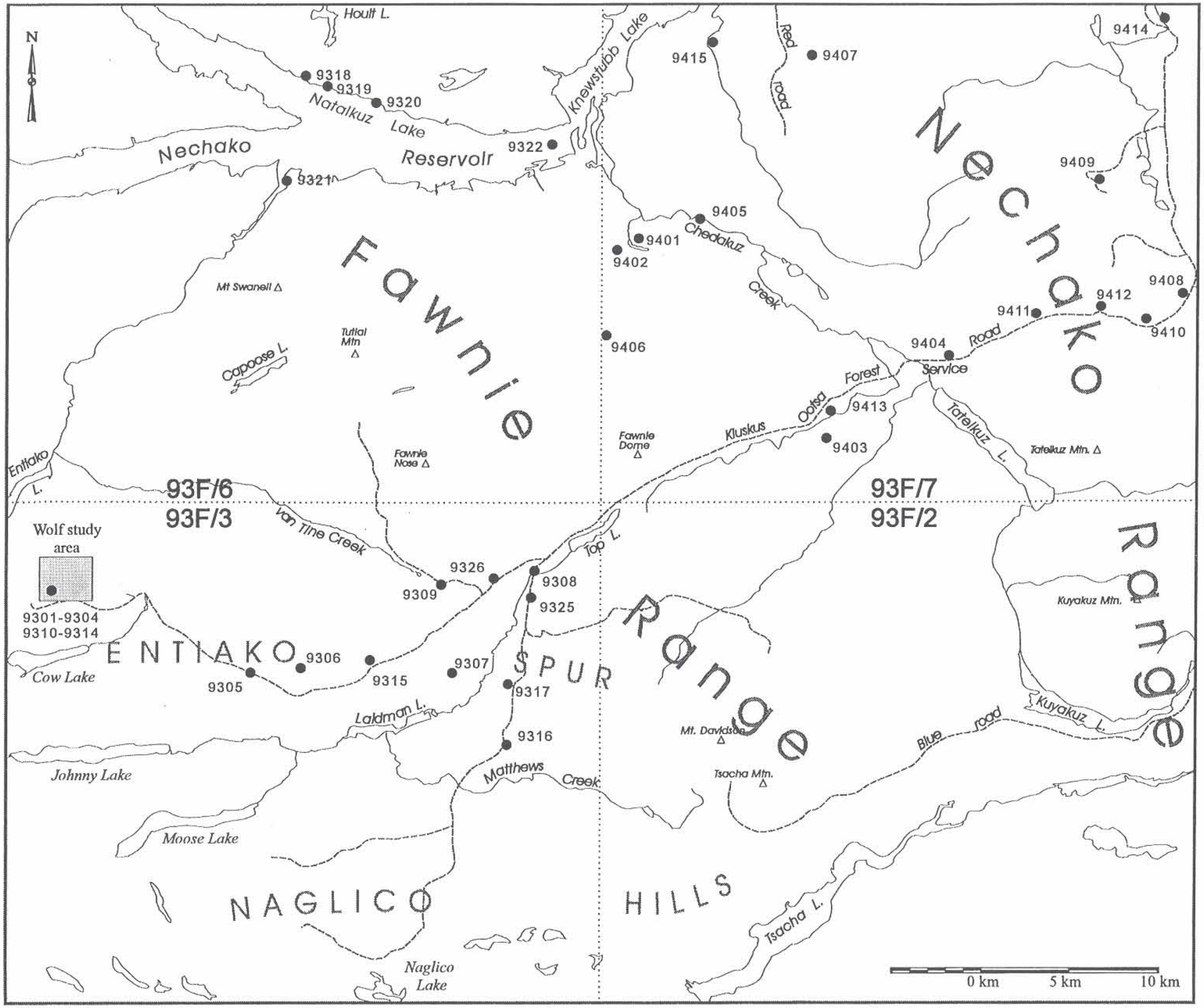

Figure 2. Location map of Quaternary stratigraphic sections described in the southern Nechako Plateau area. Shaded area is the Wolf prospect study area shown in Figure 4.

In the regional till geochemistry program, basal till samples (each 3 to 5 kg in weight) were collected for geochemical analysis in order to locate glacially dispersed metallic minerals in the region. Sample sites were selected to provide complete coverage of the map areas, with the greatest density of samples along transects perpendicular to established ice-flow direction. Along transects parallel to ice flow, where samples repeatedly represent the same terrain directly up-ice and therefore duplicate each other, wide spaced sampling was used. An intermediate sample spacing was used on transects oblique to flow. Sample sites consisted of natural and man-made exposures (roadcuts, borrow pits, soil pits and trenches). Sample depths averaged about 1 metre but varied from about one-half to several metres. Locations were plotted on a 1:50 000 topographic base maps. Sampling was conducted mainly in truck accessible areas near logging roads and forest clear-cuts. Trail bikes, boats and helicopters were also used where feasible. Foot traverses were completed in otherwise inaccessible regions.

Detailed till and soil geochemical sampling were also conducted at several mineral prospects: Wolf (MINFILE 93F 045), Malaput (MINFILE 93F 056), Buck (MINFILE 93F 050), CH (MINFILE 93F 04), Uduk Lake (MINFILE 93F 057), Pem (Blackwater-Davidson, MINFILE 93F 037), Yellow Moose (MINFILE 93F 058) and Stubb (MINFILE 93F 066) properties, in the southern Nechako Plateau, and the Bell mine (MINFILE 93M 001), Babs (MINFILE 93L 325), Lennac (MINFILE 93L 190, 191), Hearne Hill (MINFILE 93M 006) and Saddle Hill (MINFILE 93M 008) properties, in the northern Nechako Plateau (Giles and Levson, 1994a; O'Brien *et al.*, 1995; Stumpf *et al.*, 1995). Samples were collected along linear or fan-shaped traverses to document glacial dispersal and transport distance at these sites and to provide a clearer understanding of glacial dispersal processes. Follow-up studies of newly discovered geochemical anomalies based on results from the Fawnie Creek survey of 1993 (Levson *et al.*, 1994) were also completed.

To reflect mechanical dispersal processes, samples were collected from within the C mineral horizon, which is comparatively unaffected by the pedogenic processes operative in the A and B soil horizons (Agriculture Canada Expert Committee on Soil Survey, 1987; Gleeson *et al.*, 1989). The utility of C-horizon sampling of basal tills for outlining areas of mineralization has long been known (*e.g.*, Shilts, 1973a, b) but, until recently, exploration companies working in the Interior Plateau have generally favoured B-horizon sampling (Kerr, 1995). Although C-horizon samples can be effectively used to identify glacial dispersal trains, important data can also be obtained by sampling the upper soil horizons because, in terms of elemental concentrations, local pedological and hydromorphic processes often favour one soil horizon over another (Bradshaw *et al.*, 1974; Gravel and Sibbick, 1991; Sibbick and Fletcher, 1993). However, it is important to remember that the heterogeneity of elemental concentrations in various soil horizons is dependent on the overburden composition and underlying bedrock lithology as well as geochemical processes acting within the environment (Boyle and Troup, 1975).

Sedimentologic data were collected at all sample sites in order to distinguish till from glacigenic debris flow, colluvium, glaciofluvial or glaciolacustrine sediments. These sediments have different processes of transportation and deposition which must be recognized in order to understand associated mineral anomaly patterns. For example, local variations will be reflected in some sediments while regional trends may be observed in others. Analysis of these sediments will be useful only where their origin is understood. Sedimentologic data collected at each sample site included descriptions of sediment type, primary and secondary structures, matrix texture, presence of fissility, compactness, total percentage and modal size of clasts, rounding of clasts, presence of striated clasts, and sediment genesis and thickness. Further information was noted on soil horizons, local slope, bedrock striae, bedrock lithology, clast provenance and abundance and type of mineralized clasts.

## *ANALYSIS OF CLASTS IN TILLS*

The till sampling program included an evaluation of clasts in the till at each sample site. The objectives were to look for mineralized clasts, decipher patterns of glacial dispersal, determine the distances of glacial transport and rates of clast abrasion and rounding, and relate till-clast lithology to the bedrock lithology to aid in bedrock mapping. The procedure involved field identification of lithology, angularity and abrasion characteristics of each of five categories of clasts: 1) subangular to angular clasts in the basal tills with little or no evidence of glacial transport (*i.e.*, clasts of very local origin); 2) distally derived surface erratics (*i.e.*, clasts of probable supraglacial origin; often cobble to boulder sized); 3) clasts showing abundant evidence of glacial abrasion such as striae and faceting (*i.e.*, basally transported clasts of probable local to intermediate provenenace); 4) clasts of any size or shape showing evidence of potential mineralization (*e.g.*, sulphides, heavy iron oxidation, drusy quartz); and 5) other rock types. A visual survey of a wide area around the sample sites was conducted to locate rocks of category 4, the main focus of the sampling program; these clasts were described and collected for assay.

## *LABORATORY METHODS AND QUALITY CONTROL*

Till samples collected during the regional geochemical surveys were air dried, split and sieved to -230 mesh (<62.5 µm). This fraction was analyzed by instrumental neutron activation analysis (INA) and inductively coupled plasma analysis - atomic emission spectroscopy (ICP-AES) for a total of about 47 elements. The -230 mesh fraction is frequently dominated by phyllosilicates which are generally enriched in metallic elements (Shilts, 1993, 1995) and for this reason it is the preferred fraction to analyze. Half of each sample split was reserved for grain size or other follow-up analyses.

In order to discriminate geochemical trends related to geological factor from those that result from spurious sam-

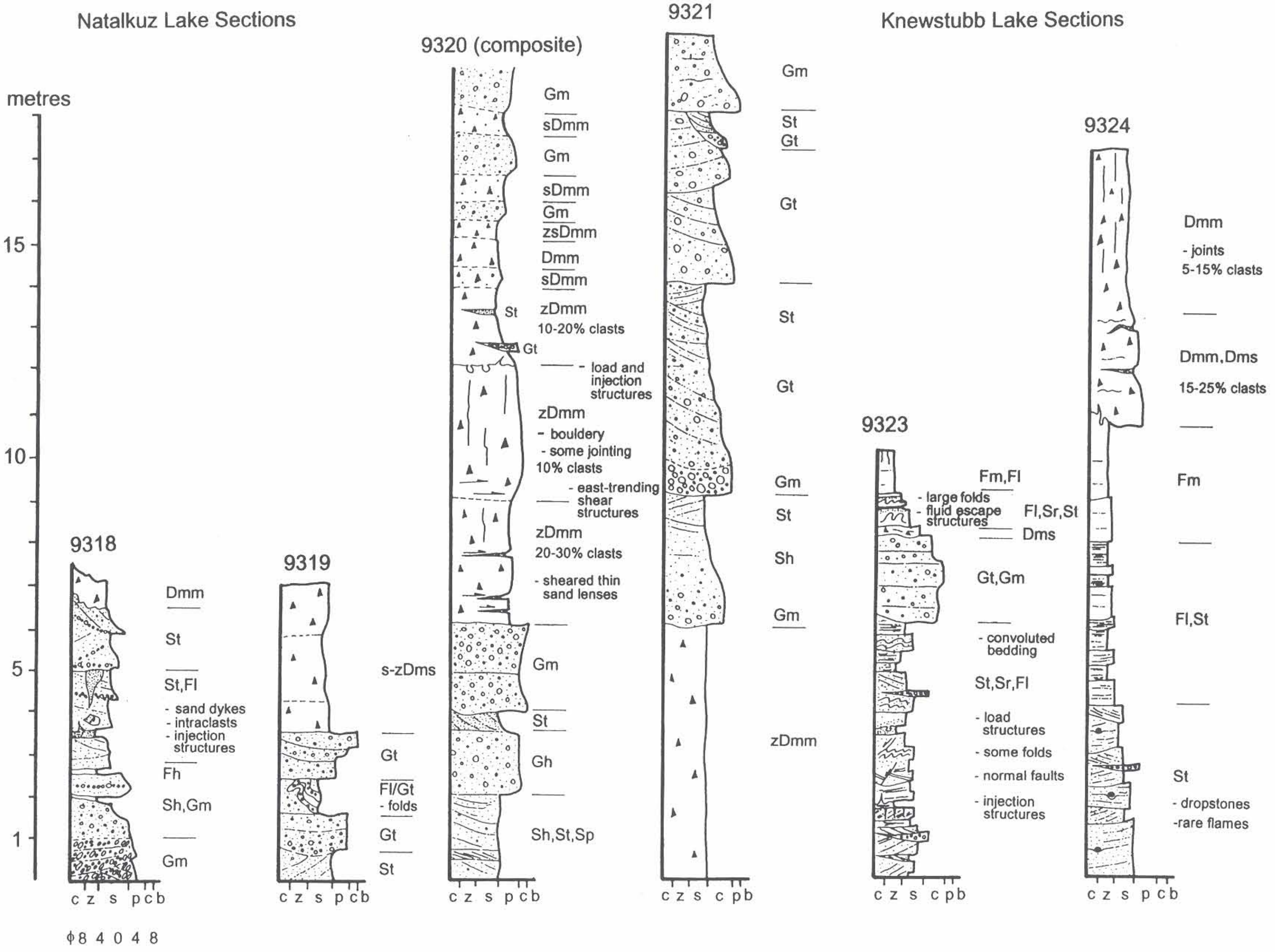

Figure 3. Quaternary stratigraphic sections in the Nechako Reservoir area. Sections located on the Natalkuz Lake reach (9318 to 9321) are shown on Figure 2. Sections 9323 and 9324 are on the Knewstubb Lake Reach just north of the area outlined in Figure 2.

pling or analytical errors, a number of quality control measures were included in both the field and laboratory analysis components of the program. These included the use of field duplicates, analytical or blind duplicates and control standards, one of each being randomly inserted into each set of 17 routine field samples to make a block of 20 samples that were submitted for analysis. Field duplicates were taken from randomly selected field locations and were subjected to the identical laboratory preparation procedures as their replicate pairs. Analytical duplicates consisted of sample splits taken after laboratory preparation procedures but prior to analysis. Control reference standards included several British Columbia Geological Survey (Analytical Sciences Unit) geochemical reference materials comprising the -180 micron size fraction of a variety of bulk samples. A geochemical reference standard of the Canada Centre for Mineral and Energy Technology (Lynch, 1990) was also used.

## QUATERNARY STRATIGRAPHY

### *LATE WISCONSINAN GLACIAL DEPOSITS AND OLDER SEDIMENTS*

Morainal sediments in the Nechako Plateau region were assigned by Tipper (1971) to the Fraser glaciation which is dated in several parts of British Columbia as Late Wisconsinan (Ryder and Clague, 1989). A Late Wisconsinan age for the last glaciation in the region is also indicated by radiocarbon dates on wood and mammoth bones recovered from lacustrine deposits under till at the Bell Copper mine (NTS 93 L/16) on Babine Lake. Single fragments of spruce (*Picea* sp.) and fir (*Abies* sp.), yielding dates of 42 900±1860 years B.P. (GSC-1657) and 43 800±1830 years B.P. (GSC-1687), and a date of 34 000±690 years B.P. (GSC-1754) on mammoth bone collagen from the interglacial sediments (Harington *et al.*, 1974), indicate that the overlying till was deposited during the Late Wisconsinan glaciation. Palynological data from interglacial lake sediments are indicative of a shrub tundra vegetation.

The Quaternary stratigraphy of the southern Nechako Plateau has been reconstructed from a number of exposures in the region (Figure 2). Quaternary sediments underlying till are rarely exposed in the survey areas.

The most complete stratigraphic sections encountered in the region mainly occur in the vicinity of the Nechako Reservoir (Figure 2). The stratigraphic record of pre-Late Wisconsinan events elsewhere in the area was largely removed during the last glaciation. Representative stratigraphic sections from the Nechako Reservoir area are provided in Figure 3. Exposures there reveal a widespread, massive diamicton unit, interpreted as a till, that is stratigraphically underlain by both stratified sands and gravels of inferred fluvial and glaciofluvial origin (sections 9318 to 9320, Figure 3) and horizontally bedded sand, silt and clay sequences, interpreted to be advance-phase glaciolacustrine sediments (base of section 9324, Figure 3). The upper part of the older glaciofluvial sequence locally contains sand wedges and dikes (section 9318, Figure 3) that may be relict permafrost features formed in cold environments just prior to the last glaciation. Advance-phase glaciolacustrine deposits are rarely seen, but they are locally well preserved and include well bedded fine sands and silts with dropstones (section 9324, Figure 3).

Morainal sediments of the last glaciation are the most widespread Quaternary deposits in the region and include dense, matrix-supported, silty diamictons interpreted as lodgement and melt-out tills. Compressive deformation structures, such as shear planes, occur near the base of the till, and overturned folds and thrust faults, interpreted as glaciotectonic structures, are locally present in the upper part of the underlying glaciofluvial sediments. Also common are loose, massive to stratified, sandy diamictons of inferred debris-flow origin. These diamictons are often interbedded with gravels and sands (*e.g.*, upper part of section 9320, Figure 3) or may contain thin laminae or lenses of fine sediments (*e.g.*, lower diamicton at section 9324, Figure 3). Debris-flow diamictons commonly have loaded or gradational contacts with interbedded sediments. These data indicate that debris-flow deposition occurred during both the advance and retreat phases of the last glaciation in both subaerial glaciofluvial and subaqueous glaciolacustrine environments (Figure 3).

Glacial deposits form a cover of variable thickness across much of the Interior Plateau and may occur as hummocky, kettled, fluted or relatively flat topography. Basal tills usually unconformably overlie bedrock or, more rarely, older deposits. They seldom occur at the surface, usually being overlain by glacigenic debris-flow deposits, glaciofluvial deposits or, on steep slopes, by diamicton of colluvial origin. Till thickness varies from less than a metre along bedrock ridges and steep slopes to several tens of metres in main valleys and in the lee (down-ice) of bedrock highs. Thick exposures of till (>10 m) also occur locally in narrow valleys oriented at high angles to the regional ice-flow direction. In many valleys, morainal sediments are largely buried by glaciofluvial, fluvial and organic sediments.

### *LATE WISCONSINAN DEGLACIAL DEPOSITS*

Deposits formed during deglaciation of the area include both glaciofluvial and glaciolacustrine sediments. Exposures of glaciolacustrine sediments occur mainly in low-lying areas, generally at elevations below 750 to 950 metres, often near modern lakes. Lake levels were at least locally controlled by ice dams, as in the southern Nechako Plateau (*e.g.*, Levson and Giles, 1994). Maximum lake levels are recorded by the upper elevation of deltaic deposits (*e.g.*, Levson *et al.*, 1994; Huntley *et al.*, 1996). Two common sediment associations are recognized, based on grain size and structure: rhythmically bedded fine sands, silts and clays, and horizontally bedded and trough crosslaminated fine to coarse sands (Figure 3). A shallow-water delta or proximal glaciolacustrine origin is inferred for the sand-dominated facies and the finer grained sediments are interpreted to be deeper water or more distal glaciolacustrine deposits. Dropstones, load structures, normal faults, deformed beds, fluid escape structures and gravel lenses may occur in either sediment association (*e.g.*, section 9323, Figure 3), and indicate the proximity of retreating glaciers or stagnant ice blocks. Beds commonly fine upwards from coarse sand dominated units to fine sand, silt and clay units, reflecting the transition from proximal to distal environments as glaciers retreated from the lake basins.

Meltwater channels of all scales are common in the region and glaciofluvial sediments occur extensively as outwash plains, eskers, kames, terraces and fans in valley bottoms and along valley flanks. They consist mainly of poorly to well sorted, stratified, pebble and cobble gravels and sands of variable thickness. Clasts are typically rounded to well rounded and vary in size from small pebbles to cobbles with rare boulders. If present in upland areas, glaciofluvial sands and gravels usually occur as a veneer or thin blanket. Many of these deposits are interbedded with gravelly diamictons suggesting a proximal outwash origin. Eskers and esker complexes are locally common features. They are characterized by sinuous, gravel ridges (Photo 1) that formed in subglacial tunnels. They are composed mainly of well stratified gravels and sands but normal faults, deformed strata and diamicton beds are common, especially on the outer edges of the eskers, reflecting collapse and deposition of meltout till as the supporting ice melted. Hummocky topography, consisting of ridges and knobs of sand and gravel with large kettles, locally indicates the presence of ice blocks within gravelly sediments during deposition of glaciofluvial outwash. Large kame deposits are uncommon but locally developed along the margins of the stagnating ice and in association with eskers. Gravel and sand terraces on valley sides are deposits of ice-marginal streams formed during ice retreat or stagnation.

## *HOLOCENE FLUVIAL, COLLUVIAL AND ORGANIC DEPOSITS*

Holocene fluvial sediments in the region are dominated by floodplain silts, fine sands and organics and channel gravels in meandering streams. In upland areas, small gravelly creeks have reworked glacial, glaciofluvial and colluvial sediments and locally are incised into bedrock. The flat, open terrain of many large valleys is characterized by marshes and shallow lakes filled with organic sediment consisting of decayed marsh vegetation with minor sand, silt and clay. Organic deposits also occur in low areas in the floors of some valleys, as a thin veneer of decaying vegetation over cobble and boulder gravel.

A thin veneer of weathered and broken bedrock clasts in a loose sandy matrix occurs on steep slopes throughout the area. These deposits grade downhill into a thicker cover of colluvial diamicton derived from both local bedrock and till remobilized by gravity after deposition. Colluvial veneers commonly overlie thin tills on steep slopes. Thick accumulations of talus are relatively uncommon due to the

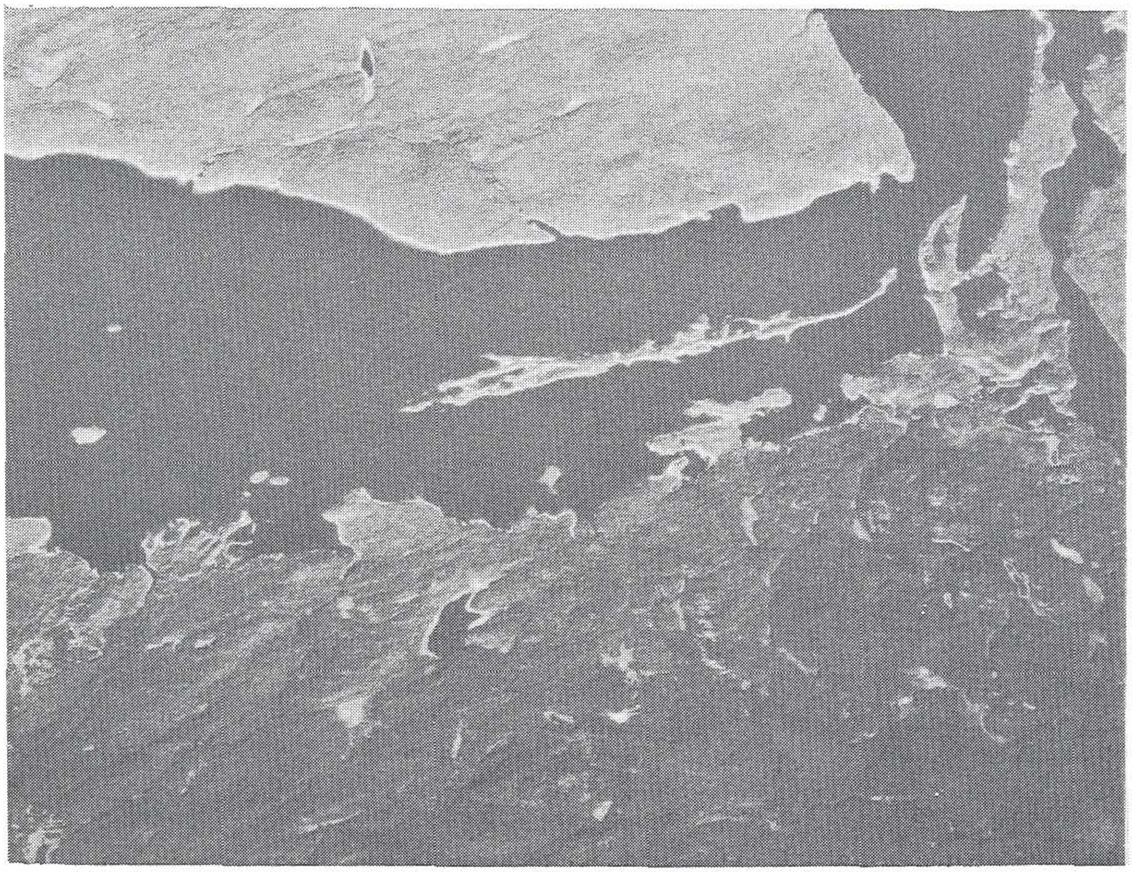

Photo 1. Upper part of glaciofluvial esker-kame complex exposed above water level in the Nechako Reservoir at the junction of the Knewstubb and Natalkuz reaches; also note, in the southwest and northern parts of the area, northeast-trending linear landforms formed by subglacial water and/or ice erosion (north towards top of photo).

overall subdued topography, but they do occur below steep rocky cliffs that are locally present in the more mountainous areas.

Postglacial alluvial fans occur where steep-gradient streams issue onto valley floors. These fans are still active in some areas, as evidenced, for example, by major channel shifts on a large fan at the west end of Top Lake in the Fawnie Range. Coarse cobble to boulder gravels and large trees were transported in the main fan channel during flood events in recent years, and twice rendered a large logging-road bridge over the channel unusable. Evidence for many such events is indicated by numerous channel scars on the surfaces of this and other fans in the area (Giles and Levson, 1994a; Levson and Giles, 1994).

## ICE-FLOW HISTORY

A basic understanding of ice-flow direction, glacial dispersal patterns and transportation distances is required for successful drift exploration programs. Interpretation of data with respect to glaciation provides new avenues to explore for bedrock sources of mineralized float or geochemically anomalous soil samples.

In the Nechako Plateau, results of ice-flow studies indicate that in most areas there was one dominant flow direction during the Late Wisconsinan glaciation, that shifted from southeast, in the north part of the plateau (Babine Lake region), to east in the central part (Francois Lake area) and east-northeast in the south (Nechako Reservoir area; Figure 1). Crag-and-tail features, drumlins and glacial flutings are present throughout the region and typically reflect these regional trends (Photo 1). Although some of these features may have formed by subglacial water erosion (*cf.* Shaw, 1989; Shaw and Kvill, 1984; Shaw and Sharpe, 1987; Shaw *et al.*, 1989; Shoemaker, 1992), they generally tend to parallel regional dispersal patterns (Levson and Giles, 1995) and for this reason they are considered to reflect the dominant ice-flow direction. In addition, subglacial meltwater flow and ice-flow directions are expected to be parallel because both respond to the same driving potential created by the surface slope of the ice sheet (Kor *et al.*, 1991).

At the Late Wisconsinan glacial maximum, ice covered the highest peaks in the region and movement appears to have been unaffected by topography. In the Fawnie Range, the ice surface was in excess of 1750 metres as indicated by glacial erratics and regionally trending striae and flutings on top of topographic highs such as Tsacha Mountain (elevation 1734 m). In the Rainbow, Ilgachuz and Itcha mountains in the southern part of the region (Figure 1), the ice reached an elevation of at least 2000 metres and was about 1000 metres thick (Tipper, 1971). Topographic control of ice flow during early glacial phases is locally indicated by valley-parallel striae on bedrock surfaces that are buried by thick till sequences. Similarly, during deglaciation, ice flow was increasingly controlled by topography as the glaciers thinned. Striae and other ice flow indicators that locally diverge from the regional trend reflect this topographically influenced ice-flow during waning stages of glaciation. A more complex local ice-flow history is indicated by highly variable striae trends at a few sites.

In the northern Fraser Plateau, north to northeastward ice flow also dominated during the last glaciation, but there is some evidence for later easterly ice flow in the west part of the region, reflecting a re-advance of Fraser ice (Tipper, 1971). This ice originated to the west in the Coast Mountains and was named the Anahim Lake advance. Proudfoot (1993) observed that northeasterly trending striae, flutings and crag-and-tail ridges dominate the Clusko River (93C/9) and Toil Mountain (93C/16) map sheets, but to the southwest a limited number of easterly trending (about 080°) flutings occur. The eastward limit of this advance is identified on the basis of differential ice-flow directions and pitted or kettled terrain (Tipper 1971). A second late-glacial re-advance may also have reached the northern Fraser Plateau in the Chilanko Forks map area (93C/1). This event, named the Kleena-Kleene advance, originated to the south and terminated in the Tatla Lake Creek area in the southern part of the Chilanko Forks map sheet. The terminus areas of the Anahim Lake and Kleena-Kleene advances are indistinct and not marked by well developed end moraines (Tipper, 1971). Hummocky morainal sediments locally may have been deposited along the margins of these late-glacial advances but no unequivocal deposits of either advance were identified by Giles and Kerr (1993) in their studies in the region.

## SUMMARY OF QUATERNARY EVENTS

The first lobes of Late Wisconsinan, Fraser Glaciation ice advancing into the Nechako and Fraser plateaus were probably confined to major valleys. Damming of tributary drainages and the development of proglacial lakes occurred locally. The advancing glaciers also caused local reversals in the regional drainage (Giles and Levson, 1995). At the margins of the advancing ice, coarse-grained proglacial outwash was deposited locally in the valley bottoms. Debris-flow sediments were deposited with the outwash and in proglacial lakes. Lodgement and melt-out tills were eventually deposited by the glaciers as they advanced over the entire region. Results of ice-flow studies indicate that in most areas there was one dominant flow-direction. Drumlins, crag-and-tails, flutings and striae in many areas crosscut major topographic highs, such as the Fawnie and Nechako ranges (Levson and Giles, 1994; Giles and Levson, 1995; Weary *et al.*, 1995), and indicate that the ice was thick enough to be relatively unaffected by topography during full-glacial times. Glacial dispersal patterns appear to be dominated by this regional ice-flow direction (Levson and Giles, 1995), which varies from southeasterly, in the northern part of the study area, to northeasterly in the south. In many areas, the regional ice flow was modified by topographic control during both early and late stages of glaciation, but effects of these modifications on glacial dispersal patterns are not well documented.

During deglaciation, loose, sandy, gravelly diamictons were deposited on top of the tills by debris flows. Stagnant ice masses locally resulted in the development of large esker complexes and dammed meltwater to create glacial lakes and associated glaciofluvial deltas (Giles and Levson, 1994a; Levson and Giles, 1994). Deeply incised meltwater channels also commonly formed. In some areas, kame deposits and extensive meltwater channels developed parallel to the ice margin and indicate prolonged ice stagnation. Moderately sorted, crudely bedded gravel and sand terraces high on valley sides are deposits of high-level ice-marginal channels formed during ice retreat and ablation. Gravelly outwash plains covered the main valley bottoms as large volumes of sediment and water were removed from the ice margin.

During postglacial times, the surficial geology of the area was modified mainly by fluvial activity and the local development of alluvial fans in the valley bottoms, as well as by colluvial reworking of glacial deposits along the valley sides.

## TILL GEOCHEMISTRY

The primary objectives of till geochemical studies conducted in the region were to identify geochemically anomalous sites that reflect areas of buried mineralization and investigate patterns of glacial dispersal. Several regional till geochemistry surveys have been conducted in the area for this purpose (Table 1). The average density of samples per square kilometre has increased from less than 0.1 in the 1992 survey areas to about 0.2 in the 1993 and 1994 programs to about 0.3 in the 1995 surveys (Table 1). The results of the 1993 survey (Levson *et al.*, 1994), conducted in the Fawnie Creek map area (NTS 93 F/3), are summarized below as an example of the utility of till geochemistry programs.

Till geochemical anomalies identify areas where glaciers eroded mineralized bedrock and redeposited the mineral debris in down-ice dispersal trains. As glacial dispersal trains may be hundreds to thousands of times larger in area than their original bedrock source, they provide a cost effective target for mineral exploration programs in drift-covered terrains (Shilts, 1976; DiLabio, 1990; Levson and Giles, 1995). In addition, tills are 'first-derivative' products of bedrock and, having been transported to their present location mainly by the relatively linear flow of glaciers during one or more glacial episodes, they are more readily traced to source than higher order derivatives such as glaciofluvial or glaciolacustrine sediments (Shilts, 1993). In the simplest case of unidirectional ice flow, mineralized material at a point source is eroded, transported and redeposited to produce a ribbon-shaped dispersal train parallel to ice flow. Although these processes were first documented in Canada in shield areas (Shilts, 1973a, b; 1976), some examples have also been described from the interior of British Columbia (*e.g.*, Fox *et al.*, 1987; Kerr *et al.*, 1992, 1993; Levson and Giles, 1995; see also references in Kerr and Levson, 1995, 1996, this volume). Variations in the ice-flow direction, caused by topographic irregularities or changing dynamics at the base of the ice, may produce a fan-shaped dispersal train. In more complex areas, where there have been numerous flow directions during glaciation, or multiple glaciations, the dispersal train may be diffuse or irregularly shaped, making it difficult to trace to its source. Consequently, geochemical exploration programs in drift-covered regions must rely on an understanding of glacial processes and the glacial history of the area.

### *SAMPLING MEDIUM*

Basal till was selected as the preferred sampling medium for this program rather than other types of surficial materials, for several reasons:

- Basal tills are deposited in areas directly down-ice from their source and therefore mineralized material dispersed within the tills can be more readily traced to its origin than can anomalies in other sediment types. Processes of dispersal in ablation tills, glaciofluvial sands and gravels, and glaciolacustrine sediments are more complex and they are typically more distally derived than basal tills.
- Due to the potential for the development of large dispersal trains, mineral anomalies in basal tills may be readily detected in regional surveys.
- The dominance of one main regional ice-flow direction throughout much of the last glacial period in the survey area has resulted in a simple linear, down-ice transport of material. This makes tracing of basal till anomalies to source relatively easy compared to regions with a more complex ice-flow history.

Sampled deposits, interpreted as basal tills, typically consist of compact, fissile, matrix-supported, sandy-silt diamicton (defined as poorly sorted deposits consisting of mud, sand and gravel). They are typically overconsolidated and often exhibit moderate to strong subhorizontal fissility (Photo 2). Vertical jointing and blocky structure are also common, especially in dry exposures. Oxidation of the till, characterized by reddish brown staining, is common and may occur pervasively or along vertical joint planes and horizontal partings. Subhorizontal slickensided surfaces are sometimes present, especially in clay-rich parts of the till. Clasts are mainly medium to large pebbles but they range in size from granules to large boulders. Total gravel content generally is between 10 and 30% but locally may be up to 50%. Subangular to subrounded clasts are most common and typically up to about 20% are glacially abraded. Striated clasts are commonly bullet shaped, faceted or lodged; the a-axes of elongate clasts are often aligned parallel to ice-flow direction. Lower contacts of basal till units are usually sharp and planar. All of these characteristics are consistent with a basal melt-out or lodgement till origin (Levson and Rutter, 1988; Dreimanis, 1990). Injections of till into bedrock fractures locally indicate high pressure conditions at the base of the ice during deposition. The presence of sheared, folded and faulted bedrock slabs within these deposits indicates the local development of deformation tills.

Basal till deposits can be confused with other facies of morainal sediments such as glacigenic debris-flow deposits or with other poorly sorted sediments such as colluvial deposits (Photo 3). A summary of some characteristics useful for distinguishing basal tills from other deposits of glacial or nonglacial origin is provided in Table 2. This distinction is critical as the dispersal characteristics of different sediment types vary widely (*see* below). Basal tills are first order derivative products whereas glacigenic debris-flow deposits, for example, have undergone a second depositional

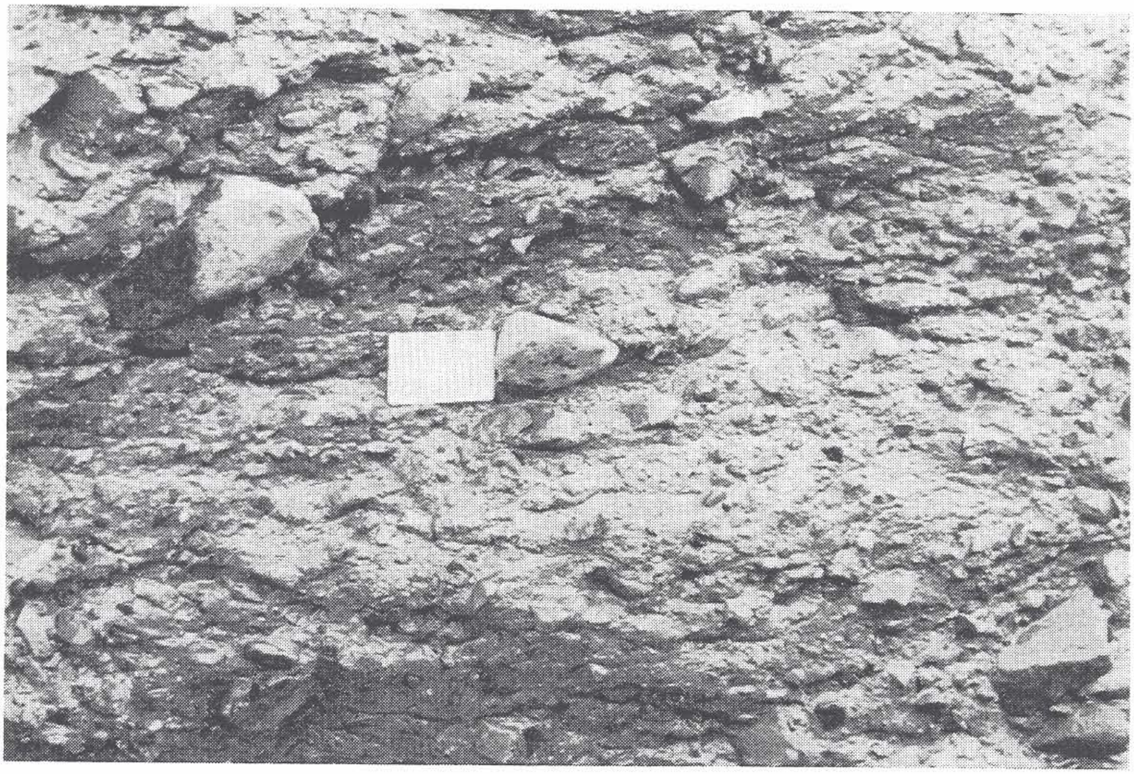

Photo 2. Massive, matrix-supported diamicton interpreted as basal till; note the well developed subhorizontal fissility and presence of subrounded to subangular clasts; scale in centimetres.

Photo 3. Massive gravelly sand (colluvium), about 70 centimetres thick, overlying 1 metre of massive, sandy diamicton interpreted as glacigenic debris-flow deposits (resedimented till).

## TABLE 2
## DISTINGUISHING CHARACTERISTICS OF BASAL TILL, SUPRAGLACIAL TILL, DEBRIS FLOW DEPOSITS AND COLLUVIAL DIAMICTON

| SEDIMENT TYPE | TYPICAL CHARACTERISTICS AND SEDIMENTARY STRUCTURES | MATRIX TEXTURE/ DENSITY | CLAST PROVENANCE[2]/ SHAPE | PEBBLE FABRIC[3] | LOWER CONTACT | ASSOCIATED LANDFORMS |
|---|---|---|---|---|---|---|
| **Basal till[4]** | massive, matrix-supported, diamicton; overconsolidated; fissile; oxidized blocky joint planes; shear structures; thrust faults | sand-silt-clay; very dense | mainly local; striated, faceted; subangular to subrounded | mod. to strong fabric, parallel to paleoflow | sharp and planar (erosional) | level to rolling moraine, drumlins, flutings, crag-and-tails |
| **Supraglacial till[5]** | massive to crudely stratified, diamicton; matrix- or clast-supported; normally faulted or collapsed sand and gravel lenses | sandy; usually loose | far-traveled, from high elevations; large angular to subangular | chaotic or weak, random orientations | gradational, irregular | hummocky moraine, kames, kettles |
| **Cohesive debris flow[6]** | massive to crudely stratified, diamicton; matrix-supported, ungraded or coarse-tail inverse grading; thin discontinuous sandy or gravelly strata | sand-silt-clay; loose to compact | local to distal; subangular to subrounded | weak fabric, parallel to slope or paleoslope | clear to gradational; subhorizontal | streamlined or hummocky moraine; gentle to moderate slopes |
| **Non-cohesive debris or flood flow[7]** | crudely stratified diamicton / poorly sorted gravel; clast-supported; ungraded or normal grading; often interbedded with trough-shaped sand and gravel lenses | sand-silt; usually loose | distal and local; well rounded to subangular | weak to moderate fabric; rare imbrication | gradational to sharp; often trough-shaped (scoured) | proximal glaciofluvial: sandurs, eskers, kame terraces, kame deltas, fans |
| **Subaqueous flows & ice-rafted debris** | massive to stratified, diamicton / gravelly mud; matrix-supported, silt and clay laminae; folded and convoluted strata | silt-clay-sand; compact | distal; subangular to subrounded; mainly pebbles | chaotic or weak a-axis fabric | sharp, horizontal, loaded | lacustrine basins in valley bottoms; often near large lakes |
| **Colluvium** | massive to crudely stratified, diamicton; clast-supported, strata parallel slope | sandy; often very loose | dominantly local; subangular to angular | weak to strong downslope dip | clear, parallel to slope | moderate to steep bedrock slopes |

[1] based on data from Levson and Rutter (1986, 1988), Dreimanis (1988, 1990), Levson and Giles (1993) and Giles and Levson (1994a, b).

[2] local provenance indicates source rocks within a few kilometres; distal indicates source is more than a few kilometres

[3] fabric strength ($S_1$) is a normalized measure of clustering, varying from weak ($S_1 <$ about 0.5) to strong ($S_1 >$ about 0.7)

[4] mainly lodgement and melt-out till

[5] also referred to as ablation till

[6] also referred to as mudflow; locally includes colluviated (remobilized) till

[7] includes gravelly debris flows, hyperconcentrated flood flows and washed tills

phase, related either to the paleo-ice surface or the present topography, and they are therefore more difficult to trace to their source. Glacigenic debris-flow deposits include some supraglacial tills, basal tills reworked by gravity (often producing cohesive debris flows) or water (often producing non-cohesive debris flows) and subaqueous debris flows (Table 2). Subaerial varieties typically consist of loose, massive to stratified, sandy diamicton (Photo 3). They are usually loose to weakly compact and either massive or interbedded with stratified silts, sands or gravels. Clasts vary in size from small pebbles to large boulders, but are usually medium to large pebbles. These diamictons typically contain 20 to 50% gravel, but locally may have up to 70% clasts. Subangular to subrounded clasts are most common, but local angular fragments dominate in some shallow exposures over bedrock. Lenses and beds of sorted silt, sand and gravel occur in many exposures and may be continuous for up to 5 metres, although they are most frequently 10 to 100 centimetres wide. Debris-flow deposits may exhibit weak to strong preferential oxidization along more permeable sandy or gravelly horizons. These deposits commonly are in gradational contact with underlying basal tills. Colluvial diamictons are differentiated from basal tills by their loose unconsolidated character, the presence of coarse, angular clasts of local bedrock, crude stratification and lenses of sorted sand and gravel (Table 2).

## *CHARACTERISTICS OF GLACIAL DISPERSAL IN THE NECHAKO PLATEAU REGION*

### SOIL GEOCHEMICAL ANOMALIES

The main characteristics of glacial dispersal trains in the study region and surrounding parts of the Nechako Plateau, as indicated by soil geochemical anomaly patterns, were discussed by Levson *et al.* (1994) and Levson and Giles (1995) and are summarized here. This information was compiled in 1993 from existing industry records, in order to provide geochemical orientation data reflecting glacial dispersal patterns in the region and to aid in the design of a sampling strategy for regional till geochemistry programs. Limitations of the industry data for these purposes include the use of a variety of different surficial sediment types as sample media, although mainly tills were sampled, and the use of mainly B-horizon, rather than C-horizon samples. The industry samples are referred to here as soil geochemical samples in order to distinguish them from basal till samples (*see* below).

Soil geochemical anomalies associated with glacial dispersal of mineralized bedrock in the region studied generally are a few kilometres long and several hundred metres or more wide; isolated anomalies associated with the trains may cover much larger areas. The dispersal trains show a pronounced elongation parallel to ice-flow direction, with mineralized source rocks occurring at or near their up-ice end. They are commonly very narrow in comparison with their length and have clear lateral and vertical contacts with the surrounding till. Length to width ratios of 5:1 are typical. Progressive dilution of the mineralized material generally occurs in a down-ice direction until the train can no longer be detected. Erratics trains in the region appear to be much longer (up to several km long) and more readily detected than soil anomalies (typically 1-2 km long). For example, the Arrow Lake mineral showing was discovered in 1987 by tracing a train of stibnite-bearing quartz feldspar wacke/tuff erratics, 7 kilometres long (Bohme, 1988), whereas soil geochemical anomalies in the area are much shorter. This emphasizes the importance of pebble studies and clast provenance investigations (*e.g.*, boulder tracing) in drift exploration programs.

The elongate nature of soil geochemical anomalies resulting from glacial dispersal in the region is well evidenced by the Arrow Lake antimony anomaly which is about 1 kilometre long and only 200 metres wide (Levson and Giles, 1995). At the Wolf epithermal deposit, anomalous silver concentrations occur as much as 2.3 kilometres directly down-ice from the deposit (Dawson, 1988). Similarly, at the CH property, dispersal of mineralized material is defined by an elongate, multi-element, geochemical soil anomaly as well as by a boulder train that extends for over a kilometre down-ice from the mineralized outcrop (Warner and Cannon, 1990; Edwards and Campbell, 1992). Zinc, silver and lead geochemical anomalies at the property are typically 200 to 300 metres wide and 1 to 1.5 kilometres long. The copper soil anomaly is much broader (800 m) and longer (2 km). These anomalies typically have relatively sharp lateral boundaries and cigar or fan shapes, characteristic of trains formed by mechanical dispersal processes at the base of glaciers. Geochemical data from tills reflect the geochemistry of the up-ice bedrock sources and not that of the immediately underlying bedrock. In areas of thick till, near-surface geochemical anomalies may be offset, in a down-ice direction, by 500 metres or more from their bedrock source. Drill targets in these areas should be sought up-ice, rather than at the head of the anomaly.

Except along some creeks and steep slopes, hydromorphic dispersion effects have apparently not modified anomaly patterns in tills in the region to any great degree. The main influence of topography seems to be the preferential deposition of till in lee-side settings. Although topography may also have temporarily effected local ice-flow directions, dispersal of mineralized materials appears to have been dominated by the regional ice-flow; subsequent local variations have not obscured this primary pattern. This is well illustrated by the predominant down-ice dispersal of molybdenum in the Chutanli Lake region, even though the down-ice direction is mainly up-slope from the deposit (Mehrtens, 1975).

Pathfinder elements vary with deposit type, and elements most abundant in the mineralized material appear to produce the largest and strongest soil geochemical anomalies (*e.g.*, Sb at the stibnite-bearing Arrow Lake deposit, Cu at the CH porphyry copper prospect, and Ag at the Wolf Au-Ag epithermal deposit). However, multi-element analysis of all samples is recommended, to increase the likelihood of discovering unexpected mineralization, even in property-scale investigations.

## GLACIAL DISPERSAL AT THE WOLF PROSPECT USING TILL GEOCHEMISTRY

Recent investigations of glacial dispersal patterns using C-horizon basal till samples, rather than B-horizon soil samples, indicate that dispersal trains can be detected over much larger areas in tills than in soils. In the Wolf area, for example, a study of dispersal patterns, conducted in conjunction with the regional till sampling program (Levson *et al.*, 1994), shows more than 5 kilometres of down-ice dispersal from areas of known mineralization (Figure 4). At these distances, gold concentrations in basal till are still elevated (greater than the 90th percentile compared to the regional data set). This contrasts with soil geochemical dispersal patterns in the area that extend for only about 2 kilometres down-ice from the deposit (*see* Levson and Giles, 1995, their Figure 6-4). The maximum down-ice extent of gold dispersal in till is not known but at least 5 kilometres of transport below mineralized outcrop is indicated. It is also important to note that the head of the gold anomaly is about 500 metres down-ice from the prospect and gold concentrations directly over the mineralized area are much lower. The same pattern is observed in the soil geochemistry data (Levson and Giles, 1995) and again highlights the importance of exploring up-ice, and not directly below, anomalous zones in areas with a thick till cover. The highest gold concentrations in soils (305 and 495 ppb) occur at the up-ice end of the dispersal plume (Figure 4) 1 to 1.5 kilometres from the mineralized area, but the highest gold concentration encountered in till is about 3.7 kilometres down-ice from the prospect.

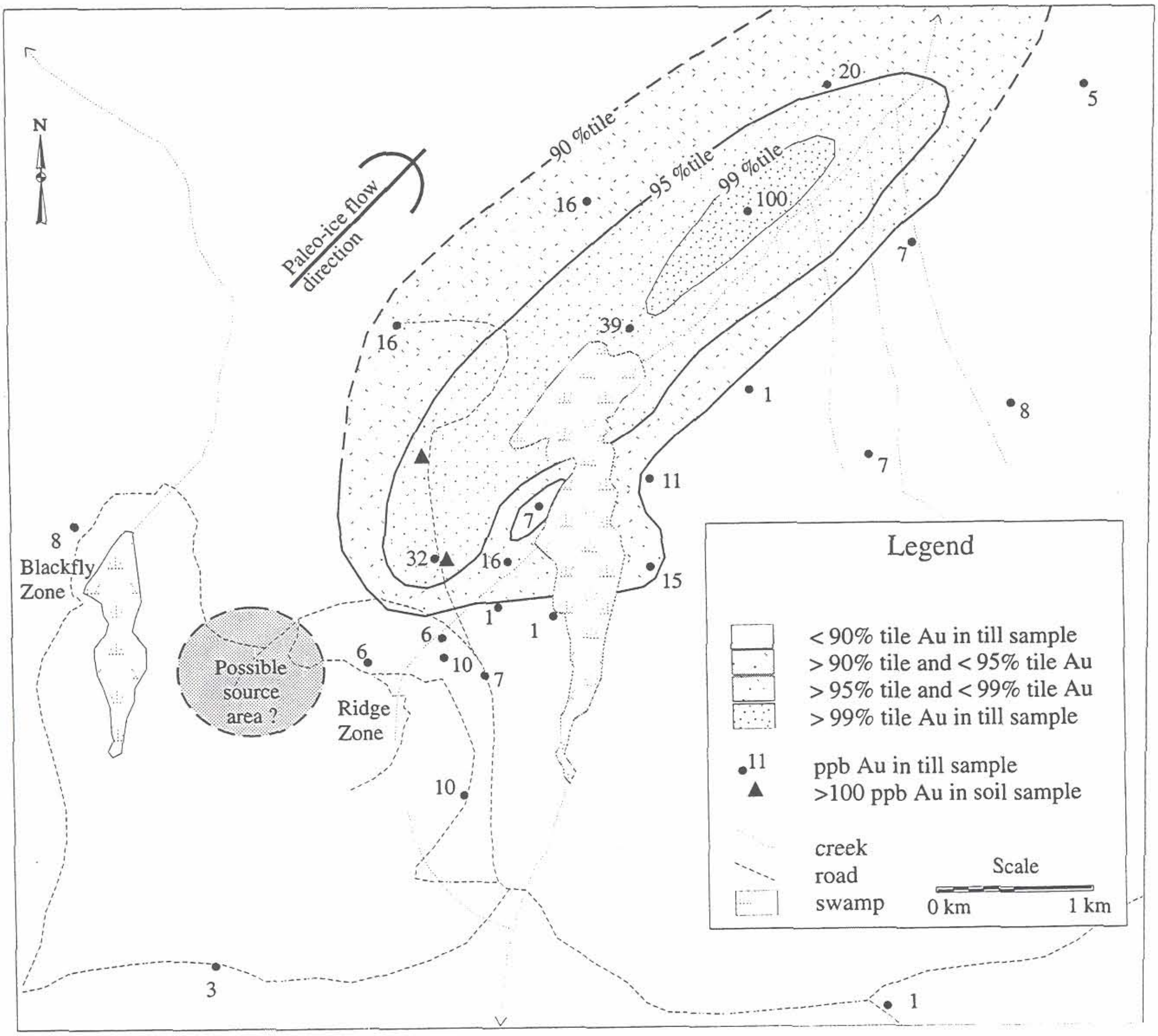

Figure 4. Gold concentrations in basal till (-63 μm fraction, analyzed by INAA) down-ice of the Wolf prospect (*see* text for explanation); area shown is located on Figure 2.

The northwest margin of the gold anomaly in till below the Wolf prospect (Figure 4) is not constrained by samples with background gold concentrations. Elevated gold concentrations in this area are not what would be expected if the Ridge zone was the only source of the gold anomaly and they may reflect down-ice dispersal of mineralization from the Blackfly zone (*cf.* Levson and Giles, 1995), located about 2 kilometres west-northwest of the Ridge zone. This interpretation is supported by arsenic concentrations in till on the northwest side of the dispersal plume that are generally two to three times higher than on the southwest side (the Blackfly zone is the only part of the mineralized system known to have anomalous arsenic; Schroeter and Lane, 1994). In addition, the highest gold concentrations in till occur down-ice of the area between the Ridge and Blackfly zones, suggesting that the main source of the gold dispersal plume may occur between the two areas of known mineralization.

## *BACKGROUND VARIATIONS*

Background levels of various elements in tills are controlled in part by the background concentrations in their source rocks. The influence of bedrock geology, therefore, must also be considered when interpreting regional till geochemical data. To evaluate the effect of bedrock geology on the regional geochemical data set for the Fawnie Creek map area, for example, Levson *et al.* (1994) related background metal concentrations for gold, silver, arsenic, antimony, lead, zinc and molybdenum to the lithology of the underlying bedrock. Background concentrations, as defined by median values, are generally similar in tills underlain by mafic volcanics and sediments of the Hazelton Group, but are distinctive in tills underlain by rhyolitic Ootsa Lake Group rocks or Tertiary mafic volcanics (*e.g.,* Chilcotin Group rocks). For example, Ootsa Lake Group sites have the highest median gold concentrations and Chilcotin Group sites have the lowest gold, arsenic and antimony concentrations. Sites underlain by these two groups also have low background concentrations of lead, zinc and copper relative to other rock types in the area.

## *COMPARISON OF TILL WITH OTHER SAMPLING MEDIA*

Different types of surficial sediments have distinctly different provenances based on their transportation and depositional histories. Six genetic categories of surficial sediment are common in the Interior Plateau region: morainal, glaciofluvial, glaciolacustrine, fluvial, colluvial and organic sediments. It is critical, for interpretation purposes, that detailed descriptions of the sampling media are obtained and that different types of materials are distinguished (Giles and Levson, 1994a, b; Levson *et al.*, 1994). The importance of separating overburden geochemical data into populations that correspond to different types of surficial materials (and bedrock lithologies) was demonstrated by a study in the Nechako Plateau region by Boyle and Troup (1975). Regional variations due to surficial geology (or bedrock lithology) can therefore be minimized in favour of processes relating to mineralization. There is a particularly significant difference between till-covered areas and colluvial deposits in more mountainous areas. For example, mean copper, molybdenum, zinc, nickel and lead concentrations in the A and B soil horizons over a large part of the Capoose Lake region (Boyle and Troup, 1975) were all higher in colluvium (17-24 ppm Cu, 0.9-1 ppm Mo, 51-79 ppm Zn, 11-14 ppm Pb and 5-7 ppm Ni) than in till (7-15 ppm Cu, 0.5-0.9 ppm Mo, 31-41 ppm Zn, 5-6 ppm Pb and 5-6 ppm Ni). In addition, mean C-horizon concentrations in till (12-18 ppm Cu, 0.5-8 ppm Mo, 22-27 ppm Zn, 5 ppm Pb, and 5-6 ppm Ni) were similar or higher than A or B-horizon concentrations. In order to minimize this variability related to different surficial sediment types or soil horizons, the regional geochemical surveys conducted as part of this program relied on samples collected only from the C-horizon of basal tills.

It is also important to emphasize that glacial sediments can be eroded, transported and deposited by a wide variety of mechanisms, all of which may produce deposits of distinctly different character (Table 2). Tills may form by primary processes involving the direct release of debris from a glacier, or by secondary resedimentation processes in the glacial environment (Dreimanis, 1988). Till characteristics are dependent on their position of deposition (subglacial, supraglacial or ice marginal), place of transport (basal, englacial or supraglacial) and dominant depositional mechanism (lodgement, melt-out, flow or deformation). For the purposes of drift prospecting, distance of transport is especially critical and two main varieties of till are commonly distinguished: basal tills, comprised of debris transported at or near the glacier base, and supraglacial tills, comprised of debris transported on or near the top of the glacier (Dreimanis, 1990). The latter are usually deposited as debris flows and are comprised of relatively far-traveled debris. Basal tills, deposited by lodgement or melt-out processes, are typically more locally derived than supraglacial tills. Supraglacial tills may be distinguished from basal tills by higher total clast contents, more angular and fewer striated clasts, typically weaker and more randomly oriented pebble fabrics, and the common presence of interbedded sand and gravel deposits (Levson and Rutter, 1988; Table 2). The two till varieties may also be distinguished geomorphologically; supraglacial tills typically occur in areas of hummocky topography and basal tills in fluted or drumlinized regions. However, geomorphic data alone are not always diagnostic as, for example, fluted and drumlinized areas may be blanketed by a thin cover of supraglacial till. Similarly, basally derived, flow tills may be confused with relatively far-traveled, supraglacial, flow tills (Table 2). Because of this difficulty in distinguishing different till facies, a multiple criteria approach using sedimentologic, stratigraphic and geomorphic data is recommended for the interpretation of glacial deposits (Levson and Rutter, 1988; Dreimanis, 1990).

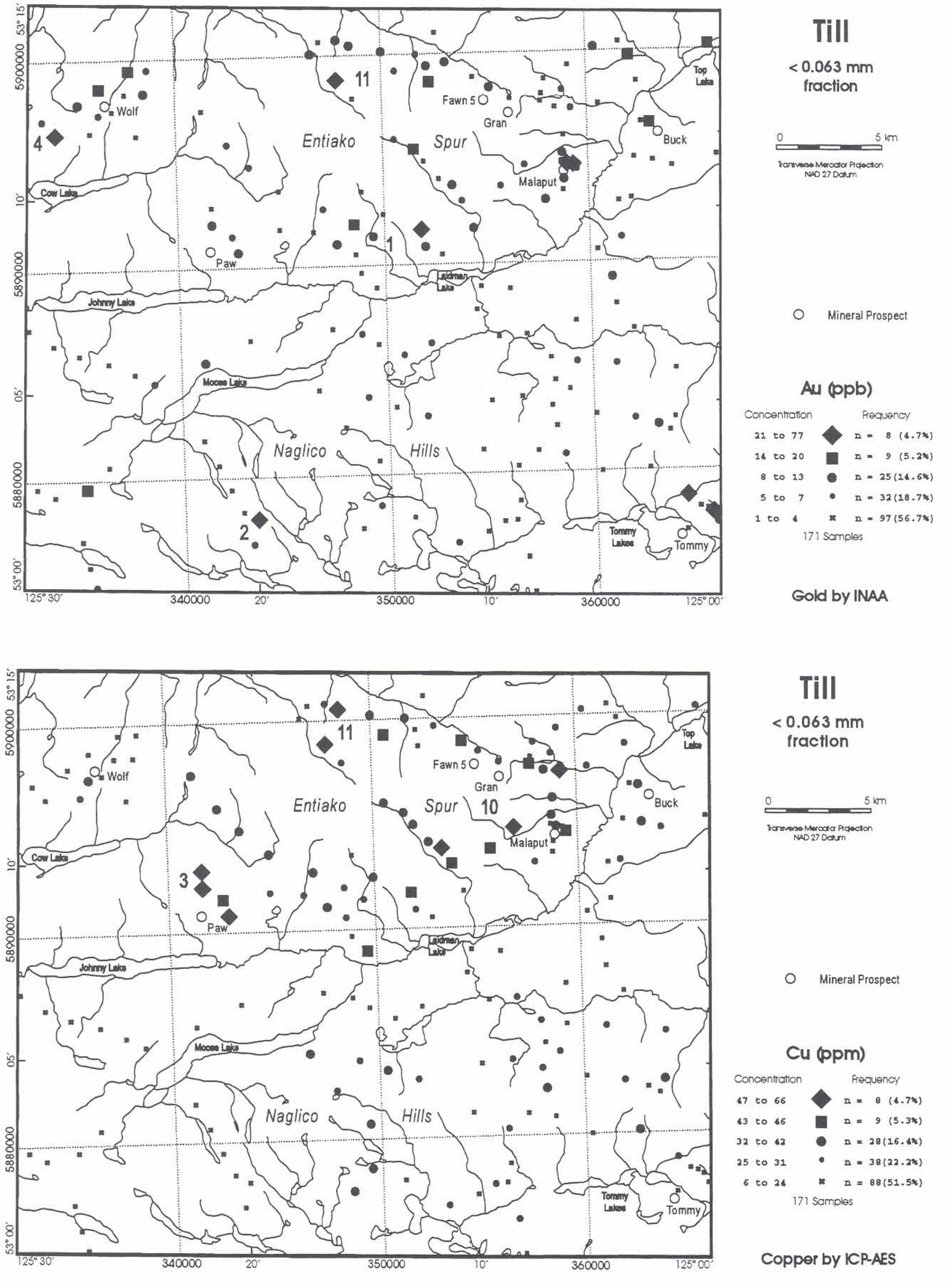

Figure 5. Gold (a) and copper (b) concentrations in basal till (-63 µm fraction) in the area covered by the Fawnie Creek regional till geochemical survey; numbers refer to areas discussed in the text.

## *EFFECTIVENESS OF REGIONAL TILL SAMPLING PROGRAMS*

Regional till geochemical sampling, combined with surficial geology mapping, has proven to be a useful method for detecting buried mineralization in the Interior Plateau region. This was demonstrated by the detection of all existing mineral occurrences in the Fawnie regional till geochemical survey (Figures 5 and 6; *cf.* Levson *et al.*, 1994), including several sites not known to the samplers before the survey was conducted.

The effectiveness of till geochemical sampling programs, together with lake sediment sampling, surficial geology mapping and bedrock geology mapping, is discussed by Cook *et al.* (1995). In the 1:50 000 map area included in the Fawnie survey, described in more detail below, eleven new exploration targets with multi-element geochemical anomalies were highlighted by till and lake sediment geochemical surveys. Six of these target areas are indicated by both lake sediment and till geochemical data, three by till data alone and two by lake sediment data alone (Table 3). These targets include strongly anomalous (greater than 95th percentile) concentrations of gold in six areas, lead and zinc in five areas, copper in five areas and molybdenum in four areas. Strongly anomalous concentrations of arsenic and antimony occur in four of the five areas that have elevated lead and zinc and in one area with gold. Anomalous gold also occurs with copper, lead and molybdenum. The till geochemical anomalies discovered, show values comparable to those down-ice of advanced prospects in the area. These data strongly suggest that geochemical surveys, using basal tills as a sampling medium, are an effective tool for regional exploration in the Interior Plateau region, especially when integrated with other types of geological and geochemical surveys.

## FAWNIE REGIONAL TILL GEOCHEMICAL SURVEY

The results of the Fawnie regional till geochemical survey are summarized here to illustrate the effectiveness (and limitations) of this type of program in highlighting new exploration targets (Figures 5 and 6). Some of the multi-element anomalies were found in till at several adjacent sample sites, such as in an area along the western margin of the

TABLE 3
ANOMALOUS ELEMENTS IN TILL AND LAKE SEDIMENTS IN THE VICINITY OF KNOWN AND POTENTIAL MINERAL PROSPECTS

| Location of prospect or geochemical anomaly[1] | Anomalous Elements[2] (>95th percentile) at geochemical sites[3] | Method of Detection[4] L - lake sediment T - till |
|---|---|---|
| **Known Prospects** | | |
| 1) Wolf | Au-Zn-Mo-As-Sb | L & T |
| 2) Gran / Fawn | Cu-Pb-Zn-As-Sb | L & T |
| 3) Buck | Pb-Zn-As | T & L |
| 4) Paw | Cu-Mo | T & L |
| 5) Tommy | Au-Pb-Zn-Sb | T & L |
| 6) Malaput | Au-As-Sb | T |
| 7) Fawn-5 | Cu-Sb | T |
| **Potential New Prospects** | | |
| 1) NW of Laidman Lake | Au-As-Sb | T & L |
| 2) SW Naglico Hills (SE of Trophy Lake) | Au-Pb | T & L |
| 3) SE of Cow Lake | Au-Cu-Pb-Zn-Mo | L & T |
| 4) NW of Cow Lake | Au-Mo | T |
| 5) S Naglico Hills | Pb-Zn-As-Sb | T & L |
| 6) SW of Top Lake | Pb-Zn-As-Sb | T & L |
| 7) S of Cow Lake | Cu-Pb-Zn | L |
| 8) SE of Moose Lake (North Naglico Hills) | Pb-Zn-Mo-As-Sb | T & L |
| 9) SW corner of mapsheet | Cu-Mo | L |
| 10) South and east sides of Entiako Spur | Cu-As-Sb | T |
| 11) N Entiako Spur | Cu-Au | T |

[1] Numbers of potential prospects correspond to bold numbers on Figures 5 and 6 (from Levson *et al.*, 1994 and Cook *et al.*, 1995).

[2] Only seven elements considered (Au, Cu, Pb, Zn, Mo, As, Sb).

[3] For known prospects, only sample sites within a few kilometres down-ice (for tills) or down-slope (for lake sediments) are included.

[4] Geochemical media listed in order of significance for each prospect.

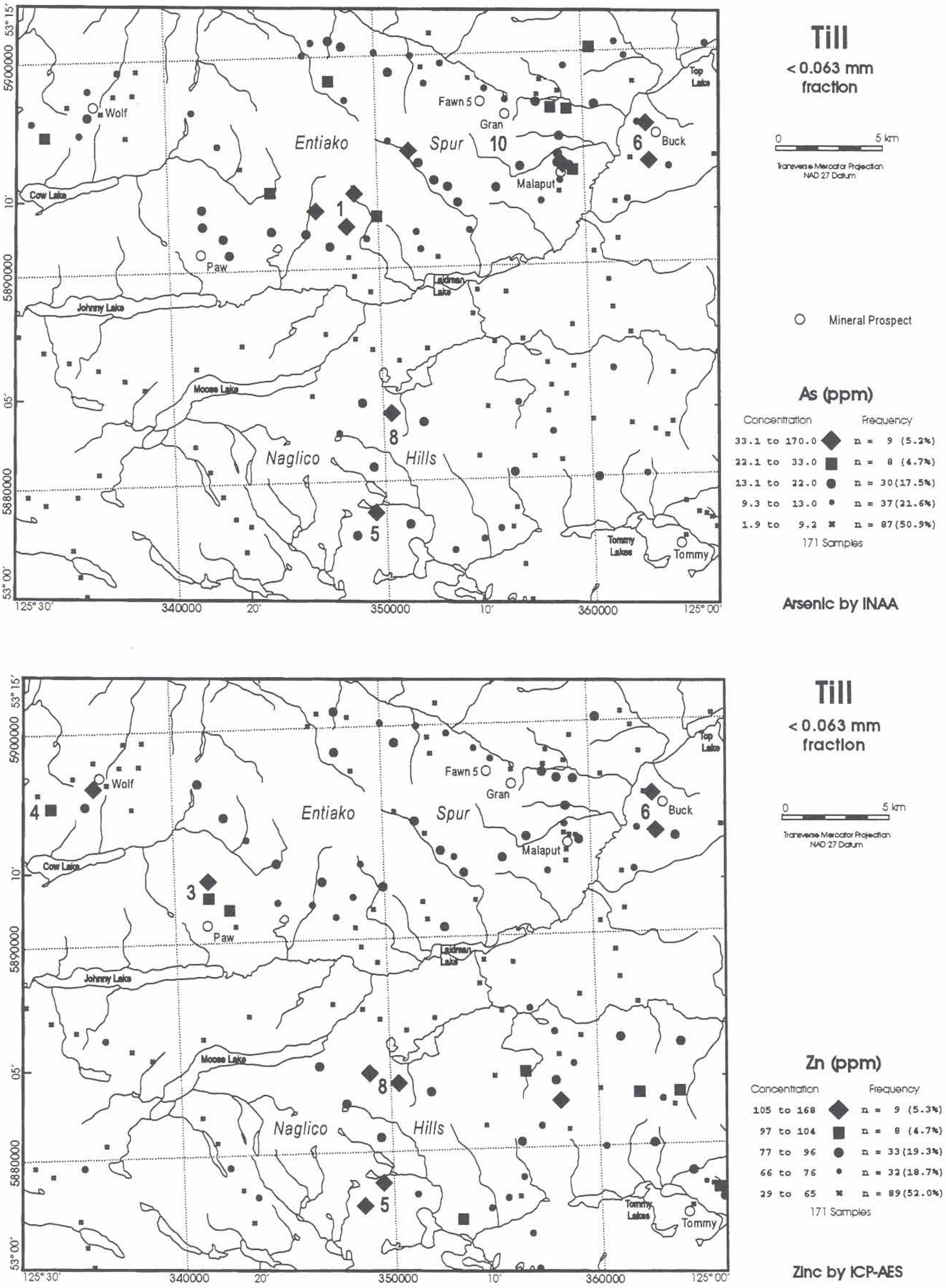

Figure 6. Arsenic (a) and zinc (b) concentrations in basal till (-63 μm fraction) in the area covered by the Fawnie Creek regional till geochemical survey; numbers refer to areas discussed in the text.

Capoose batholith, described by Levson *et al.* (1994) and studied in more detail by Best *et al.* (1996). Anomalous gold values, including the highest gold concentration encountered in the regional sampling program, were detected in this area along a zone that is about a kilometre wide and several kilometres long (area 1, Figure 5a, b) and trends easterly, parallel to the local ice-flow direction (Figure 7). Till samples at several sites in the area contain anomalous gold, arsenic, silver and antimony.

Another area of interest identified in the Fawnie regional survey lies between the southern margin of the Capoose batholith and a small associated intrusion in the south-central part of the map sheet (areas 5 and 8, Figure 6a, b). Anomalous zinc, lead, silver, molybdenum, arsenic and antimony concentrations occur here and tills in the vicinity of the small southern intrusion (area 5) also contain anomalous barium, iron and aluminum. Rocks around the intrusion are oxidized and contain finely disseminated and fracture-controlled pyrite. The former ice-flow direction is almost due east near the anomalies (Figure 7), indicating that mineralized source rocks are located farther to the west.

A third multi-element geochemical anomaly identified in the Fawnie survey occurs northeast of Johnny Lake (area 3, Figure 5b and 6b). Tills in this area contain anomalous copper, zinc, lead, silver and molybdenum. Rocks in the area contain disseminated and fracture-controlled sulphides. The Paw mineral showing occurs south of the main part of the anomalous region and, as the local ice-flow there is northeasterly (Figure 7), it is unlikely to be the only source of the high metal concentrations in the tills. The area is considered to have potential for porphyry-style mineralization.

An area of potential stratabound sulphide mineralization on the Buck property is reflected in the till geochemical data by a fourth multi-element anomaly (area 6, Figures 6a, b). Significantly, the highest lead, zinc, arsenic and antimony concentrations occur at a site south of the main zone of interest, suggesting that bedrock mineralization may be present up-ice of that location. Other exploration targets identified include: high gold concentrations in till and mineralized float south of Moose Lake (area 2, Figure 5a); moderately high gold, silver, arsenic and antimony and high copper concentrations in till overlying altered rocks south of Entiako Spur (area 10, Figure 5b, 6a); and high gold and copper concentrations north of Entiako Spur (area 11, Figure 5a, b).

In addition to identifying new exploration targets, the till geochemical data suggest that mineralization in the vicinity of the known Wolf, Tommy Lakes (Tascha) and Malaput prospects (Figures 5 and 6) may be more significant than previously recognized. For example, in the Wolf area, the highest gold concentration in the regional till samples is southwest or up-ice (Figure 7) of the known mineralized zones, suggesting that there is potential for discovery of a new auriferous zone southwest of the main part of the property (area 4, Figure 5a). This area also shows moderately anomalous arsenic, molybdenum, lead and zinc. Similarly, at the Tommy Lakes (Tascha) site, anomalous gold in till north of the known showings suggests that the bedrock mineralization may extend farther to the north than initially

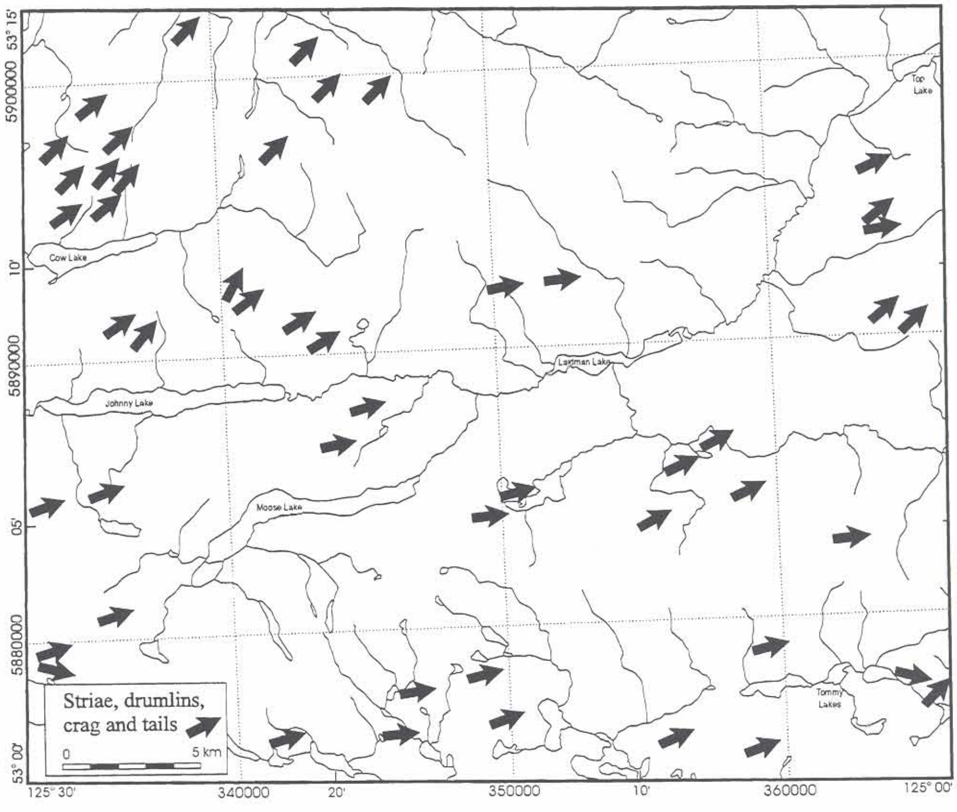

Figure 7. Ice-flow directions in the Fawnie Creek map area (NTS 93 F/3) as indicated by drumlin, fluting, crag-and-tail and striae data.

## TABLE 4
## DRIFT EXPLORATION POTENTIAL: SURFICIAL SEDIMENT TRACEABILITY AND DISPERSAL CHARACTERISTICS

| Terrain map unit | Dominant surficial materials[1] | Traceability (to bedrock source) | Transport distance[2] (order of magnitude) | Probable dispersal pattern[3] | Applicable survey scale; and type[4] |
|---|---|---|---|---|---|
| **VERY HIGH POTENTIAL** | | | | | |
| **Cv/R** | colluvial diamicton: < 1 m thick with sporadic rock outcrops | very good | < 1 to ~100 m; increasing with slope | downslope, linear to fan shaped | 1:5 000 (property-scale); S, C |
| **Cb** | colluvial diamicton and rubbly talus deposits: typically 1 to 10 m thick | good to very good | ~10 to ~100 m, increasing with slope | downslope, fan shaped | 1:5 000 (property-scale); S, C |
| **HIGH POTENTIAL** | | | | | |
| **Mv** | Morainal diamicton: mainly basal till deposits, < 1 m thick | good | often 10s to 100s m; varies with topography | down-ice, linear ribbon or narrow fan shape | 1:5 000 to 1:50 000; S, C, T, HM |
| **Mb** | Morainal diamicton: dominantly basal tills, 1 to 10s of m thick | good to moderate | ~100 m to ~2 km, increases with thickness | down-ice, narrow or elongated fan | 1:5 000 to 1:100 000; S, C, T, HM |
| **MODERATE POTENTIAL** | | | | | |
| **Mu,h** | Resedimented morainal diamicton: (often with glaciofluvial ($F^G$) veneer) | moderate; poor if transport is supraglacial | 100s m to ~ 5 km; many km if supraglacial | down-ice, broad, elongated fans | 1:10 000 to 1:100 000; S, C, T, HM |
| **LOW POTENTIAL** | | | | | |
| **$F^G$, F** | glaciofluvial and fluvial gravels and sands: often 1 to 10s of m thick | generally poor; may be moderate if shallow | 100s m to 10s km; thickness dependent in part | down-flow, discontinuous ribbons and fans | 1:50 000 to 1:250 000 (mainly regional scale); C, HM |
| **VERY LOW POTENTIAL** | | | | | |
| **$L^G$** | glaciolacustrine silt, fine sand and clay: often 1 to 10s of m thick | generally very poor | generally 10s km or more (basin wide) | discontinuous; irregular; possible textural control | 1:100 000 to 1:250 000 (regional scale): N |

---

[1] Analysis excludes common geochemical sample media such as modern lake, organic and stream sediments.

[2] Transport distances are approximate and refer to the bulk (but generally not all) of the sediment.

[3] Refers to mechanical dispersal by sedimentary processes (does not include hydromorphic dispersion patterns).

[4] S- soil geochemistry; T - till geochemistry; C - clast provenance surveys (boulder tracing, clast indicator surveys, pebble lithology studies); HM - heavy mineral sampling; N - not recommended for sampling in most cases. See text for explanation.

indicated by bedrock exposures in the area. Likewise, gold concentrations in till at the Malaput showing, that are several times higher than in assayed bedrock, suggest that a more significant mineralized zone is yet to be found there.

## *DRIFT EXPLORATION POTENTIAL*

Drift exploration potential, also known as drift prospecting potential, refers to the ease with which a surficial sediment can be traced back to its original bedrock source using common methods of sampling near-surface sediments (Levson *et al.*, 1994; Proudfoot *et al.*, 1995). Maps that portray drift exploration potential on a regional basis are derived from surficial geology or terrain map data (*e.g.*, Giles and Levson, 1994b; Levson and Giles, 1994). Maps with a similar theme have also been referred to as sample reliability maps (Kerr *et al.*, 1992) and sample media confidence maps (Meldrum and Bobrowsky, 1994). The use of the concept in the Interior Plateau is discussed at length by Levson *et al.* (1994) and is summarized in Table 4.

Drift exploration potential refers only to the relative usefulness of different surficial sediments for geochemical, lithological and heavy mineral sampling programs, particularly those conducted at property scales (~ 1:5000 or more detailed), and does not apply to other types of surveys such as biogeochemistry, vapour geochemistry, lake and stream sediment geochemistry and geophysical surveys. Factors involved in determining drift exploration potential include sediment genesis, number of erosional and depositional cycles (derivative phases), sediment thickness, transport distance (proximity to source) and the size, shape and continuity of the dispersal plumes. Mechanical dispersal by glacial, colluvial, fluvial and other sedimentary processes is considered in the assessment, whereas the effects of hydromorphic dispersion or weathering are not directly included. Drift exploration potential maps are intended primarily to aid in the planning of exploration surveys. The use of mapped drift exploration categories to select priority sampling areas saves time and effort and also yields more useful information than indiscriminate surveys. This approach thus provides a cost-effective means of conducting an exploration program and also has greater potential for success than sampling programs that do not discriminate between different surficial sediment types.

The drift exploration potential of each of the main types of surficial materials in the Interior Plateau is categorized into very high, high, moderate, low and very low in Table 4. During anomaly follow-up surveys, sampling of surficial materials with high or very high potential will provide results that are more readily interpreted and more likely to lead to the discovery of the source of the anomaly, than will sampling sediments with lower potential. The main characteristics of each of five different drift exploration categories are summarized in Table 4; the probable dispersal pattern of mineralization and the applicable type and scale of survey to locate such mineralization are also indicated. Transport distance is the expected distance of sediment travel, measured from the bedrock source to the place of deposition. It may vary substantially, within each sediment type, due to variations in the entrainment, transport and depositional processes and variable effects of factors such as grain size and topography. For these reasons, sediment transport distances must be determined for each deposit of interest and distances cited in the table should only be used as a general guide.

In addition to transport distance, traceability to bedrock source is a reflection of the number of derivative phases and the processes of dispersal. One cycle of erosion, transport and deposition of bedrock material to form a sedimentary deposit is considered to be one derivative phase (Shilts, 1993). If the sediment is then re-eroded, transported and redeposited, then the sediment is a second derivative. Colluvial deposits are first derivatives of bedrock and they can be traced up-slope along linear to fan-shaped dispersal paths, commonly less than 100 metres long, to their original source. These deposits typically consist of unsorted or very poorly sorted diamicton with abundant angular clasts of bedrock. Basal till, formed of comminuted bedrock material, transported by ice and deposited directly by lodgement or melt-out processes, is also a first derivative of bedrock. Basal tills are considered to have high drift exploration potential as they can be readily traced to their bedrock sources in an up-glacier direction along linear cigar-shaped or narrow, elongated, fan-shaped dispersal paths (*e.g.*, Figure 4). Thin tills tend to be closer to source than thicker tills but anomalous element concentrations, in both cases, are separated or offset from the bedrock source by an area of 'barren' sediment with background or only slightly elevated element concentrations.

Resedimented glacial deposits are considered to be second derivatives and have a moderate drift exploration potential. Dispersal paths in these deposits are typically dominated by a down-ice component modified to varying degrees (depending mainly on local relief) by down-slope movement. Morainal sediments in areas of hummocky topography are even more difficult to trace to source, due to their more complicated sedimentary history.

Secondary dispersal vectors in these deposits are often chaotic and difficult to determine, sometimes being more related to the position of former ice blocks than the present topography. Pebble fabric analyses, however, can help decipher the last direction of debris-flow movement. Distance of transport is largely dependent on the original position of transportation within the glacier, more distally derived deposits generally being derived from higher levels in the ice. Supraglacial deposits are typically the farthest traveled, sometimes exceeding tens or even hundreds of kilometres. They have low drift exploration potential and must be differentiated in the field from other resedimented glacial deposits by characteristics such as abundant, far-traveled erratics, that are commonly angular with few or no glacial abrasion features, and by sedimentologic studies.

Glaciofluvial sediments, derived from till or from material within the ice, have undergone at least two episodes of transport and are viewed as second or third derivatives of bedrock. Transport distances are highly variable and dependent on factors such as paleostream energy, bedrock lithology (resistance to abrasion) and grain size. Processes of entrainment, transportation and redeposition result in discontinuous, irregular, often sinuous dispersal patterns. These deposits are not expected to reflect nearby mineralization except in areas where they are less than a few metres thick and erosionally overlie bedrock. Glaciolacustrine sediments are at least third-derivative sedimentary products of bedrock, invariably having undergone multiple cycles of erosion, transportation and deposition by glaciers, streams and finally in the lacustrine environment. Due to this complex history, the potential for locating the original source of any mineralized material that may be discovered in these sediments is very low. Geochemical anomalies in glaciolacustrine sediments are more likely to reflect grain size or sedimentologic controls such as heavy mineral concentrations in coarser beach sands, than bedrock sources. In addition, these deposits are often comprised of sediment transported from a wide region and the potential for dilution of mineralized material by barren sediment is therefore much higher.

## SUMMARY

Morainal sediments deposited during the last glaciation are widespread in the Interior Plateau and form a cover, varying in average thickness from a few to several metres in low-lying areas, to less than a metre in upland regions. Glaciofluvial sediments are also common, occurring as eskers, kames, terraces, fans and outwash plains in valley bottoms and along valley flanks. They consist mainly of poorly to well sorted, stratified, pebble and cobble gravels and sands. Glaciolacustrine sediments are common in some valleys, generally at elevations below 750 to 950 metres, often near modern lakes. Stratigraphic studies of Quaternary deposits in the region indicate ice damming during both advance and retreat stages of the last glaciation. The Late Wisconsinan ice-flow record in most areas is dominated by one regional flow direction. In areas of relatively high relief, the regional flow was modified by topographic control during both early and late stages of glaciation. Glacial dispersal patterns in most areas tend to reflect mainly the influence of the last regional flow direction and they are not obscured by the effects of topography or earlier glaciations.

Soil geochemical anomalies associated with glacial dispersal of mineralized bedrock in the region are up to a few kilometres long and several hundred metres or more wide, but isolated anomalies associated with the dispersal trains may cover much larger areas. Erratics trains and till geochemical anomalies are up to several kilometres long and more readily detected than soil anomalies. They show a pronounced elongation parallel to ice-flow direction, with mineralized source rocks occurring at or near the up-ice end of the trains and dispersal plumes. Till geochemistry reflects up-ice bedrock sources and not the immediately underlying bedrock. In areas of thick till, near-surface anomalies may be displaced by 500 metres or more down-ice from their bedrock source. Subsurface exploration targets in these areas should be up-ice, rather than at the head, of the geochemical anomaly.

Results of till geochemical surveys indicate that basal till sampling programs are an effective tool for locating mineralized zones in drift-covered parts of the Interior Plateau. To reflect mechanical dispersal processes, samples should be collected from within the C mineral soil horizon. Sedimentologic data should be collected at all sample sites in order to distinguish till from glacigenic debris-flow, colluvial, glaciofluvial or glaciolacustrine sediments. These sediments have different processes of transportation and deposition which must be recognized in order to understand associated mineral anomaly patterns. Local variations will be reflected in some sediments while regional trends may be evident in others. Analysis of these sediments will be useful only if their origin is understood.

A basic understanding of ice-flow direction, glacial dispersal patterns, transportation distances, Quaternary stratigraphy and the origin of different sampling media are considered essential for successful drift exploration programs in this region. Interpretation of data with respect to glaciation may provide new avenues to explore for bedrock sources of mineralized float or geochemically anomalous soil samples.

## ACKNOWLEDGMENTS

The authors would like to thank the following field and office staff and associates of the British Columbia Geological Survey for their cooperation on this integrated program: Steve Cook, Larry Diakow, Gord Weary, Erin O'Brien, Ian Webster, Jack Whittles, Bob Lane, Michelle Luscombe, Daniel Meldrum, Paul Matysek, Peter Bobrowsky, Tom Richards, Janet Riddell and Tom Schroeter. Analytical assistance and quality control on all laboratory analyses were provided by Ray Lett. Sample preparation was completed by Tony Eldridge, Joni Borges and staff of Rossbacher Laboratory Ltd. Administrative assistance was provided by Beverly Brown. Figures 1 and 3 were drafted by Dave Huntley and Figure 4 was drafted by Dan Meldrum. We also extend thanks to numerous others who provided information, access to properties or other assistance including: Bruce Broster (University of New Brunswick), Barry and Marion Mills (Tatelkuz Lake ranch), Joe Meier (Northern Mountain Helicopters), Dave Heberlein and Dave Love (Inmet), Karl Schiemann and Ken McDonald (Cogema Canada Ltd.), Dave Tupper and Dave Dunn (Pioneer Metals), Warren Bates and Val VanDamme (Granges Inc.), Dave Flemming and Andrew Davies (Kennecott Canada), Gary Wong (Placer Dome), Arne Birkland (Arnex Resources), James Dawson (Lucero Resources), Jean Pautler (Teck), Ken Pride (Cominco), Dave Caulfield (Equity Engineering), Geoffrey Goodall (Fox Geological Consultants), Linda Dandy, Parry Grunenberg, Ralph Keifer and Donald McInnes (Western Keltic), Bruce Youngman (Northern Dynasty Exploration) and Hugh Grenfal (Booker Gold Explorations). This project has benefited greatly from the comments of various reviewers including W.B. Coker, S.J. Cook, L.J. Diakow, D.E. Kerr, P.F. Matysek, M.B. McClenaghan, J.M. Newell, A. Plouffe and S.J. Sibbick.

## REFERENCES

Agriculture Canada Expert Committee on Soil Survey (1987): The Canadian System of Soil Classification, Second Edition; *Agriculture Canada*, Publication 1646, 164 pages.

Best, M.E., Levson, V.M. and Diakow, L.J. (1996): Time-domain Electromagnetic Surveys in Drift Covered Regions of the Fawnie Creek Map Area, British Columbia; *in* Current Research, Part A, *Geological Survey of Canada*, Paper 1996-A, pages 91-100.

Bohme, D.M. (1988): Geological, Geochemical and Geophysical Report on the White Claim Group, Omineca Mining Division (NTS 93F/11E, 6E; Latitude 53°30'N, Longitude 125°05'W); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 18191, 54 pages.

Boyle, D.R. and Troup, A.G. (1975): Copper-Molybdenum Porphyry Mineralization in Central British Columbia, Canada: An Assessment of Geochemical Sampling Media Useful in Areas of Glaciated Terrain; *in* Prospecting in Areas of Glaciated Terrain, Jones, M.J., Editor, *The Institution of Mining and Metallurgy*, London, pages 6-15.

Bradshaw, P.M.D., Thomson, I., Smee, B.W. and Larsson, J. (1974): The Application of Different Analytical Extractions and Soil Profile Sampling in Exploration Geochemistry; *Journal of Geochemical Exploration*, Volume 3, pages 209-225.

Cook, S. (1996): Regional and Property-scale Application of Lake Sediment Geochemistry in the Search for Buried Mineral Deposits in the Southern Nechako Plateau Area, British Columbia (93C, E, F, K, L); *in* Interior Plateau Geoscience Project: Summary of Geological, Geochemical and Geophysical Studies, Newell, J.M. and Diakow, L.J., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1997-2, this volume.

Cook, S.J., Levson, V.M., Giles, T.R. and Jackaman, W. (1995). A Comparison of Regional Lake Sediment and Till Geochemistry Surveys: A Case Study from the Fawnie Creek Area, Central British Columbia; *Exploration and Mining Geology*, Volume 4, Number 2, pages 93-110.

Dawson, J.M. (1988): Geological and Geochemical Report on the Wolf Property, Omineca Mining Division; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 16995, 23 pages.

Delaney, T.A. and Fletcher, W.K. (1994): Quaternary Geology/Geochemical Exploration Studies in the Wolf-Capoose and AOK-Moondust Areas of the Central Interior Plateau of British Columbia; Mineral Deposits Research Unit, *The University of British Columbia*, Technical Report MT-8, 9 pages and appendices.

Diakow, L.J., Webster, I.W.E., Richards, T.A. and Tipper, H.W. (1996): Geology of the Fawnie and Nechako Ranges, Southern Nechako Plateau, Central British Columbia (93F/2, 3, 6, 7);*in* Interior Plateau Geoscience Project: Summary of Geological, Geochemical and Geophysical Studies, Newell, J.M. and Diakow, L.J., Editors, *B.C. Ministry of Employment and Investment*, Paper 1997-2, this volume

DiLabio, R.N.W. (1990): Glacial Dispersal Trains; *in* Glacial Indicator Tracing; Kujansuu. R. and Saarnisto, M., Editors, *A.A. Balkema*, Rotterdam, pages 109-122.

Dreimanis, A. (1988): Tills: Their Genetic Terminology and Classification; *in* Genetic Classification of Glacigenic Deposits, Goldthwait, R.P. and Matsch, C.L., Editors, *A.A. Balkema*, Rotterdam, pages 17-83.

Dreimanis, A. (1990): Formation, Deposition and Identification of Subglacial and Supraglacial Tills; *in* Glacial Indicator Tracing; Kujansuu. R. and Saarnisto, M., Editors, *A.A.Balkema*, Rotterdam, pages 35-59.

Edwards K. and Campbell, T. (1992): Geological, Geochemical, Geophysical Assessment Report for the CH 10-16 Mineral Claims, Omineca Mining Division (NTS 93F/7E, 8W; Latitude 53°31'N, Longitude 124°25'W); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 22027, 25 pages.

Fox, P., Cameron, R. and Hoffman, S. (1987): Geology and Soil Geochemistry of the Quesnel River Gold Deposit, British Columbia; *in* Geoexpo '86, Elliot, I.L. and Smee, B.W., Editors, *The Association of Exploration Geochemists*, pages 61-67.

Giles, T.R. and Kerr, D.E. (1993): Surficial Geology in the Chilanko Forks and Chezacut Areas (93C/1, 8); *in* Geological Fieldwork 1992, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 483-490.

Giles, T.R. and Levson, V.M. (1994a): Surficial Geology and Drift Exploration Studies in the Fawnie Creek Region (93 F/3); *in* Geological Fieldwork 1993, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 27-38.

Giles, T.R. and Levson, V.M. (1994b): Drift Prospecting Potential of the Fawnie Creek Area (NTS 93 F/3); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1994-10 (1:50 000 map).

Giles, T.R. and Levson, V.M. ( 1995): Surficial Geology and Quaternary Stratigraphy of the Tsacha Lake Area (NTS 93F/2); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1995-10 (1:50 000 map).

Giles, T.R., Levson, V.M. and Weary, G.F. (1995): Surficial Geology and Drift Exploration Studies in the Tsacha Lake and Chedakuz Creek Areas (NTS 93F/2, 7), Central British Columbia; *in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 199-205.

Gleeson C.F., Rampton, V.N., Thomas, R.D. and Paradis, S. (1989): Effective Mineral Exploration for Gold Using Geology, Quaternary Geology and Exploration Geochemistry in Areas of Shallow Till; *in* Drift Prospecting, DiLabio, R.N.W. and Coker, W.B., Editors, *Geological Survey of Canada*, Paper 89-20, pages 71-96.

Gravel, J.L. and Sibbick, S.J. (1991): Geochemical Dispersion in Complex Glacial Drift at the Mount Milligan Copper-Gold Porphyry Deposit (93N/1E, 93O/4W); *in* Exploration in British Columbia 1990, *B.C. Ministry of Energy, Mines and Petroleum Resources*, pages 117-134.

Harington, C.R., Tipper, H.W. and Mott, R.J. (1974): Mammoth from Babine Lake, British Columbia; *Canadian Journal of Earth Sciences*, Volume 11, pages 285 - 303.

Holland, S.S. (1976): Landforms of British Columbia, A Physiographic Outline; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 48, 138 pages.

Howes, D.E. (1977): Terrain Inventory and Late Pleistocene History of the Southern Part of the Nechako Plateau; *B.C. Ministry of Environment, Lands and Parks*, RAB Bulletin 1, 29 pages.

Huntley, D.H., Stumpf, A., Levson, V.M. and Broster, B.E. (1996): Babine Porphyry Belt Project: Quaternary Geology and Regional Till Geochemistry Sampling in the Old Fort Mountain (93M/01) and Fulton Lake (93L/16) Map Areas, British Columbia; *in* Geological Fieldwork 1995, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1996-1, pages 45-53.

Kerr, D.K. (1995): Drift Exploration Data from B.C. Ministry of Energy, Mines and Petroleum Resources Assessment Reports: NTS 93N (Manson River) South Half, Northern Quesnel Trough Region, B.C.; *in* Drift Exploration in the Canadian Cordillera, Bobrowsky, P.T., Sibbick, S.J., Newell, J.M. and Matysek, P.F., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-2, pages 265-276.

Kerr, D.E. and Giles, T.R. (1993a): Surficial Geology in the Chilanko Forks Map Area (93C/1); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1993-16 (1:50 000 map).

Kerr, D.E. and Giles, T.R. (1993b): Surficial Geology of the Chezacut Map Area (93C/8); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1993-17 (1:50 000 map).

Kerr, D.K. and Levson, V.M. (1995): Annotated Bibliography of Drift Prospecting Activities in British Columbia; *in* Drift Exploration in the Canadian Cordillera, Bobrowsky, P.T., Sibbick, S.J., Newell, J.M. and Matysek, P.F., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-2, pages 277-303.

Kerr, D.K. and Levson, V.M. (1996): Drift Prospecting Activities in British Columbia: An Overview with Emphasis on the Interior Plateau; *in* Interior Plateau Geoscience Project: Summary of Geological, Geochemical and Geophysical Studies, Newell, J.M. and Diakow, L.J., Editors, *B.C. Ministry of Employment and Investment*, Paper 1997-2, this volume.

Kerr, D.E., Sibbick, S.J. and Jackaman, W. (1992): Till Geochemistry of the Quatsino Map Area (92L/12); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1992-21, 15 pages and appendices.

Kerr, D.E., Sibbick, S.J. and Belik, G.D. (1993): Preliminary Results of Glacial Dispersion Studies on the Galaxy Property, Kamloops, B.C. (92I/9); *in* Geological Fieldwork 1992, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1993-1, pages 439-443.

Kor, P.S.G., Shaw, J. and Sharpe D.R. (1991): Erosion of Bedrock by Subglacial Meltwater, Georgian Bay, Ontario: A Regional View; *Canadian Journal of Earth Sciences*, Volume 28, pages 623-642.

Lane, R.A. , Schroeter, T.G. and Diakow, L.J. (1996): Metallogeny of the Interior Plateau, Central British Columbia (Parts of 93B, C, F); *in* Interior Plateau Geoscience Project: Summary of Geological, Geochemical and Geophysical Studies, Newell, J.M. and Diakow, L.J., Editors, *B.C. Ministry of Employment and Investment,* Paper 1997-2, this volume.

Levson, V.M. and Giles, T.R. (1993): Geology of Tertiary and Quaternary Gold-bearing Placers in the Cariboo Region, British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 89, 202 pages.

Levson, V.M. and Giles, T.R. (1994): Surficial Geology and Quaternary Stratigraphy of the Fawnie Creek Area (NTS 93F/3); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1994-9 (1:50 000 map).

Levson, V.M. and Giles, T.R. (1995): Glacial Dispersal Patterns of Mineralized Bedrock with Examples from the Nechako Plateau, Central British Columbia; *in* Drift Exploration in the Canadian Cordillera, Bobrowsky, P.T., Sibbick, S.J., Newell, J.M. and Matysek, P.F., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-2, pages 67-76.

Levson, V.M., Giles, T.R., Cook, S.J. and Jackaman, W. (1994): Till Geochemistry of the Fawnie Creek Area (93F/03); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1994-18, 34 pages with appendices.

Levson, V.M., and Rutter, N.W. (1986): A Facies Approach to the Stratigraphic Analysis of Late Wisconsinan Sediments in the Portal Creek Area; *Geographie Physique et Quaternaire*, Volume 40, Number 2, pages 129-144.

Levson, V.M. and Rutter, N.W. (1988): A Lithofacies Analysis and Interpretation of Depositional Environments of Montane Glacial Diamictons, Jasper, Alberta, Canada; *in* Genetic Classification of Glacigenic Deposits, Goldthwait, R. P. and Matsch, C. L., Editors, *A.A. Balkema*, Rotterdam, pages 117-140.

Lynch, J. (1990): Provisional Element Values for Eight New Geochemical Lake Sediment and Stream Sediment Reference Materials LKSD-1, LKSD-2, LKSD-3, LKSD-4, STSD-1, STSD-2, STSD-3, STSD-4; *Geostandards Newsletter*, Volume 14, No.1, pages 153-167.

Mehrtens, M.B. (1975): Chutanli Mo Deposit, British Columbia; in Conceptual Models in Exploration Geochemistry, *Journal of Geochemical Exploration*, Volume 4, Number 1, pages 63-65.

Meldrum D.G. and Bobrowsky, P.T. (1994): Drift Exploration Potential of the Alice Lake Area (NTS 92L/6); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1994-12 (1:50 000 map).

O'Brien, E.K. Broster, B.E. Giles, T.R. and Levson, V.M. (1995) Till Geochemical Sampling: CH, Blackwater-Davidson, and Uduk Lake Properties, British Columbia: Report of Activities; *in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 207-211.

Plouffe, A. (1994a): Surficial Geology, Chuchi Lake, British Columbia (93N/SE); *Geological Survey of Canada*, Open File 2842 (1:100 000 map).

Plouffe, A. (1994b): Surficial Geology, Tezzeron Lake, British Columbia (93K/NE); *Geological Survey of Canada*, Open File 2846 (1:100 000 map).

Plouffe, A. (1995): Geochemistry, Lithology, Mineralogy and Visible Gold Grain Content of Till in the Manson River and Fort Fraser Map Areas, Central British Columbia (NTS 93K, N); *Geological Survey of Canada*, Open File 3194, 119 pages.

Plouffe, A. and Ballantyne, S.B. (1993): Regional Till Geochemistry, Manson River and Fort Fraser Area, British Columbia (93K, 93N), Silt Plus Clay and Clay Size Fractions; *Geological Survey of Canada*, Open File 2593, 210 pages.

Plouffe, A. and Ballantyne, S.B. (1994): Regional Till Geochemistry, Mount Tatlow and Elkin Creek Area, British Columbia (93O/5 and 93O/12); *Geological Survey of Canada*, Open File 2909, 62 pages.

Proudfoot, D.N. (1993): Drift Exploration and Surficial Geology of the Clusko River (93C/9) and Toil Mountain (93C/16) Map Sheets; *in* Geological Fieldwork 1992, Grant, B. and

Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 491-498.

Proudfoot, D.N. and Allison, R.F. (1993a): Surficial Geology of the Clusko River Map Area (93C/9); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1993-18 (1:50 000 map).

Proudfoot, D.N. and Allison, R.F. (1993b): Surficial Geology of the Toil Mountain Map Area (93C/16); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1993-19 (1:50 000 map).

Proudfoot, D.N., Bobrowsky, P.T. and Meldrum, D. (1995): Drift Exploration Potential Maps Derived from Terrain Geology Maps; *in* Drift Exploration in the Canadian Cordillera, Bobrowsky, P.T., Sibbick, S.J., Newell, J.M. and Matysek, P.F., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-2, pages 23-31.

Ryder, J.M. and Clague, J.J. (1989): British Columbia Quaternary Stratigraphy and History, Cordilleran Ice Sheet; *in* Quaternary Geology of Canada and Greenland, Fulton, R.J., Editor, *Geological Survey of Canada*, Geology of Canada, Number 1, pages 48-58.

Schroeter, T.G. and Lane, R.A. (1994): Mineral Resources (93F/3 and parts of 93F/2,6 and 7); *in* Geological Fieldwork 1993, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 45-56.

Shaw, J. (1989): Drumlins, Subglacial Meltwater Floods and Ocean Responses; *Geology*, Volume 17, pages 853-856.

Shaw, J. and Kvill, D. (1984): A Glaciofluvial Origin for Drumlins of the Livingstone Lake Area, Northern Saskatchewan; *Canadian Journal of Earth Sciences*, Volume 21, pages 1442-1459.

Shaw, J. and Sharpe, D. R. (1987): Drumlin Formation by Subglacial Meltwater Erosion; *Canadian Journal of Earth Sciences*, Volume 24, pages 2316-2322.

Shaw, J., Kvill, D. and Rains, B. (1989): Drumlins and Catastrophic Subglacial Floods; *Sedimentary Geology*, Volume 62, pages 177-202.

Shilts, W. (1973a): Glacial Dispersion of Rocks, Minerals and Trace Elements in Wisconsin Till, Southeastern Quebec, Canada; *Geological Society of America*, Memoir 136, pages 189-219.

Shilts, W. (1973b): Till Indicator Train Formed by Glacial Transport of Nickel and other Ultrabasic Components: A Model for Drift Prospecting; *Geological Survey of Canada*, Paper 73-1, pages 213-218.

Shilts, W. (1976): Glacial Till and Mineral Exploration; *in* Glacial Till, An Interdisciplinary Study, Legget, R.F., Editor, *Royal Society of Canada*, Special Publication 12, pages 205-224.

Shilts, W. (1993): Geological Survey of Canada's Contributions to Understanding the Composition of Glacial Sediments; *Canadian Journal of Earth Sciences*, Volume 30, pages 333 - 353.

Shilts, W. (1995): Geochemical Partitioning in Till; *in* Drift Exploration in the Canadian Cordillera, Bobrowsky, P.T., Sibbick, S.J., Newell, J.M. and Matysek, P.F., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-2, pages 149-164.

Shoemaker, E.M. (1992): Subglacial Floods and the Origin of Low-relief Ice-sheet Lobes; *Journal of Glaciology*, Volume 38, pages 105-112.

Sibbick, S.J. and Fletcher, W.K. (1993): Distribution and Behavior of Gold in Soils and Tills at the Nickel Plate Mine, Southern British Columbia, Canada; *Journal of Geochemical Exploration*, Volume 47, pages 183-200.

Sibbick, S.J. and Kerr, D.E. (1995): Till Geochemistry of the Mount Milligan Area, North-central British Columbia; Recommendations for Drift Exploration for Porphyry Cu-Au Mineralization; *in* Drift Exploration in the Canadian Cordillera, Bobrowsky, P.T., Sibbick, S.J., Newell, J.M. and Matysek, P.F., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-2, pages 167-180.

Stumpf, A., Huntley, D.H., Broster, B.E. and Levson, V.M. (1996): Babine Porphyry Belt Project: Detailed Drift Exploration Studies in the Old Fort Mountain (93M/01) and Fulton Lake (93L/16) Map Areas, British Columbia; *in* Geological Fieldwork 1995, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1996-1, pages 37-44.

Tipper, H.W. (1963): Nechako River Map-area, British Columbia; *Geological Survey of Canada*, Memoir 324, 59 pages.

Tipper, H.W. (1971): Glacial Geomorphology and Pleistocene History of Central British Columbia; *Geological Survey of Canada*, Bulletin 196, 89 pages.

Warner, L. and Cannon, R. (1990): Geochemical and Geophysical Assessment Report for the CH 10-14 Mineral Claims, Omineca Mining Division (NTS 93F/7E, 8W; Latitude 53° 31'N, Longitude 124°25'W); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 20765, 17 pages.

Weary G.F., Giles, T.R., Levson, V.M. and Broster, B.E. (1995): Surficial Geology and Quaternary Stratigraphy of the Chedakuz Creek Area (NTS 93F/7); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1995-13 (1:50 000 map).