Yukon Targeted Geoscience Initiative, Part 2: Glacial history, till geochemistry and new mineral exploration targets in Glenlyon and eastern Carmacks map areas, central Yukon

J.D. Bond[1]
Yukon Geology Program

A. Plouffe[2]
Geological Survey of Canada

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ABSTRACT

A regional till geochemistry project was completed in conjunction with bedrock mapping across rocks of Yukon-Tanana Terrane and North American affinity in central Yukon. The high mineral potential of the area is based on recent discoveries in the Finlayson Lake area to the southeast, an area thought to juxtapose the Glenlyon area prior to displacement on the Tintina Fault.

The study area lies at the limit of the Late Wisconsinan McConnell glaciation. Ice flow was largely directed by topography. Soil profiles reveal a veneer of White River ash and loess over most till deposits.

Geochemical results from 285 till samples highlight new anomalies in gold, gold/arsenic (intrusive- and fault-related), copper (veins), copper/nickel (ultramafic rocks) and zinc (sedimentary-exhalative (SEDEX) and epithermal). An orientation survey was completed at the Clear Lake SEDEX deposit to evaluate the extent of glacial dispersion down-ice from mineralization.

RÉSUMÉ

Un programme d'échantillonnage régional du till a été complété conjointement avec la cartographie de la roche en place au-dessus des roches du terrane de Yukon Tanana et d'affinitées nord américaine dans la partie centrale du Yukon. Le fort potentiel de minéralisation dans cette région est basé sur les découvertes récentes au sud-est dans le secteur du lac Finlayson, une région qui était juxtaposée à la région de Glenlyon avant son déplacement de long de la faille de Tintina.

La région d'étude est sise à la limite de la glaciation de McConnell du Wisconsinien tardif. Les écoulements glaciaires y étaient grandement contrôlés par la topographie. Les profils dans le sol montrent que les dépôts de till sont recouverts d'un placage de cendres volcaniques de White River et de loess.

Les résultats de l'analyse géochimique de 285 échantillons de till pointent vers de nouvelles anomalies en or, or et arsenic (reliées à des intrusions ou des failles), cuivre (veines), cuivre et nickel (roches ultramafiques) et zinc (minéralisation épithermale et sédimentaire exhalatif). Un échantillonnage détaillé a été complété au-dessus de la zone minéralisée de type sédimentaire exhalatif de Clear Lake pour évaluer l'étendue de la dispersion glaciaire en aval de la minéralisation.

[1]*jdbond@gov.yk.ca*
[2]*APlouffe@NRCan.gc.ca*

INTRODUCTION

The Glenlyon (NTS 105L) and eastern Carmacks (NTS 115I) map areas were the focus of the Yukon Targeted Geoscience Initiative (TGI) in its third year. In continuing the program of bedrock mapping and till geochemistry across prospective tracks of Yukon-Tanana Terrane (YTT), the focus shifted northwest towards the Glenlyon map area (Fig. 1). Last year, TGI efforts were focused in the Finlayson Lake region where a large tract of YTT remained poorly mapped amidst areas of high mineral potential. The geology of the Glenlyon map area was suspected to mirror the Finlayson Lake district following restoration of 450 km displacement along the Tintina Fault (Colpron, 1999a). Although the geological relationship seemed favourable in the Glenlyon region, vast areas of poorly understood geology are blanketed by glacial deposits. Furthermore, drainage is poorly developed in the plateau region of the Glenlyon map area, which is reflected by a low sample density of stream sediments (Hornbrook and Friske, 1988). Consequently, to further evaluate the mineral potential of the Glenlyon and eastern Carmacks map areas, a till sampling program was conducted, focusing on areas of high mineral potential, widespread till cover, and poor RGS (Regional Geochemical survey) coverage (Hornbrook and Friske, 1988). Similar to the Finlayson TGI (Bond and Plouffe, 2002), till was favoured as a sampling medium for the following reasons: 1) it occurs abundantly on plateaus and hills in areas of poor bedrock exposure; and 2) it is considered a first-order derivative of bedrock (Shilts, 1976, 1993).

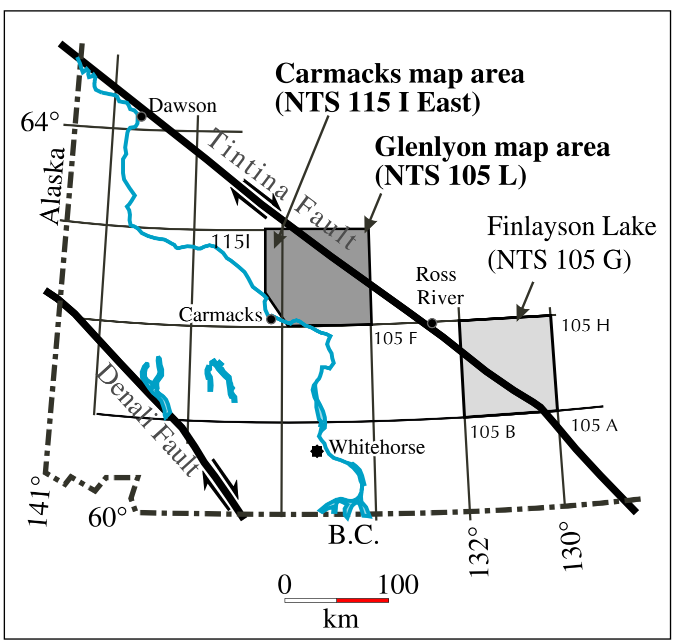

Figure 1. Location of the Glenlyon and Carmacks map areas.

PREVIOUS STUDIES

Quaternary stratigraphic investigations and surficial mapping were completed by Ward (1989; 1993), Ward and Jackson (1992; 2000) and Jackson (2000) for the Glenlyon and eastern Carmacks map areas. Surficial geological mapping was completed at 1:100 000 scale for both areas and provided the background for this work. Related studies, to the north of Glenlyon and Carmacks map areas, include surficial mapping by Hughes (1982) in Mayo (105M) and placer gold deposit studies in the Mayo mining district (LeBarge et al., 2002). Surficial mapping and Quaternary stratigraphy investigations were undertaken to the northwest in McQuesten (115P; Bond, 1997). More recently, a drift prospecting and surficial mapping study was completed to the east in the Anvil district (Bond, 2001).

Initial bedrock geological mapping was undertaken by R.B. Campbell of the Geological Survey of Canada (Campbell, 1967). Recent geological mapping by Colpron (1999a; 2001) in the Glenlyon area refined the bedrock framework and placed it in context with YTT elsewhere in Yukon.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The study area is divided into four physiographic regions (Mathews, 1986): the Lewes Plateau, the Pelly Mountains, the Tintina Trench and the MacMillan Highland. Most of the study area lies within the Lewes Plateau, which is a subdivision of the Yukon Plateau, and consists of a broad rolling lowland with poorly developed drainage and abundant small lakes (Fig. 2). Large meltwater channels containing underfit streams dissect the Lewes Plateau (Fig. 3). The Glenlyon Range is the northwestern extension of the Pelly Mountains. The highest summits in the range reach above 1970 m (6500 ft). Numerous cirques, many of which contain tarn lakes, are developed in the range (Fig. 4). Few rock glaciers are present in the southeast part of the highland. The Tintina Trench, a prominent low intermontane valley, dissects the Glenlyon Range to the north (Fig. 5). The MacMillan Highland occupies the region north of the trench and consists of a mountainous region lower in elevation and less rugged than the Glenlyon Range.

Figure 2. *The north-central lowland in the Glenlyon map area. Low relief and poor drainage characterize this region.*

Figure 3. *A McConnell meltwater channel cutting the Tatchun Hills near Frenchman Lake.*

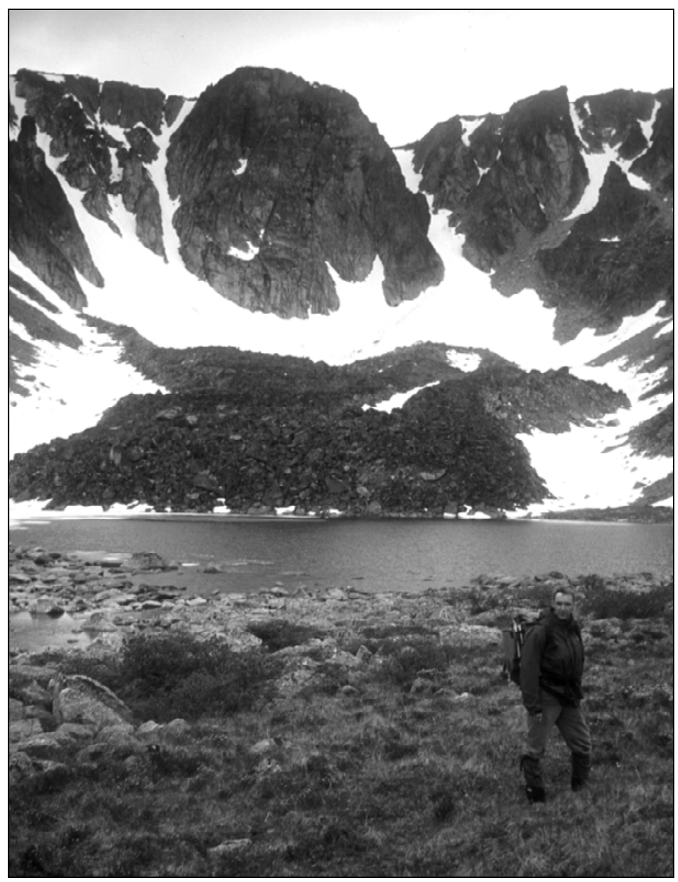

Figure 4. *A well developed north-facing cirque in the Glenlyon Range. Note the tarn in the middle ground. A debris-covered glacier blankets the back of the cirque.*

The study area lies at the boundaries of ancient North America, Yukon-Tanana and Stikinia terranes. The North American terrane is composed of rocks of the Cassiar Platform, including Earn Group strata that host the Clear Lake sedimentary-exhalative (SEDEX) deposit (Yukon MINFILE 2002, 105L 045). Yukon-Tanana Terrane is composed of two Carboniferous volcanic arc successions, associated subvolcanic plutonic suites and pre-Mississippian metasedimentary basement rocks. A series of northwest-trending strike-slip faults occur in the area. Early Jurassic batholiths intrude the western sector, whereas small mid-Cretaceous plutons intrude the eastern part. See Colpron et al. (this volume) for details on the bedrock geology.

METHODOLOGY

Preparatory investigations involved air photo interpretation and analysis of existing surficial geology (Jackson, 2000; Ward and Jackson, 2000), bedrock geology (Colpron, 2000) and geophysical maps (Gordey and Makepeace, 1999), Yukon MINFILE (2002) and regional stream sediment geochemistry (Hornbrook and Friske, 1988) to determine high mineral potential areas with a till veneer or blanket, which are most suitable for drift prospecting. During the field season, new target areas were defined for till sampling as the bedrock mapping progressed.

Fieldwork was completed from a base camp located on the Frenchman Lake Road approximately 1 km east of the Klondike Highway. The Robert Campbell Highway, Frenchman Lake Road and Klondike Highway provided staging points into the study area. Access to more remote

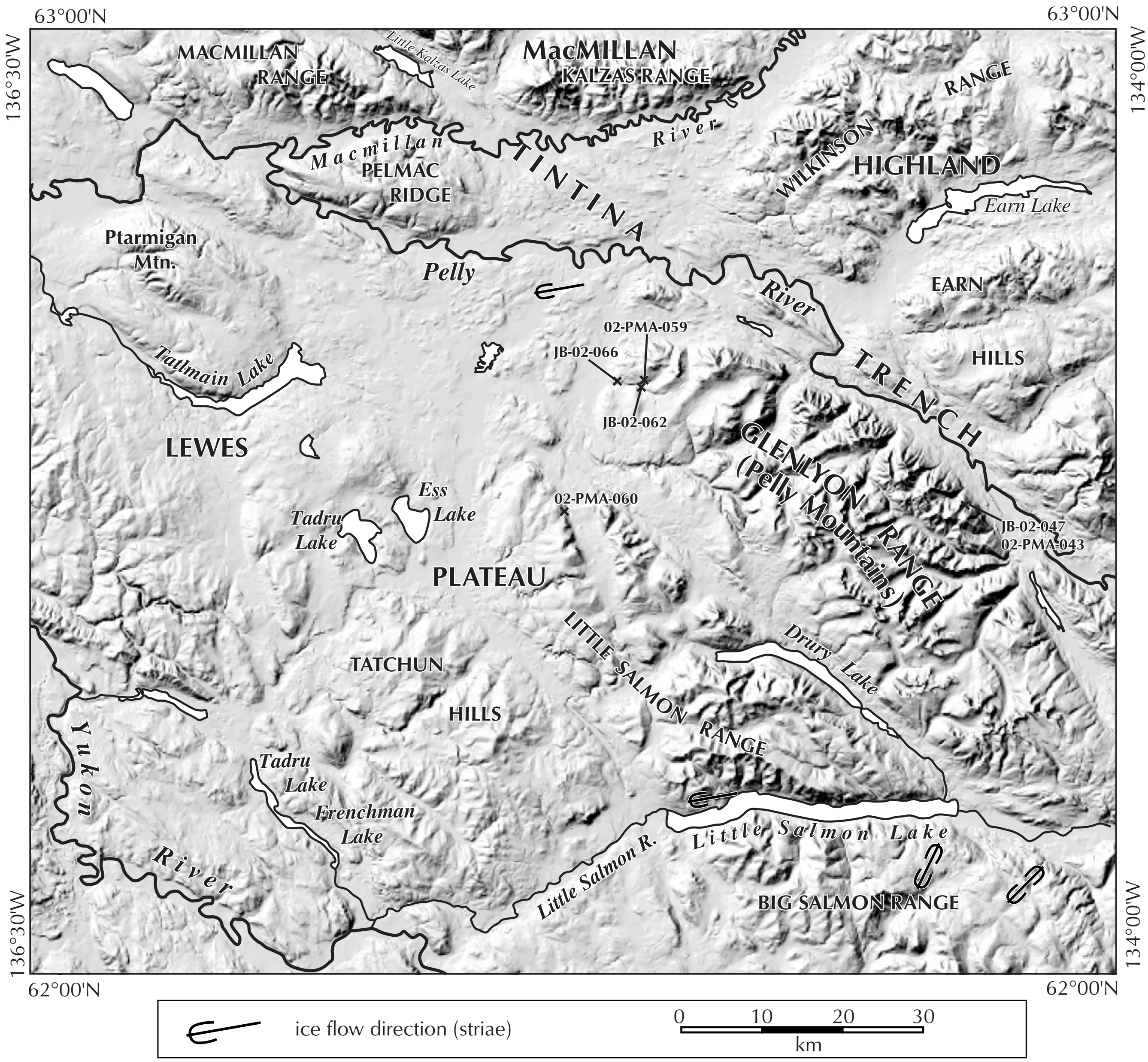

__Figure 5.__ Physiography of the study area represented on a digital elevation model (Department of Environment, Yukon Government).

parts of the field area was provided by a Bell 206 helicopter. All samples were collected during daily foot traverses. Sample lines were oriented perpendicular to the paleo-ice flow direction to maximize geochemical exposure to the underlying bedrock. Sample spacing was approximately 1 km and an average of 6-8 samples were collected on daily foot traverses.

A total of three samples were collected at each station. This included a 2 kg and a 1 kg bulk till sample for geochemical analysis of the silt plus clay-size fraction (-230 mesh or <0.063 mm) and the clay-size fraction (<0.002 mm), respectively. The third sample, comprising 50 pebbles, was collected for lithological characterization of the till. Lodgement till and colluviated lodgement till were the primary sample mediums. Each till pit was dug to a depth of about 50 cm to collect till from the C-horizon that represents unweathered parent material (Fig. 6). Where possible, till was sampled from natural exposures during stratigraphic investigations. This is beneficial when thick till deposits are encountered, and enables assessment of the vertical variability of the till geochemistry and lithology.

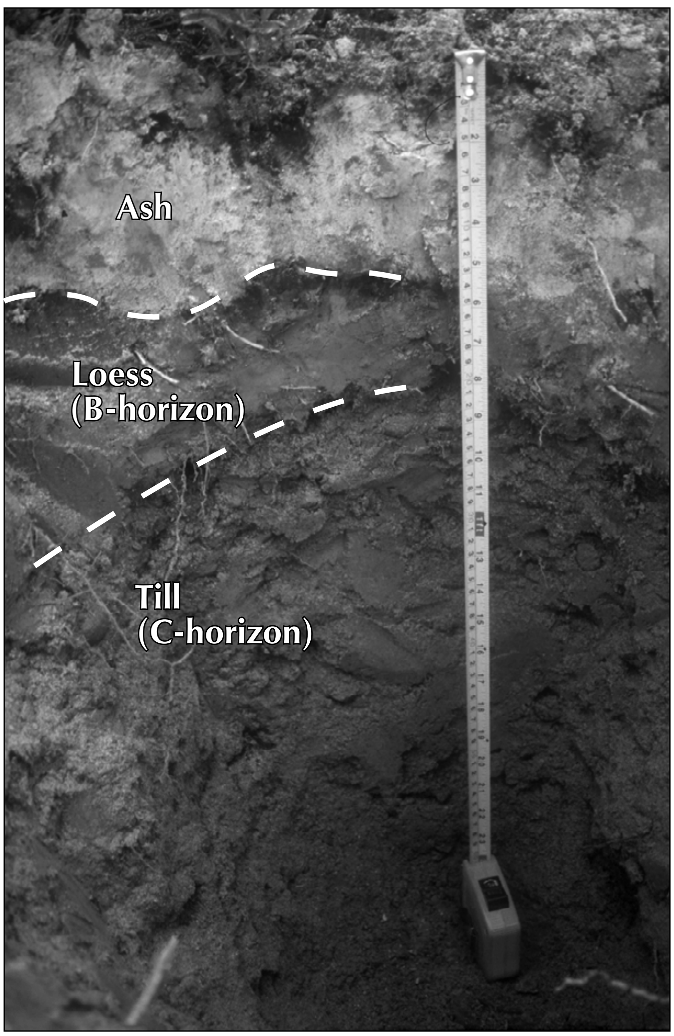

Figure 6. A typical soil profile from the study area. Loess cover is widespread in the area and often forms the B-horizon in the profile. Pit depth is 60 cm.

***Figure 7.** Taking field notes using a Compaq iPAQ handheld computer.*

Sample information was recorded and digitized in the field using a hand-held computer (Compaq iPAQ; Fig. 7). The information was downloaded at base camp and incorporated into a database. This data, combined with till geochemistry results, will be released on a CD-ROM in 2003.

Exposures of Quaternary sediments located along streams were described with respect to their colour, texture, sedimentary structures, clast lithologies, contacts and lateral continuity. Sections were logged to provide a better understanding of the glacial history, which serves to constrain the interpretation of the regional till geochemistry.

SAMPLE PREPARATION AND ANALYSIS

The till samples were sent to Acme Analytical Laboratories in Vancouver, British Columbia for 1) separation of the silt and clay-size fraction (2 kg sample) and 2) geochemical analysis. Samples were oven-dried at 40°C and dry-sieved to separate the silt- and clay-size fractions (<0.062 mm or -230 mesh). Samples of 30 g were analysed for 39 elements by inductively coupled plasma mass spectrometry (ICP-MS) after an aqua regia digestion. Aqua regia acts as a near total digestion on sulphide minerals and a partial leach on silicate minerals (Hall, 1991). Detection limits for the ICP-MS analyses are shown in Table 1. Results of the geochemical analyses of the clay-size fraction were not available at the time this paper was prepared, but will be released in a later publication, together with the 2001 clay-size results (see Bond and Plouffe, 2002).

Table 1. *Detection limits for elements analysed by ICP-MS in the 2002 study.*

Element	Detection	limit
Au	0.2	ppb
Ag	2	ppb
Al	0.01	%
As	0.1	ppm
B	1	ppm
Ba	0.5	ppm
Bi	0.02	ppm
Ca	0.01	%
Cd	0.01	ppm
Co	0.1	ppm
Cr	0.5	ppm
Cu	0.01	ppm
Fe	0.01	%
Hg	5	ppb
Ga	0.02	ppm
K	0.01	%
La	0.5	ppm
Mg	0.01	%
Mn	1	ppm
Mo	0.01	ppm

Element	Detection	limit
Na	0.001	%
Ni	0.1	ppm
P	0.001	%
Pb	0.01	ppm
Pd	10	ppb
Pt	2	ppb
S	0.02	%
Sb	0.02	ppm
Sc	0.1	ppm
Se	0.1	ppm
Sr	0.5	ppm
Te	0.02	ppm
Th	0.1	ppm
Ti	0.001	%
Tl	0.02	ppm
U	0.1	ppm
V	2	ppm
W	0.2	ppm
Zn	0.1	ppm

QUALITY CONTROL

With the 285 samples submitted for analysis, 29 field and 10 laboratory duplicates, and 37 control standards were randomly inserted to monitor analytical precision and accuracy. A mixture of field and laboratory duplicates was utilized to evaluate the combined sampling and analytical precision. Five different standards were used: two provided by the analytical laboratory, and Till-1, Till-2, and Till-4 obtained from the Canada Centre for Mineral and Energy Technology. Based on a positive correlation between field and laboratory duplicate pairs, the analytical and sampling precision is deemed satisfactory, and is best for lead, zinc, and copper, but worst for gold, probably due to the nugget effect: the heterogeneous distribution of gold particles in the sediment (Fig. 8). Given the low reproducibility of gold anomalies, extensive follow-up field work should not be conducted prior to reproducing gold anomalies herein reported. Analytical accuracy is also deemed satisfactory based on the comparison of the reported average concentrations of the standard samples and the values obtained as part of this study (Table 2).

Table 2. *Elemental concentrations of standards Till 1, 2 and 4 obtained in this study compared to reported values (Lynch, 1996).*

Elements	Pb ppm	Zn ppm	Cu ppm	Ba ppm	Ni ppm	Cr ppm	Co ppm	Au ppb	Ag ppb	As ppm	Sb ppm	Hg ppb
Till-1*	12	63	45	84	19	27	13	7	208	15	6	90
Till-1+	12	70	48	84	18	30	12	n/d	200	13	n/d	92
Till-2*	22	109	147	95	32	35	13	2	221	23	0.4	61
Till-2+	21	116	149	95	31	40	13	n/d	200	22	n/d	74
Till-4*	35	61	245	67	15	24	6	4	154	105	0.64	59
Till-4+	36	63	254	71	15	26	6	n/d	<200	102	n/d	39

**average value from this study +average value Lynch (1996)*
n/d – no data

REGIONAL QUATERNARY GEOLOGICAL CONTEXT

Central Yukon has been repeatedly glaciated since the Late Pliocene. At least six glaciations have been recognized in the Yukon, but only deposits of the three youngest glaciations (McConnell, Reid, and younger pre-Reid) are found within the study area (Duk-Rodkin and Froese, 2001; Jackson, 2000; Ward and Jackson, 2000). Dating of these events, including radiocarbon, K-Ar, Ar-Ar, paleomagnetism and tephrochronology, indicates that the McConnell Glaciation is equivalent to the Late Wisconsinan or marine oxygen isotope stage 2, approximately 26 000 to 10 000 years BP (Matthews et al., 1990; Jackson and Harington, 1991), and that the Reid Glaciation is of marine oxygen isotope stage 8, about 250 000 years BP (Huscroft et al., 2001; Westgate et al., 2001a; 2001b). The pre-Reid glacial sediments of the study area most likely correlate to the informal Fort Selkirk glaciation, which occurred about 1.5 my ago (Huscroft et al., 2001; Westgate et al., 2001b). The area under investigation was glaciated during each of these events but the western sector and some of the highest mountains remained unglaciated during the younger pre-Reid, Reid and McConnell glaciations. Because each glacial event

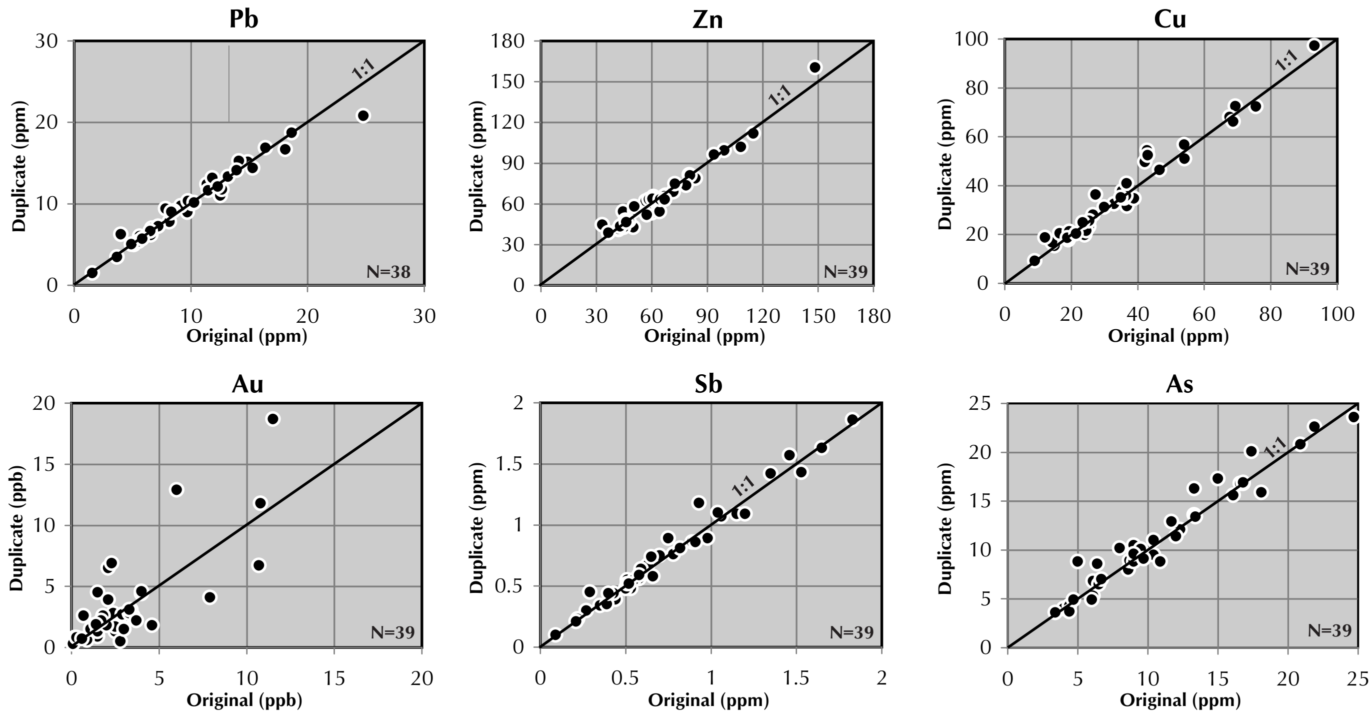

Figure 8. *Correlation plots of field and laboratory duplicates. N = number of samples.*

was less extensive than the preceding one, glacial limits within the study area decrease in elevation with decreasing age (Bostock, 1966; Hughes et al., 1969; Jackson et al., 1996).

Two ice lobes covered the study area during the McConnell Glaciation: the Selwyn Lobe, which had a source area in the Selwyn Mountains, flowed in a general northwest direction, north of the Pelly Mountains (Campbell, 1967; Hughes et al., 1969); the Cassiar Lobe, which originated from the Cassiar Mountains, flowed northwesterly south of the Pelly Mountains (Wheeler, 1961; Hughes et al., 1969). Most of the study area was affected by the Selwyn Lobe but both lobes coalesced in the southern sector of the study area (Ward and Jackson, 2000).

QUATERNARY SEDIMENTS AND STRATIGRAPHY

The Quaternary stratigraphy of the Glenlyon (105L) and Carmacks (115I) map areas is described in Ward and Jackson (2000) and Jackson (2000), respectively. This paper only describes and interprets stratigraphic data collected during the 2002 field season (Fig. 9).

PRE-REID SEDIMENTS

Sediments associated with a Pre-Reid event were not found during the 2002 field season. However, pre-Reid sediments were reported along the Pelly River by Ward and Jackson (2000) and on the Carmacks map sheet by Jackson (2000). Pre-Reid stratigraphy within the Carmacks map area includes Late Tertiary to Quaternary volcanic rocks and glacial and non-glacial sediments (Jackson, 2000).

SEDIMENTS OF THE REID GLACIATION

Evidence of Reid Glaciation may be exposed in section 02-PMA-059 (Fig. 9). Here, the lowest diamicton is massive and well compacted, contains abundant striated clasts, and is interpreted to be a till. Because it is overlain by the McConnell Glaciation succession, the lowest till could correspond to the Reid Glaciation. Alternatively, in the absence of numerical dating, paleosols or interglacial sediments, the lowest till and the upper tills (see below) could all correlate to the McConnell Glaciation and simply reflect a fluctuation of the ice front during ice advance or retreat.

As part of the regional till geochemistry survey, till of the Reid Glaciation was sampled beyond the McConnell

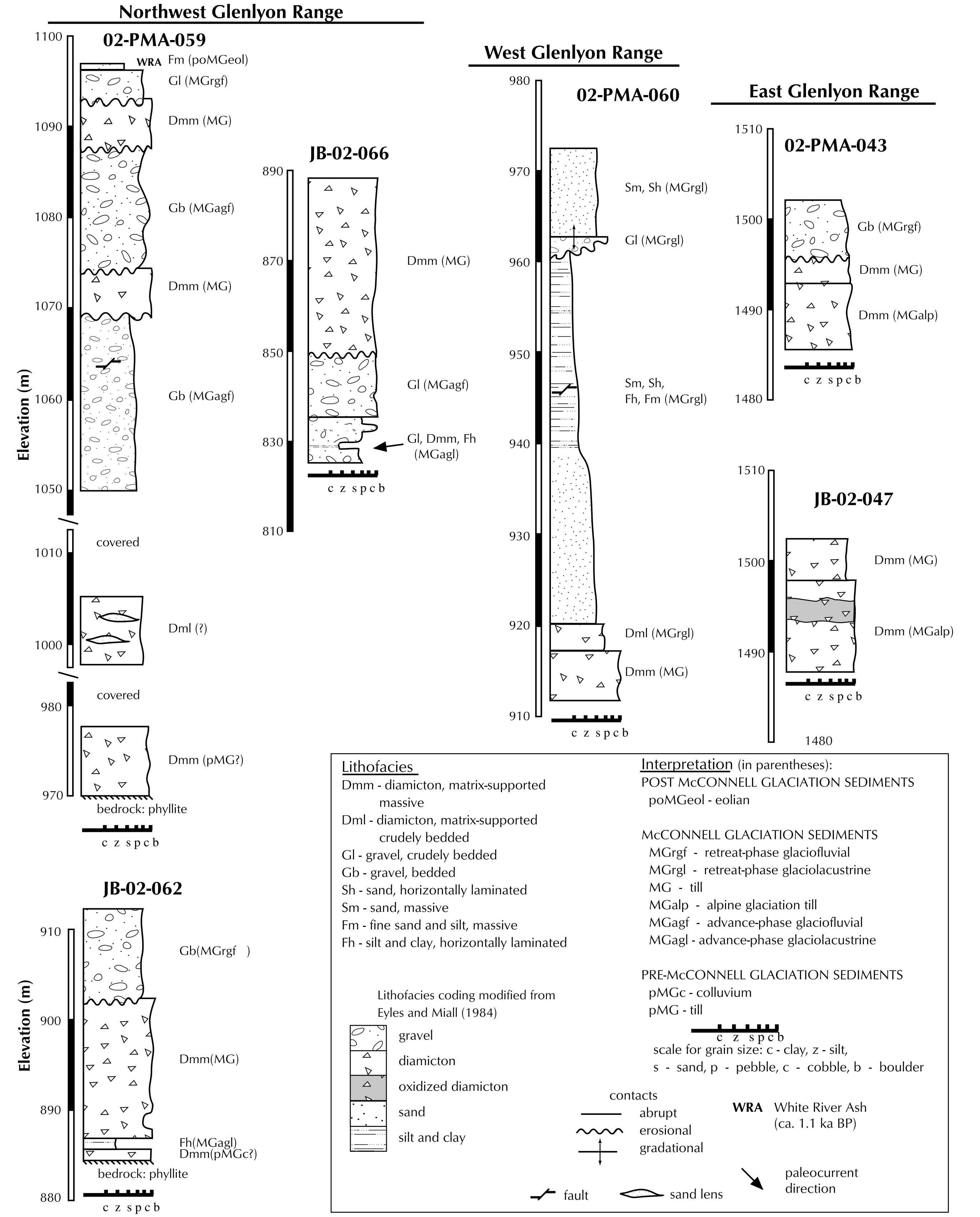

Figure 9. *Quaternary stratigraphy logged during the 2002 field season. Note the different vertical scale for station JB-02-062.*

glacial limit mapped by Ward and Jackson (2000). Reid till is characterized by a solum depth generally in excess of 60 cm, an abundance of weathered clasts, and in a few places, clay skins on some clasts. These criteria correspond to the description of the Diversion Creek paleosol, which developed on much of the Yukon landscape following the Reid glaciation (Smith et al., 1986).

SEDIMENTS OF THE McCONNELL GLACIATION

The majority of the sediments exposed within sections were deposited during the McConnell Glaciation. These sediments were deposited either at the ice front or underneath the glacier during ice advance and retreat at stations JB-02-062, JB-02-066, and 02-PMA-060. Massive to horizontally laminated units of well sorted fine sand and silt with minor clay were observed below and above McConnell till. These units commonly contain soft sediment deformations and interbeds and lenses of gravel and diamicton (Fig. 10). The fine sand, silt and clay were deposited in low energy environments of glacial lakes. Gravel lenses and interbeds reflect sedimentation at the mouth of meltwater streams that entered the glacial lakes. The diamicton within the glacial lake sediments was deposited by sediment gravity flows derived from the reworking of till and outwash deposits. Glacial lake sediments indicate that the drainage was blocked during ice advance or retreat. Part of the sediment deformation is thought to be due to the melting of supporting ice. Similar glacial lake sediments were described by Ward and Rutter (2002) for the Pelly River valley.

Massive to well bedded clast-supported gravel units are present above and underneath McConnell till (stations JB-02-062, JB-02-066, 02-PMA-043, and 02-PMA-059; Fig. 9). The gravel is pebbly to bouldery and moderately to poorly sorted. These deposits are thought to reflect glaciofluvial sedimentation and indicate free drainage conditions at the ice front.

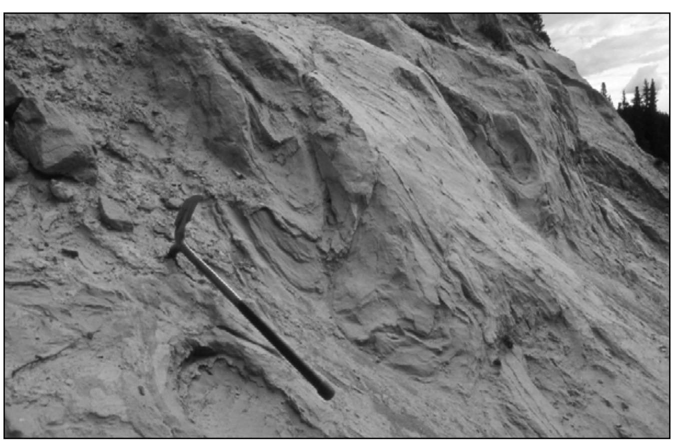

Figure 10. *Folds in glaciolacustrine sediments at site 02-PMA-060 are indicative of soft sediment deformation following the melting of supporting ice.*

Well compacted massive diamictons containing abundant striated clasts and lithologies of distal sources were observed at all stations. The diamicton units contain clasts of pebble to boulder size in a poorly sorted matrix of sand, silt and clay. They are on average 3 to 10 m thick and are continuous across the exposures. A fabric measurement of 10 elongated clasts in the diamicton unit at station JB-02-062 indicates that clasts are dominantly parallel to both the east-trending valley and the interpreted local ice flow. Based on these criteria the diamictons are interpreted to be till. Except at station 02-PMA-059 where a pre-McConnell till might be present, all diamicton units interpreted to be till are assigned to the McConnell Glaciation because they are correlated to the McConnell till present at surface throughout the region (see Ward and Jackson, 2000).

Two till units correlated to the McConnell Glaciation at section 02-PMA-059 are interpreted to reflect a fluctuation of the ice front probably during deglaciation. Further evidence for ice readvance at the end of the McConnell Glaciation was suggested in south-central Yukon by Plouffe and Jackson (1992), Jackson (2000), Ward and Jackson (2000), and Bond (2001). Two till units observed in the Glenlyon Ranges at stations 02-PMA-043 and JB-02-047 (Fig. 9) are thought to reflect ice advance from two different source regions. The lower till at both sites contains abundant large boulders of local intrusive rocks with an average diameter of 2 to 3 m; its matrix is very sandy, and the unit is gently dipping down-valley (Fig. 11). The lower till is sharply overlain by an upper till which contains smaller clasts and a more silty-clayey matrix compared to the lower till. Clasts of erratic lithologies (fine-grained sedimentary and volcanic rocks) are more abundant in the upper till than in the lower till. The lower till is thought to have been deposited by Glenlyon Range alpine glaciers at the onset of the McConnell Glaciation, and the upper till by the Selwyn Lobe. This interpretation suggests that the Selwyn Lobe overrode alpine glaciers in the Glenlyon Range and that these alpine glaciers did not make a significant contribution to the Selwyn Lobe. This interpretation corroborates Ward and Jackson's (1992) conclusions and has important implications for tracking till/soil geochemistry in this area.

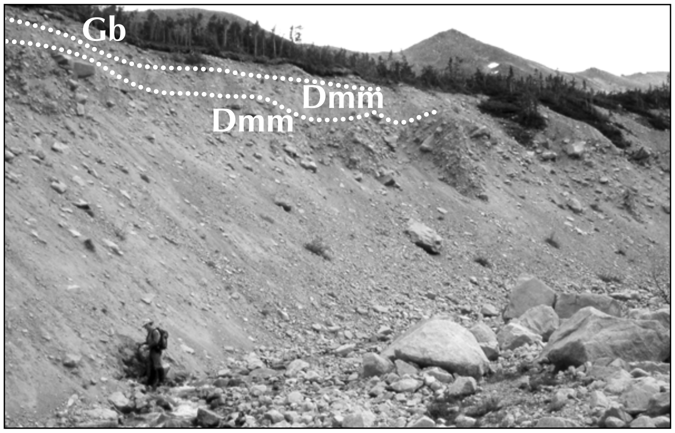

Figure 11. *Quaternary sediment exposure at station 02-PMA-043 showing a lower bouldery till (Dmm) of local provenance overlain by a second till (Dmm) deposited by the Selwyn Lobe. The gravel (Gb) was deposited by glacial meltwater at ice retreat.*

Till of the McConnell Glaciation was widely sampled as part of the regional till geochemistry survey. McConnell till is characterized by a shallow solum depth of 30 to 40 cm on average and a matrix with more silt and clay compared to Reid Till.

POSTGLACIAL SEDIMENTS

Following deglaciation, sediments left on steep slopes were subjected to gravity processes and redeposited as colluvium. In valleys, streams reworked the glacial sediments and went from a phase of aggradation to degradation. Organic sediments accumulated in poorly drained depressions.

A discontinuous veneer of eolian sediments (loess), consisting of well sorted, massive, very fine sand and silt, occurs over most of the area. It has an average thickness of 10 to 40 cm but locally may be as thick as 1 m. Where eolian sediments are greater than 30 cm thick, they were found to be an impediment to till sampling. Considering that eolian sediments are composed of fine-grained particles derived from a mixture of glacial sediments, their geochemistry reflects regional background metal concentrations and not the underlying bedrock geology. Consequently, eolian sediments were not sampled during this survey and should be avoided during a soil survey (soil B-horizon sampling). Soil samplers should be trained to recognize the eolian sediments and to distinguish them from till, which is the most preferable sediment type to sample during a soil survey.

The White River Ash, dated at 1147 calendric years BP (Clague et al., 1995), was observed in sample pits and sections and generally varies in thickness from 10 to 20 cm over the area (Fig. 12).

GLACIAL STRIATION RECORD

Four bedrock outcrops with glacial striations were examined. Three of which are located in the Little Salmon Lake region and a fourth one northeast of Glenlyon Range near the Pelly River valley (Fig. 5, 13). None of those outcrops show multiple sets of striations and consequently the striations are thought to reflect the direction of the last ice movement in each region. The lack of glacial striations is attributed to the general low abundance of fresh bedrock outcrops on which these micro-landforms are generally preserved.

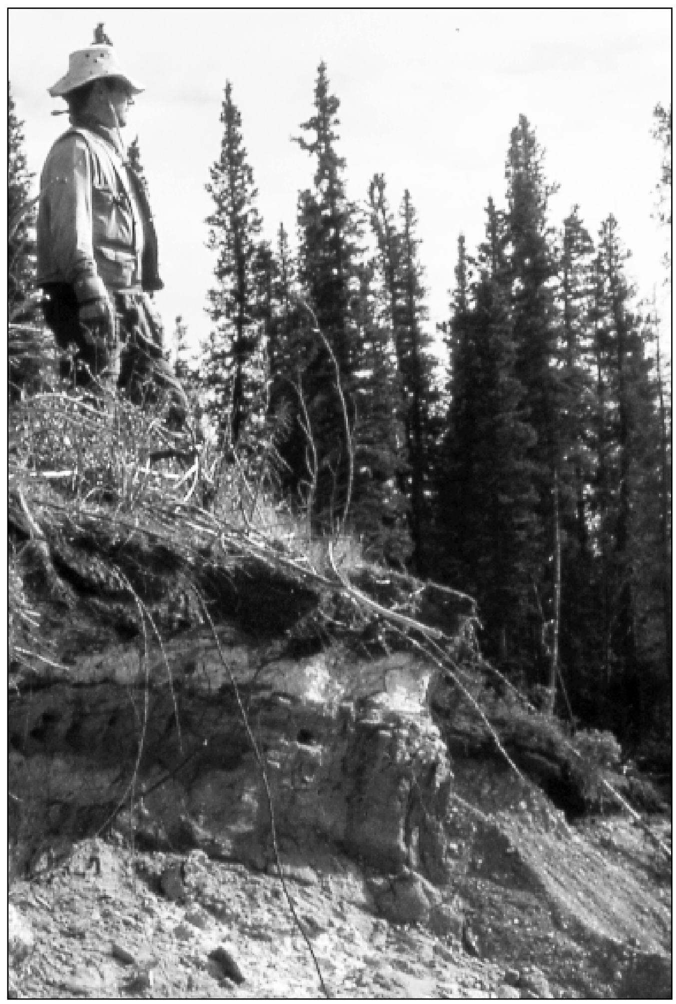

Figure 12. *White River ash (white layer) exposed in the top part of section 02-PMA-059.*

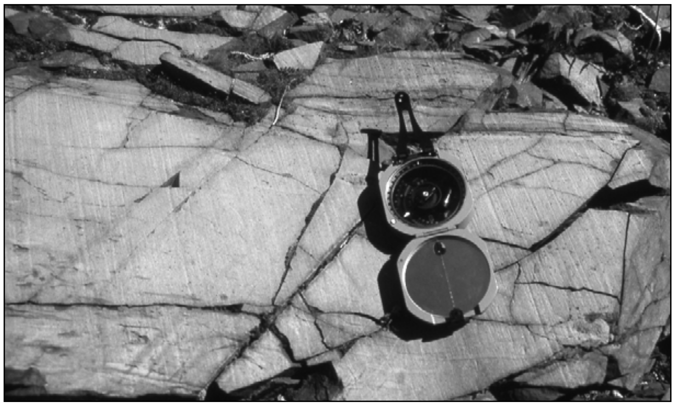

Figure 13. *Glacial striations on orthoquartzite bedrock northeast of Glenlyon Range (see Figure 5 for location).*

QUATERNARY HISTORY

The ice-flow patterns of the Reid Glaciation can only be reconstructed beyond the limit of the McConnell Glaciation. Following that reconstruction, it can be assumed that ice-flow patterns during the Reid Glaciation were similar to the McConnell Glaciation with minor modifications due to thicker ice cover during the Reid Glaciation (Jackson, 2000).

Pedological and palynological investigations indicate that the nonglacial interval between the Reid and McConnell glaciations was warmer and somewhat moister than present conditions (Smith et al., 1986; Schweger and Matthews, 1991). No evidence of an early Wisconsinan glaciation is present in the study area.

Based on radiocarbon chronology, at the onset of McConnell Glaciation, ice advanced into the major valley systems of south-central Yukon sometime after 26 ka (Jackson and Harington, 1991; Jackson et al., 1991). At that time, ice tongues advanced in the major valleys of the eastern sector of the study area, and alpine glaciers formed in the Glenlyon Ranges perturbing the drainage. Glacial lakes developed in tributary valleys blocked by ice (e.g., near station JB-02-062), and outwash fans formed at the ice front in places where the glacier was advancing downslope (e.g., near station 02-PMA-059). At glacial maximum (Fig. 14a), 1) the Selwyn and Cassiar ice lobes abutted in the southwestern sector, 2) some of the highest mountains remained unglaciated, 3) local ice accumulation in the Glenlyon Range had a limited extent, and 4) ice-flow patterns were influenced by topography (Ward and Jackson, 1992; Jackson, 2000; Ward and Jackson, 2000).

The retreat of the Cordilleran Ice Sheet is thought to have occurred through a combination of downwasting, stagnation, and complex frontal retreat (Clague, 1989; Jackson et al., 1991). Areas where the ice was thinnest were the first to be deglaciated. Within the study area, the ice generally retreated from west to east. A schematic pattern of ice retreat for the study area is here proposed which takes into account the position of moraines and lateral and direct overflow meltwater channels, along with the distribution of glaciofluvial and glaciolacustrine sediments mapped by Ward and Jackson (2000) and Jackson (2000; Fig. 14). A synchronous pattern of ice retreat between the Selwyn and Cassiar lobes was assumed in constructing the phases of deglaciation.

During deglaciation, as a result of ice or sediment dams, glacial lakes formed in the Tadru, Ess Lake and Pelly River valleys, and in the northern Little Salmon Range (Fig. 14b). Large masses of stagnant ice became detached from the retreating ice front and stagnated in situ, resulting in terrain with complex hummocky topography (Figs. 14c, 15; Ward and Jackson, 2000). As ice retreated further east, glacial lakes formed in the Drury Lake and Little Salmon River valleys (Fig. 14d). Glacial lakes drained following the collapse of the sediment or ice dams (Fig. 14e; Lye et al., 1990).

This simplified model of deglaciation provides indication of the evolution of ice-flow direction and glacial transport from glacial maximum to the end of the deglaciation. The greatest amount of glacial transport likely occurred at glacial maximum but transport also took place during glacial retreat. Ice flow, in general, was perpendicular to the ice front during deglaciation, and thus the evolution of ice flow presented in this model should be taken into account for the interpretation of the till geochemistry presented in this report.

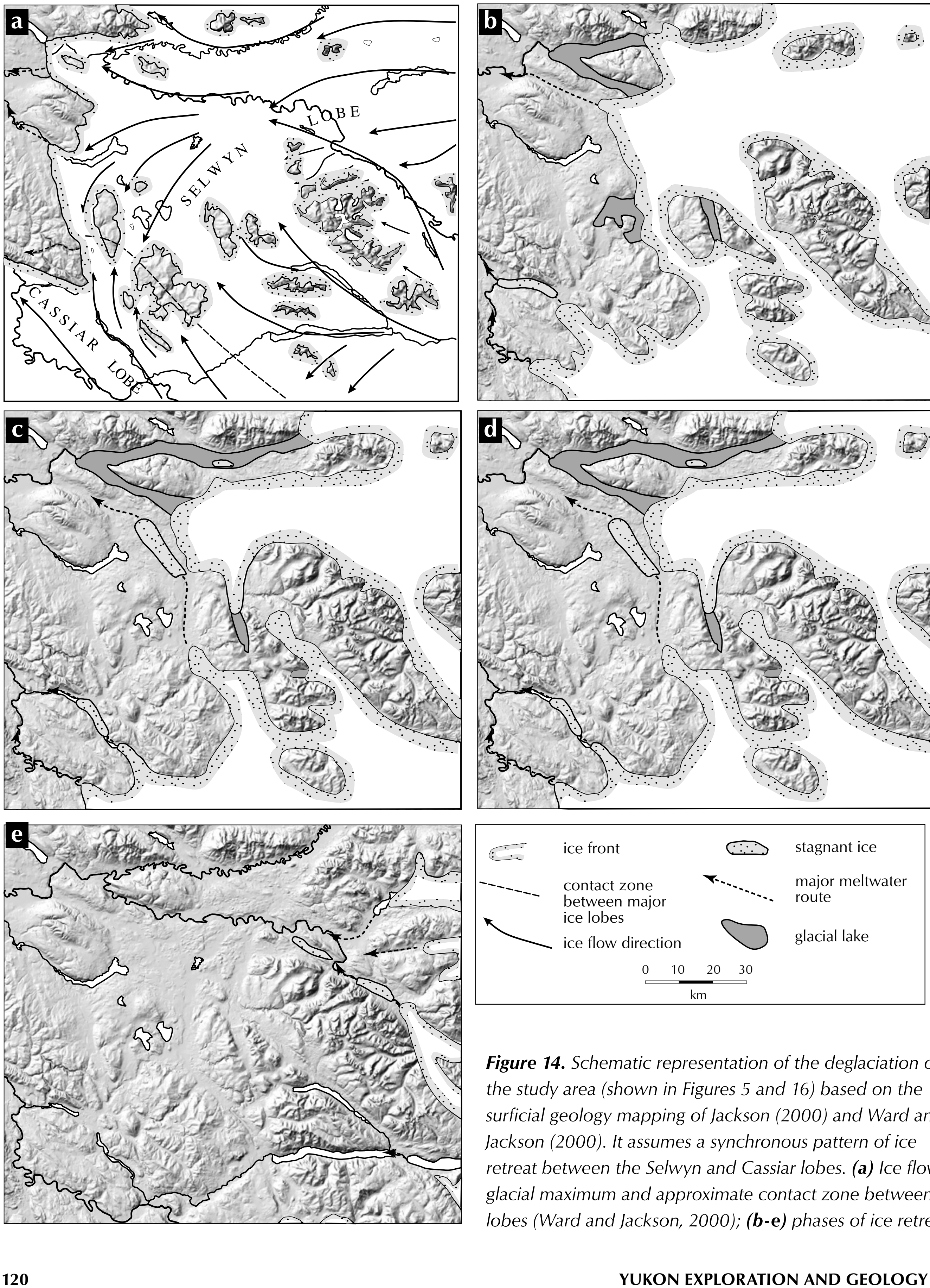

Figure 14. Schematic representation of the deglaciation of the study area (shown in Figures 5 and 16) based on the surficial geology mapping of Jackson (2000) and Ward and Jackson (2000). It assumes a synchronous pattern of ice retreat between the Selwyn and Cassiar lobes. ***(a)*** *Ice flow at glacial maximum and approximate contact zone between ice lobes (Ward and Jackson, 2000);* ***(b-e)*** *phases of ice retreat.*

Figure 15. *Ice stagnation terrain at the McConnell glacial limit near Frenchman Lake.*

TILL GEOCHEMISTRY: RESULTS

ORIENTATION SURVEY – CLEAR LAKE

An orientation survey was completed at the Clear Lake sedimentary-exhalative (SEDEX) deposit (Yukon MINFILE 2002, 105L 045), 75 km east of Pelly Crossing. This survey was conducted to establish the length of glacial dispersal and the elemental signatures associated with massive sulphide mineralization in a physiographic and geological setting typical of the study area (Fig. 16). The ore body subcrops under 10 to 25 m of McConnell till and would have been directly exposed to glacial erosion by the Cordilleran Ice Sheet. This provides an ideal setting to characterize the dispersal train down-ice from a known massive sulphide body.

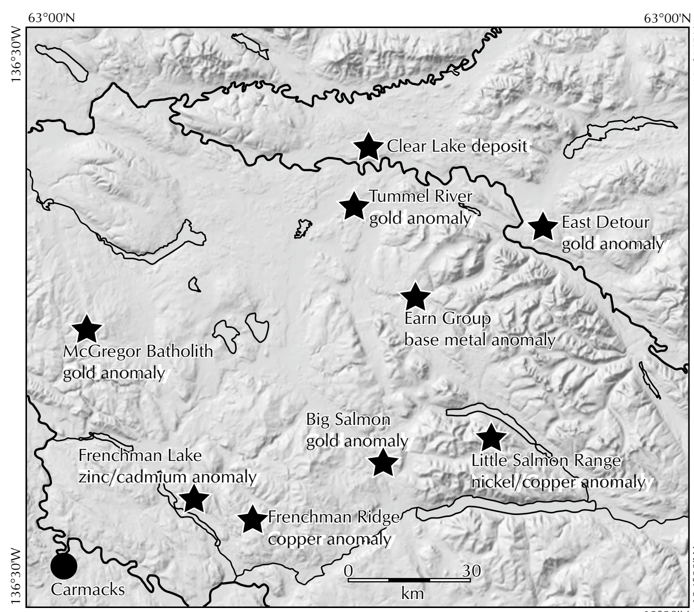

Figure 16. *Distribution of anomalies discussed in the till geochemistry section (larger map shown in Figure 5).*

The deposit is hosted by carbonaceous argillite, siltstone, chert and tuff of the Devono-Mississippian Earn Group (*ibid.*). The Tintina Fault is located to the northeast of the property. In plan view, the deposit is a sigmoidal-shaped sulphide body, approximately 1000 m long and up to 100 m thick (Fig. 17; *ibid.*). Geological reserves are 6.1 million tonnes grading 11.34% Zn, 2.15% Pb and 40.8 g/t Ag, using a cutoff grade of 7% of combined Zn and Pb (*ibid.)*.

Permafrost is present in the area, and the active layer thickness is reduced where loess, an impermeable sediment, is more than 30 cm thick. In some sampling pits, west of the deposit, loess thickness exceeded 100 cm, which hindered and prevented till sampling. Local drainage is primarily through groundwater, and is reflected in Clear Lake which has a pH of <3.0 (K. Fletcher, pers. comm., 2002). Lake-bottom sediment samples assayed up to 19 000 ppm Zn (Yukon MINFILE 2002).

In total, 25 till samples were collected, beginning 250 m up-ice and ending approximately 2300 m down-ice, in an easterly direction parallel to McConnell ice flow (Fig. 17). Sample spacing increased from 25 m over the deposit to greater than 200 m near the end of the line.

Lead

Lead concentrations are anomalous immediately west of the deposit, with concentrations as high as 344 ppm (Fig. 18). At 600 m west of the deposit, values decreased to 45 ppm Pb, and 2300 m west of the deposit, concentrations are below 19 ppm. High concentrations in the three samples immediately west of the deposit are the result of glacial transport of material from the main massive sulphide body. The outlying anomaly, 600 m west of the deposit, may also represent glacial transport or possibly a concealed mineralized zone. Previous geologic interpretations have speculated that additional mineralization may occur in Earn Group stratigraphy near the footwall of the Askin thrust fault (R. Zuran, pers. comm., 2002) and that movement on the fault may have brought mineralized rock to the surface.

Zinc

Zinc distribution in till at Clear Lake does not correlate with the lead distribution and shows no abrupt increase down-ice from the deposit. The average value of 72 ppm in the vicinity of the deposit (Fig. 19) equates to the 75th percentile from the regional data. Much higher concentrations were expected from a SEDEX deposit containing significant zinc grades dominantly bound up in sphalerite. The low zinc concentrations in till may be linked to acid weathering, as a result of the underlying massive

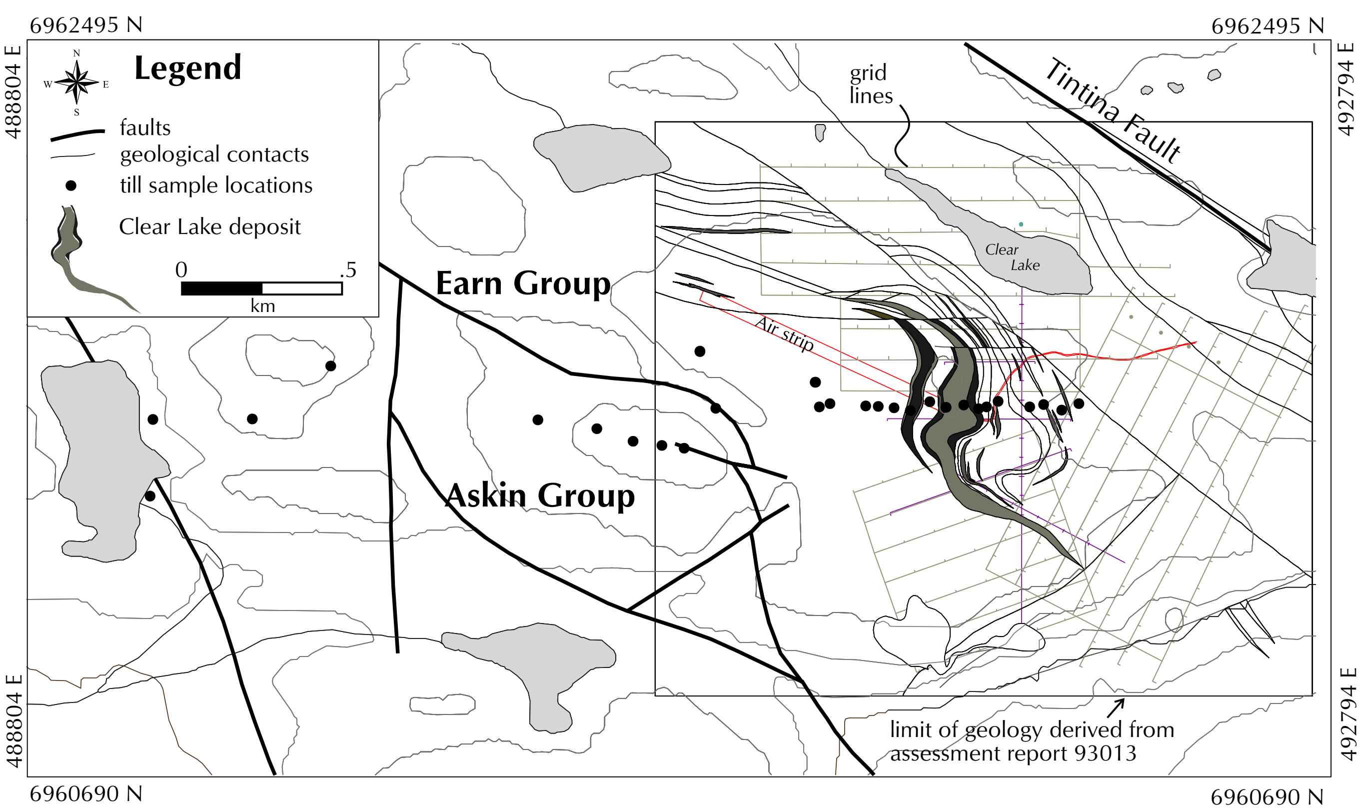

Figure 17. *Location of till samples relative to the subcropping Clear Lake deposit.*

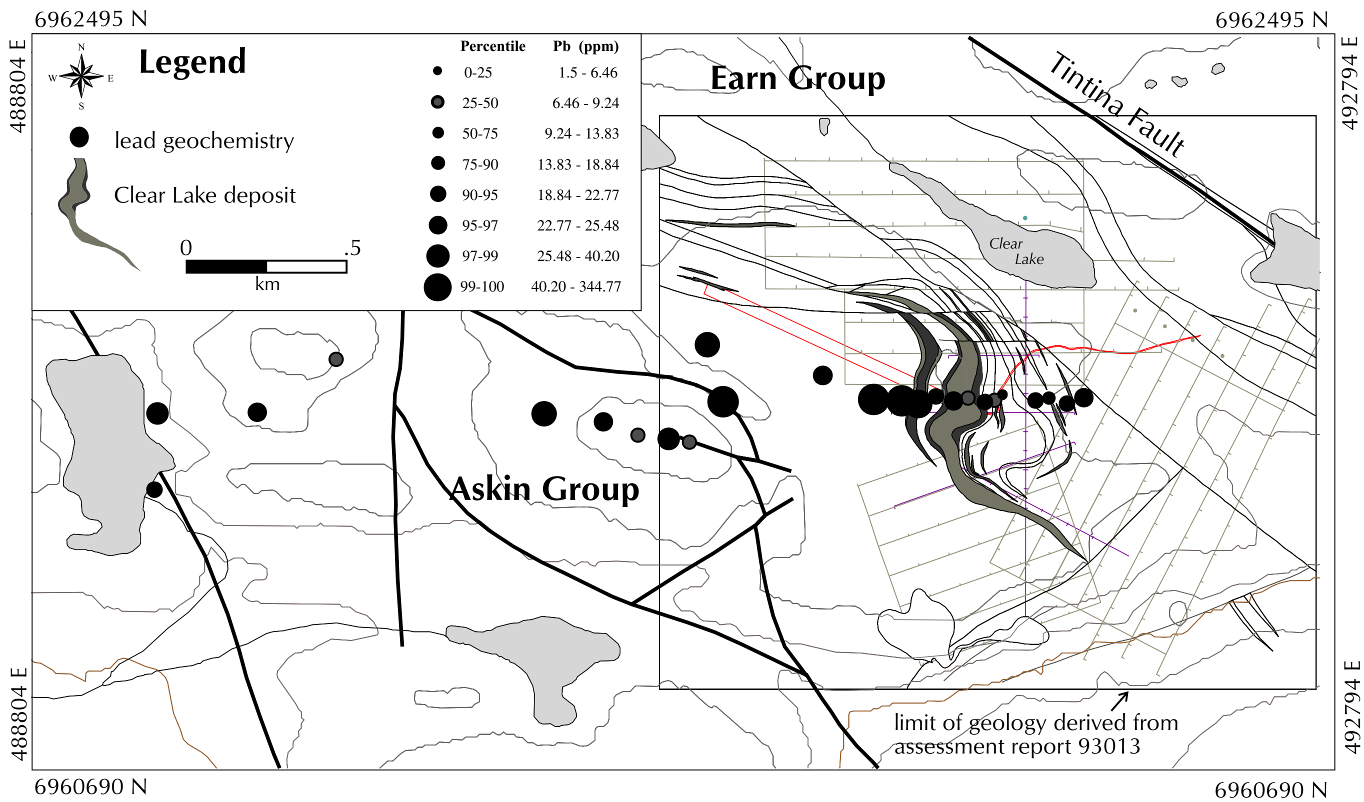

Figure 18. *Lead concentrations in till at the Clear Lake deposit.*

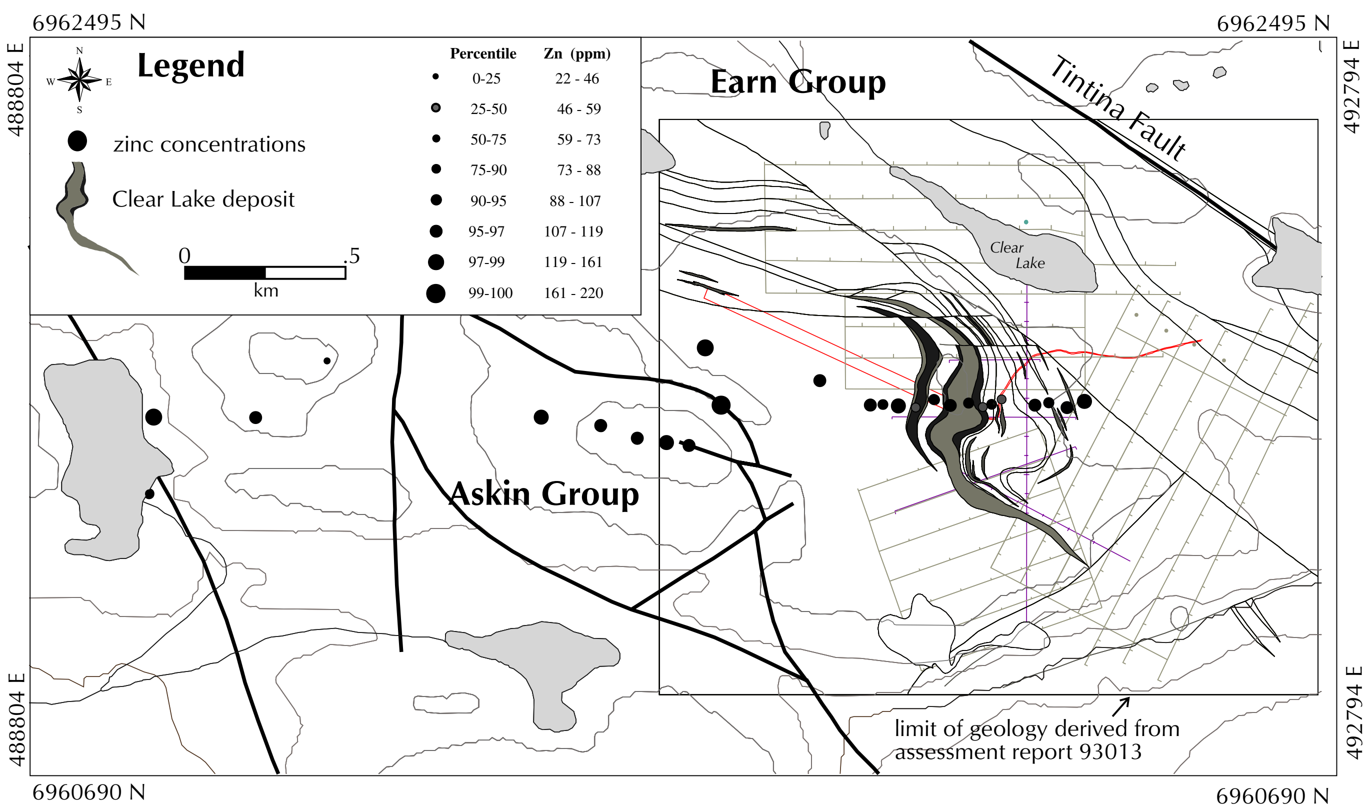

Figure 19. *Zinc concentrations in till at the Clear Lake deposit.*

sulphide deposit, which probably leached most of the sphalerite (K. Fletcher, pers. comm., 2002). Acid leaching would also account for the high Zn values in lake-bottom sediments from Clear Lake. The highest zinc concentrations near the deposit are found in till containing limestone clasts. The presence of limestone in the till, derived from the up-ice region, would act as a buffering agent and reduce acid weathering. More intense acid conditions over the deposit, however, may have removed the limestone clasts and their ability to buffer zinc leaching (K. Fletcher, pers. comm., 2002). Calcium concentrations in till are found to mimic the percentage of limestone clasts and therefore could be used as an indication of buffering potential of the till. The outlying zinc anomaly 600 m west of the deposit corresponds with the high lead value discussed earlier. At Clear lake, zinc is not considered to be a reliable pathfinder element to define the presence of concealed massive sulphide mineralization.

Mercury

Previous soil surveys at Clear Lake identified mercury to be a useful pathfinder element (R. Zuran, pers. comm., 2001). Mercury concentrations in till reach 1743 and 1452 ppb immediately west of the deposit, 143 ppb over the deposit, and 281 ppb 600 m down-ice (Fig. 20). This data supports mercury as a useful pathfinder element in till at Clear Lake.

Barium

Massive barite was intersected in several drill holes and is interpreted to be peripheral to the Clear Lake deposit (Yukon MINFILE 2002, 105L 045). Anomalous barium concentrations were identified both up-ice and down-ice of the deposit (Fig. 21). This may reflect the underlying geology or alternatively, it could be an acid leach feature creating a depletion zone. Barium is considered a reliable pathfinder element at Clear Lake. It should be noted that barite is only partially leached in aqua regia, and that a stronger leach should be used to better define the barium content of till in the vicinity of Clear Lake.

Silver

Silver grades in the main ore body average 40.8 g/t (*ibid.*). A distinct dispersal train of silver values, similar to Pb and Hg, is visible immediately west of the deposit (Fig. 22). Anomalous values are also present east of the deposit, which may suggest above background values for the local area and a depletion zone over the deposit.

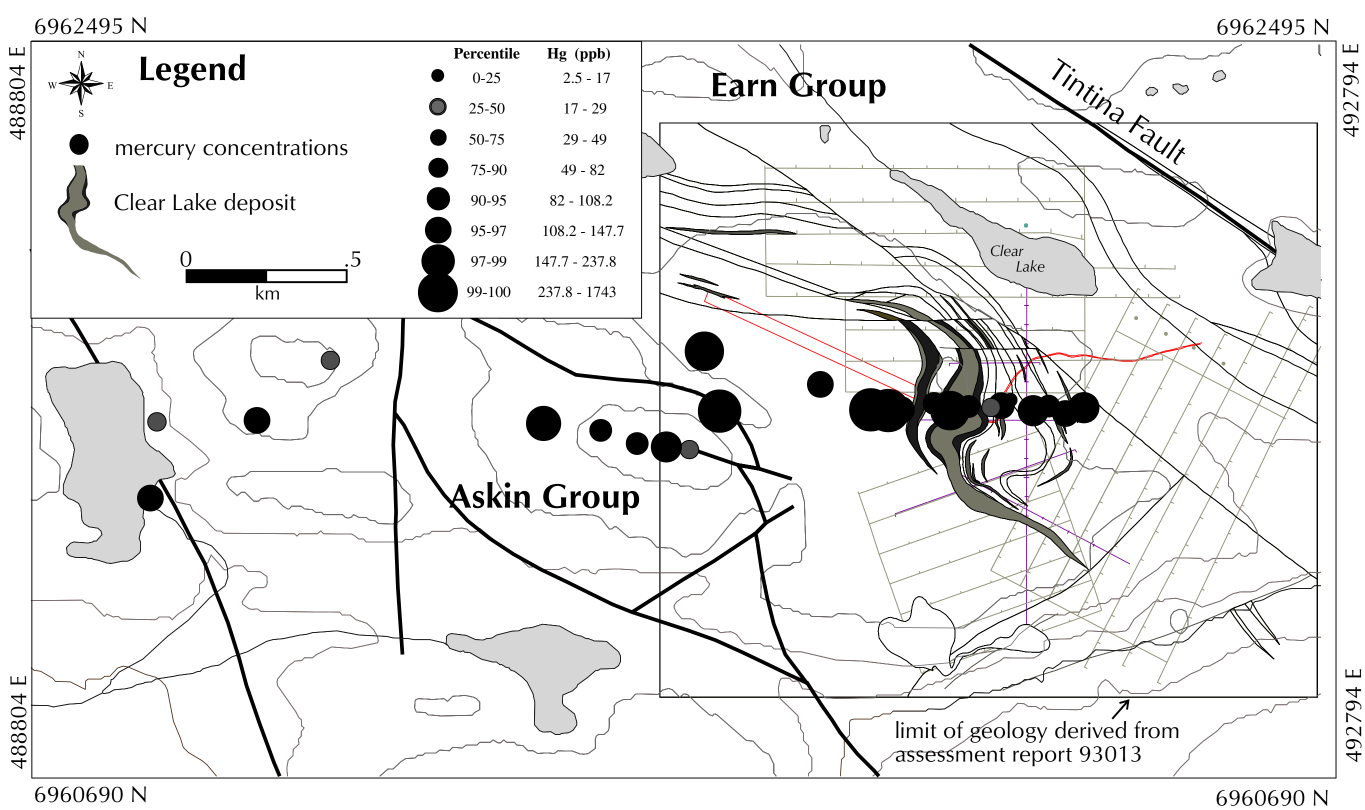

Figure 20. *Mercury concentrations in till at the Clear Lake deposit.*

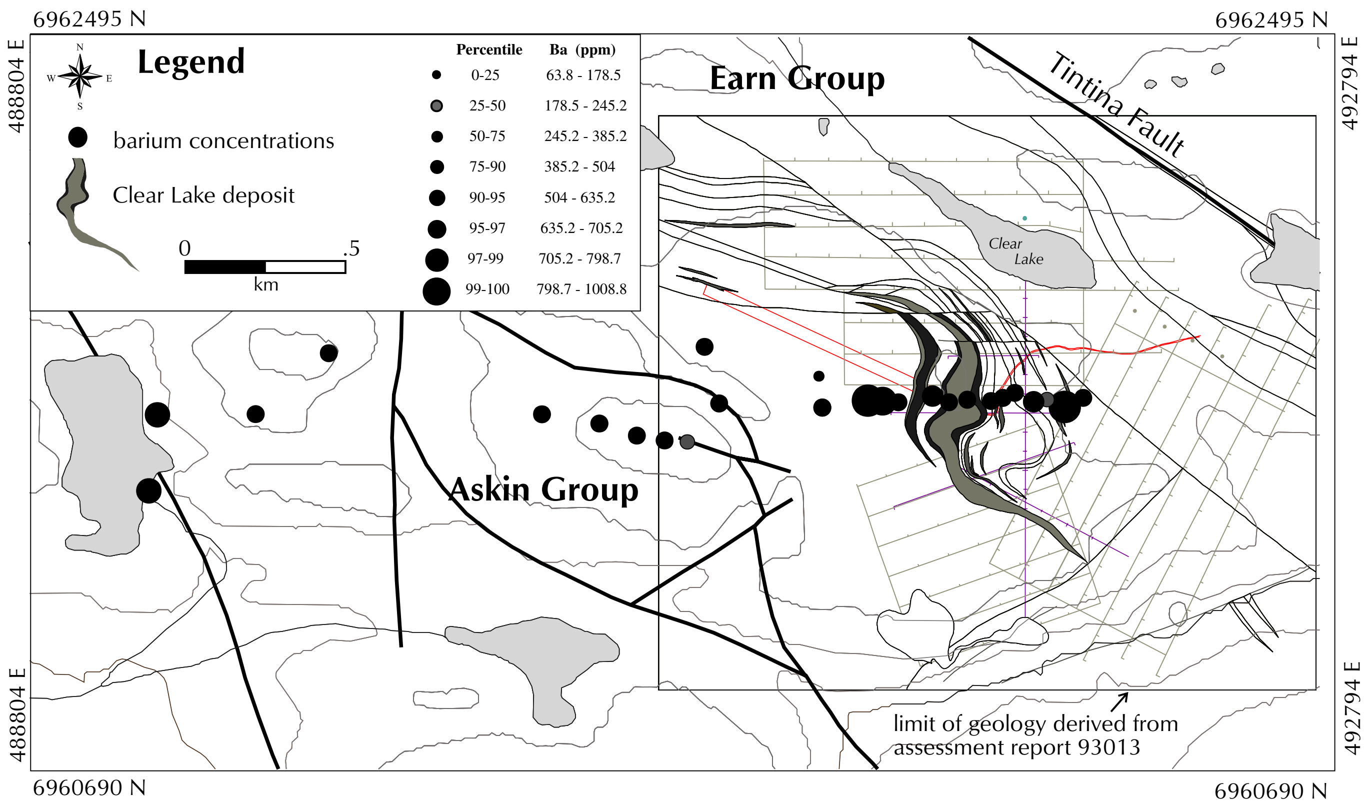

Figure 21. Barium concentrations in till at the Clear Lake deposit.

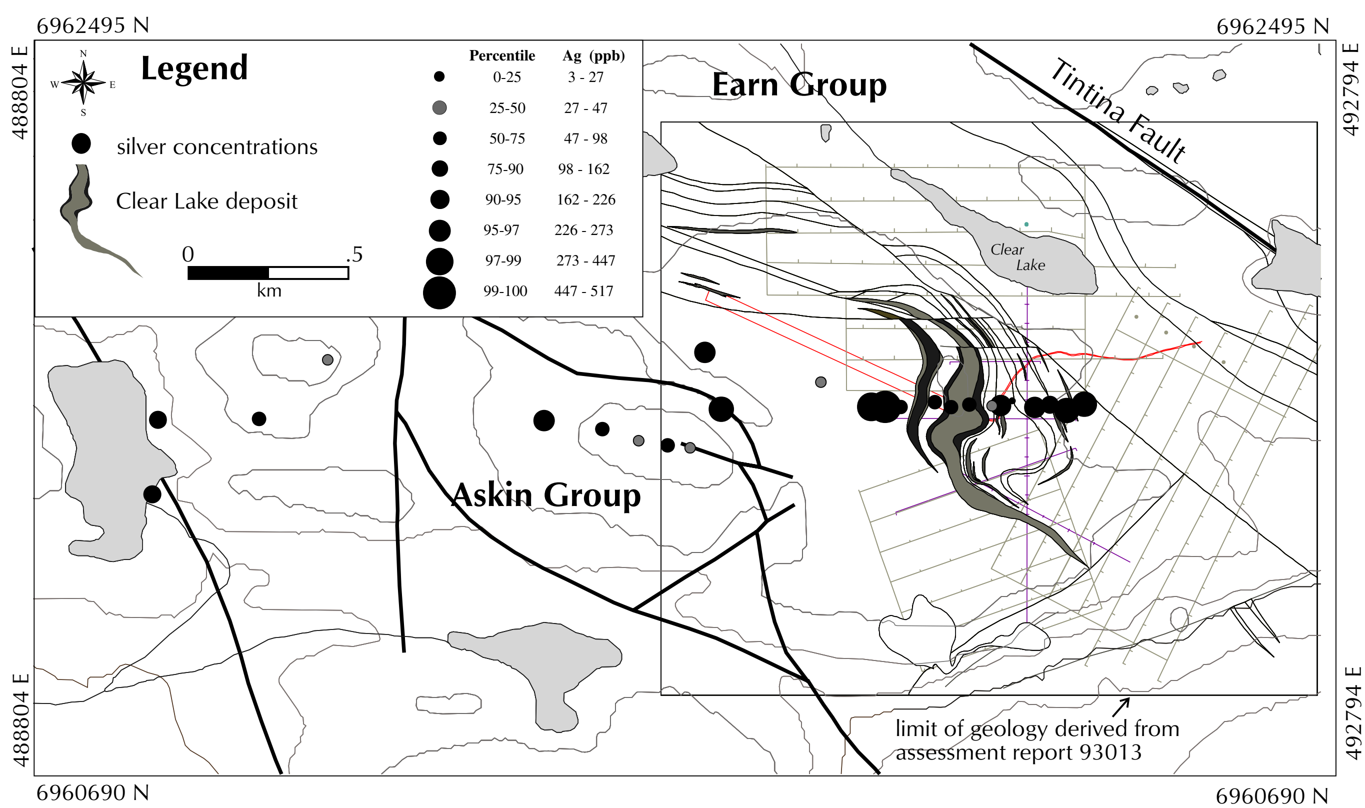

Figure 22. Silver concentrations in till at the Clear Lake deposit.

Summary

The till geochemistry at Clear Lake supports the drift prospecting methodology employed in this study. Distinct geochemical anomalies in Pb, Hg, Ba and Ag were noted immediately down-ice of the deposit. Zinc appears to have been leached from the till by acid weathering and is not a reliable pathfinder element, despite the high zinc concentrations in the deposit. The length of the glacial dispersal train for the pathfinder elements discussed above is approximately 600 m.

REGIONAL TILL GEOCHEMISTRY

A total of 285 till samples were collected in the Glenlyon and eastern Carmacks map areas (Fig. 23). Highlights from the geochemical survey are presented in this section with special attention paid to multi-element associations that have significance to mineral exploration. References to the bedrock geology are derived from Colpron et al. (2002) and Gordey and Makepeace (1999). The term anomaly used in this report designates elemental concentrations that are above the 95th percentile of the regional data.

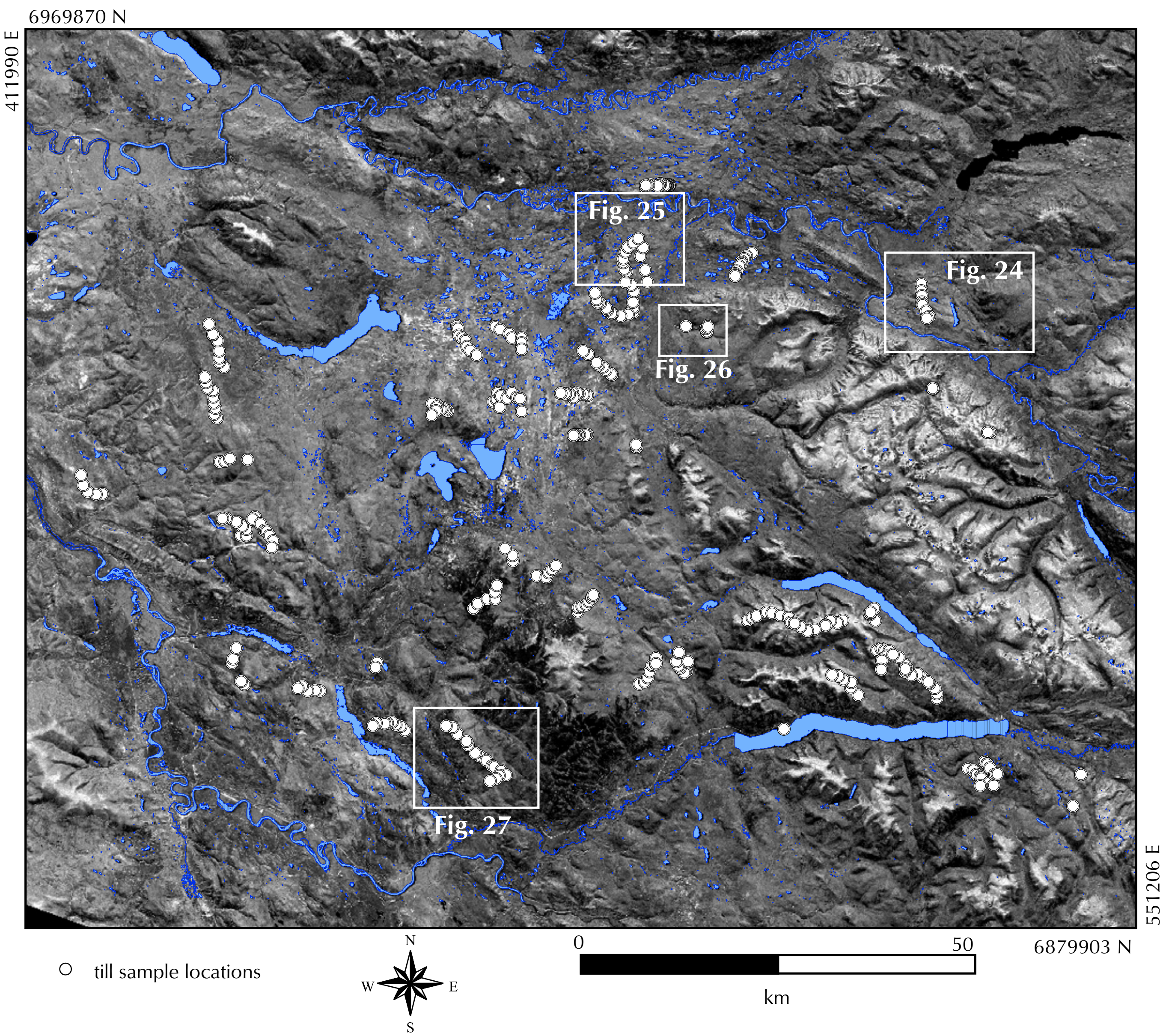

Figure 23. *Map of the study area on satellite photo background showing the distribution of regional till samples collected in 2002.*

GOLD

Bedrock lithologies and structure within the study area are favourable for both epithermal and intrusion-related gold mineralization. The mean gold concentration is 4 ppb, the 97th percentile equaled 16 ppb, and the highest value equaled 34 ppb.

East Detour Gold Anomaly

The highest gold value (34 ppb) was obtained from the northeast part of the study area near the Tintina Fault and Pelly River in Selwyn Basin rocks consisting of chert, siltstone, phyllite, limestone and conglomerate of the Rabbitkettle formation (Gordey and Makepeace, 1999; Fig. 16). It is termed the 'East Detour' gold anomaly and has a multi-element signature in Au, As, Pb, Bi and Sb that is suggestive of a plutonic association. Arsenic is perhaps the most anomalous element in this region, with six out of eight samples containing >42 ppm (98th percentile) (Fig. 23, 24). The station with the highest arsenic value (02-PMA-114, 212 ppm) also corresponds to the highest gold (34 ppb) and bismuth concentrations (0.73 ppm). Gold concentrations are not high at other sites along the sample line.

The presence of mid-Cretaceous intrusions 19 km up-ice from the sample line, together with the till geochemistry, suggests that the source of gold might be intrusion-related mineralization as observed elsewhere within the Tintina Gold Belt. Mid-Cretaceous intrusions could lie in the subsurface closer to the sample line, and hornfels in the Rabbitkettle formation may host the mineralization. This is assumed because of the dominance of arsenic and antimony, and lack of tungsten (Hart et al., 2000). The regional airborne geophysical data shows both a magnetic high and a low, up-ice flow from the sample line, which may outline a subsurface intrusion. Given the usually short length of gold dispersal trains, the source of the gold likely lies a few hundred metres to the southeast (up-ice). As part of a follow-up survey more till samples could be collected at station 02-PMA-114 (522721E, 6948736N) and up-ice from it. Access into the area includes the Detour/Clear Lake winter road which terminates at an air strip 8 km west of the sample line across the Pelly River.

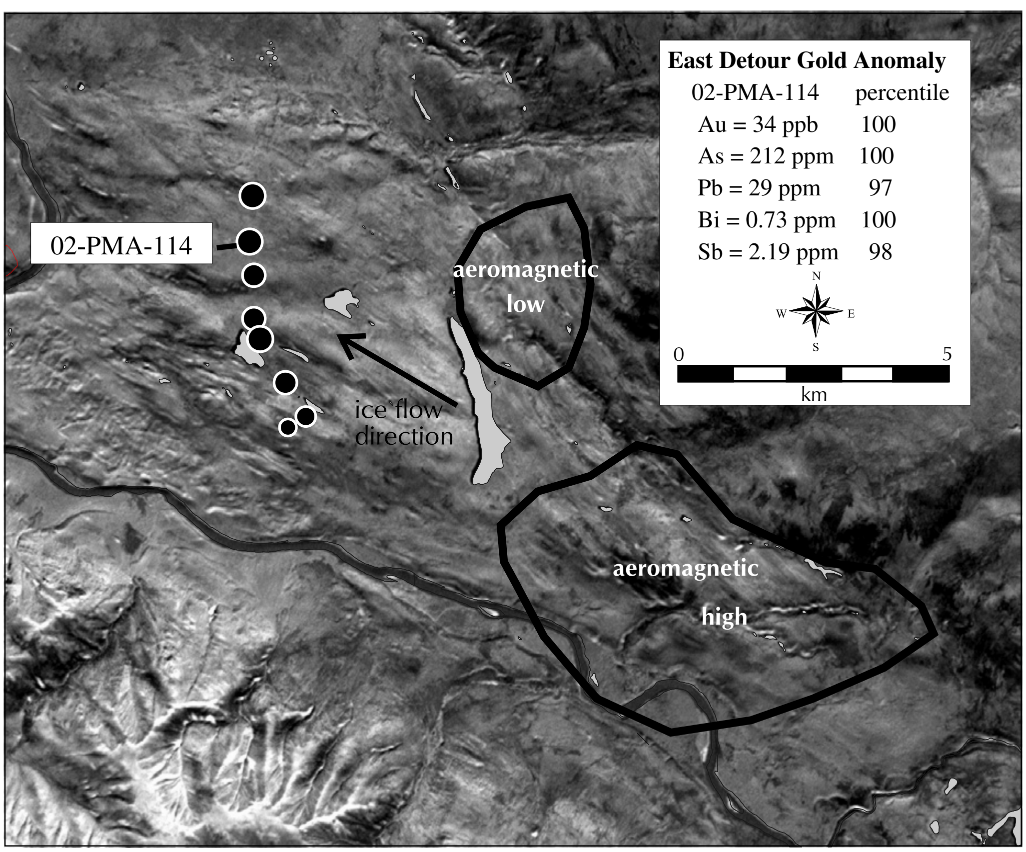

***Figure 24**. Detailed map of the East Detour gold anomaly. The samples are shown relative to an aeromagnetic high and low that may indicate buried intrusive rocks responsible for the anomalous plutonic signature. Arsenic concentrations are shown on the sample line. UTM = 522721E, 6948736N for sample 02-PMA-114.*

The area is also accessible by float plane into an unnamed lake.

Tummel River Gold Anomaly

The Tummel River gold anomaly is defined along a sample line located west of the Tummel and south of the Pelly rivers (Fig. 16). The most anomalous samples along the line are 02-PMA-074 (As 37 ppm, Sb 2.06 ppm) and 02-PMA-076 (Au 16.8 ppb; Fig. 23, 25). The multi-element association and the proximity to known granite suggest that the anomalies might be intrusion-related, similar to the East Detour anomaly. The Tummel River gold anomaly is associated with a geophysical anomaly similar to the one at Tombstone Mountain, north of Dawson City, where a magnetic high is caused by the presence of pyrrhotite in the altered country rock (Hart et al., 2000). A magnetic high is present adjacent to and up-ice flow from the mapped granite, directly underlying the samples with the highest metal concentrations (Fig. 25).

This anomaly likely has a transport distance of less than 4 km. The ice-flow trajectory is trending at approximately 256 degrees. In tracing the anomaly up-ice flow, 76 degrees should be used as a general direction to source. The Clear Lake/Detour winter road lies 1 km north of the anomalous sample and the Pelly River is 4 km north. The UTM coordinates for sample 02-PMA-076 are 487617E, 6954574N.

McGregor Batholith Gold Anomalies

The McGregor Batholith is situated immediately east of the Yukon River and Klondike Highway and north of Tatchun Lake (Fig. 16). The batholith is an early Jurassic granodiorite (Colpron et al., this volume). Anomalous gold values were obtained from two till sample locations, JB02-132 (29.2 ppb) and 02-PL-001 (23.3 ppb). These sites lie outside the McConnell glacial limit and within deposits of the Middle Pleistocene Reid glaciation. Regional stream geochemical data shows anomalous gold values near 02-PL-001 and near the north edge of the batholith at the Tatlmain mineral occurrence (Yukon MINFILE 2002, 115I 114). Stream sediment geochemistry at Tatlmain shows anomalous values for gold, arsenic and tungsten (*ibid.*).

The ice flow history in this part of the study area is poorly defined due to weathering of glacial landforms. Generally,

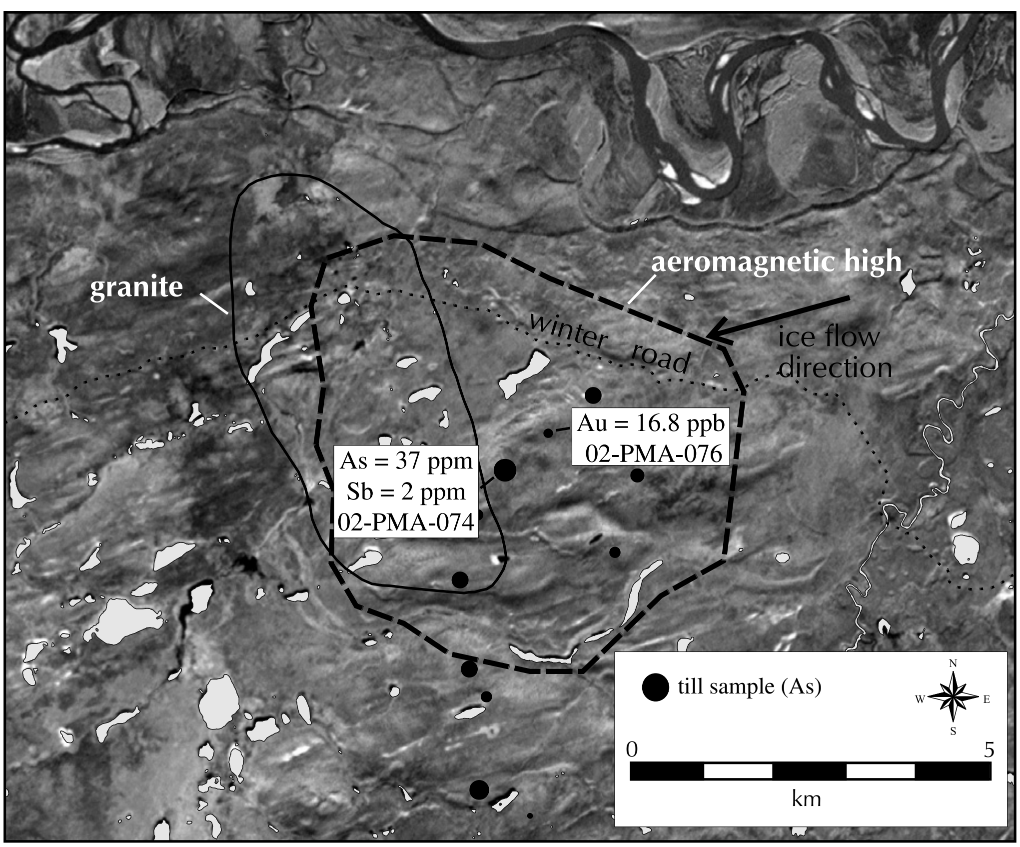

Figure 25. *The Tummel River gold anomaly is located proximal to a probable mid-Cretaceous granite and an aeromagnetic high. Potential mineralization is suspected in the hornfels aureole adjacent to the granite. UTM = 487019E, 6954089N.*

an east to west transport history should be inferred for till deposits on ridge crests, whereas topographically directed ice flow likely occurred in valley bottoms. Loess deposits can become increasingly thick outside the McConnell limit and should be avoided during soil sampling programs.

Big Salmon Fault Gold Anomaly

A weak gold/arsenic regional stream geochemical anomaly adjacent to the Big Salmon Fault was investigated using till geochemistry (Hornbrook and Friske, 1988; Fig. 16). The original anomaly is located 8.5 km north of the Robert Campbell highway on Bearfeed Creek. Seven till samples were taken in the vicinity of the stream sediment anomaly. Anomalous arsenic (99th percentile, 53.8 ppm), gold (98th percentile, 18.7 ppb), antimony (99th percentile, 2.92 ppm) and lead (99th percentile, 40 ppm) were recovered from till in the area. Potential mineralization is most likely associated with the Big Salmon Fault in a hydrothermal setting.

Basal lodgement till is the dominant surficial sediment in the area, with glacial transport to the northwest, parallel to the fault. Bedrock outcrops along Bearfeed Creek on the fault graben rim. UTM coordinates for sample JB02-032 are 492875E, 6903560N.

ZINC

Earn Group Base Metal Anomaly

Earn Group stratigraphy outcrops in Cassiar Terrane in the northeast part of the Glenlyon map area (Fig. 16). Samples were collected from Quaternary stratigraphic sections on an unnamed creek that flows into the Tummel River. Elevated zinc concentrations were obtained from three till sample sites including JB02-062 (Zn 220 ppm), JB02-066 (Zn 180 ppm) and 02-PMA-059-2 (Zn 146 ppm; Figs. 23, 26). In addition to zinc, sample JB02-062 contains anomalous concentrations of Ag (99th percentile, 458 ppb), Mo (100th percentile, 9.4 ppm) and Pb (95th percentile, 22.5 ppm). These high metal concentrations from this sample were initially considered to be background levels over Earn Group black shales. However, other samples collected on Earn Group strata to the west contain lower base metal levels.

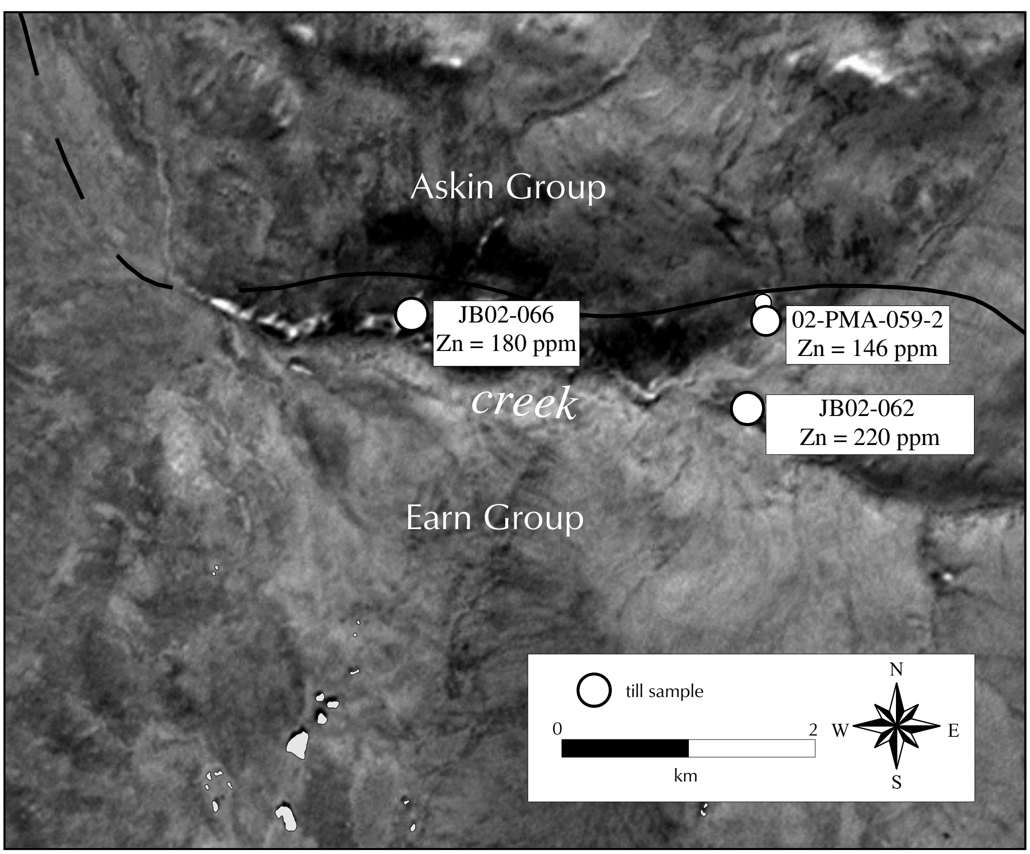

Figure 26. Map showing the distribution of zinc anomalies over Earn Group rocks. UTM = 496595E, 6874575N for sample JB02-062.

The Earn Group base metal anomaly may highlight an area of sedimentary-exhalative (SEDEX) deposit potential with geology similar to the Clear Lake deposit. Ice flow in this area is poorly understood because of its position near the confluence of two glaciers. Preliminary till fabric analyses from JB02-062 (496595E, 6943707N) suggest an ice flow direction of 260 degrees or from east to west. A graphitic phyllite comprises the local bedrock.

Frenchman Lake Zinc Anomaly

A sample located about 3 km east of Frenchman Lake (Fig. 16) contains the following elemental concentrations: Zn (187 ppm, 99th percentile), Pb (23 ppm, 96th percentile), Au (16 ppb, 97th percentile), Sb (1.97 ppm, 99th percentile), Mo (3.41 ppm, 99th percentile), Hg (134 ppb, 96th percentile), Cd (2.27 ppm, 100th percentile) and Ag (287 ppb, 97th percentile), suggestive of epithermal mineralization (C. Hart, pers. comm., 2002). Mercury is also anomalous at other stations on this sample line. The geology of the area consists of lower Jurassic Laberge Group conglomerate, sandstone, siltstone, and brecciated limestone of the Whitehorse Trough.

Till in this area was deposited by ice from the Cassiar lobe. Ice flow was to the north at 344 degrees. A source for this anomaly likely lies within 2 km to the south of sample 02-PMA-034. UTM coordinates for sample 02-PMA-034 are 458220E, 6896171N.

NICKEL/COPPER/CHROMIUM

Little Salmon Range Nickel/Copper/Chromium Anomaly

The Little Salmon Range hosts a nickel-copper-chromium anomaly in middle Mississippian – Pennsylvanian intermediate to mafic metavolcanic rocks (Fig. 16). Locally, ultramafic rocks exposed on a ridge may be more widespread than previously expected. The highest multi-element anomaly is located down-ice flow from known ultramafic rocks. Station 02-PMA-164 has anomalous concentrations of nickel (145 ppm, 99th percentile), copper (106 ppm, 99th percentile), and chromium (342 ppm, 100th percentile). Other samples in the Little Salmon Range further to the west are anomalous in cobalt (42 ppm, 100th percentile) and gold (25.7 ppm, 99th percentile). Ice flow in the area is topographically controlled, trending approximately west-northwest.

The Drury mineral occurrence (Yukon MINFILE 2002, 105L 014) is a copper vein 2 km northwest of 02-PMA-164 in the Little Salmon Range. Many of the anomalous copper values in till were obtained down-ice flow of this showing, but additional concealed veins could be present on the ridge. The base metal potential of the Little Salmon Range is addressed further by Colpron et al. (this volume).

COPPER

Frenchman Ridge Copper Anomaly

Two sample lines were completed on an unnamed ridge east of Frenchman Lake following the discovery of malachite float (Frenchman, Yukon MINFILE 2002, 105L 066) during the bedrock mapping conducted as part of this TGI project (Figs. 16, 23, 27). For reference purposes the ridge is called Frenchman ridge, after the nearby lake. Sample JB02-144 (466157E, 6894763N) was collected at the northwest end of the ridge, and confirmed the presence of copper in bedrock. A concentration of 130 ppm Cu (100th percentile) was obtained from this sample. Additional malachite float was found in an outwash channel crosscutting the ridge about 1 km southeast of this anomalous sample.

Frenchman ridge is underlain by volcanic rocks of the Upper Carboniferous Semenof formation. They consist of andesite, basalt, diorite, amphibolite, greenstone and marble. A rhyolite unit and felsic tuff also outcrops on the ridge closer to the malachite occurrence.

McConnell ice flow trends sub-parallel to Frenchman ridge in a north-northwest direction, and reaches a higher elevation on the south side versus the north side of the ridge. This suggests that the Cassiar Lobe compressed against the south-facing flank. However, the ridge summit is above the McConnell limit and is veneered with Reid till. There is no clear ice-flow indicator of Reid age on Frenchman ridge, but assuming ice-flow patterns were generally similar during the McConnell and Reid glaciation, ice flow during the Reid glaciation would have overtopped the ridge from south to north. Thus, the Reid till on the summit would have originated from bedrock material eroded on the southwest side of the ridge. Some ridge-parallel transport to the northwest could also be expected during Reid deglaciation.

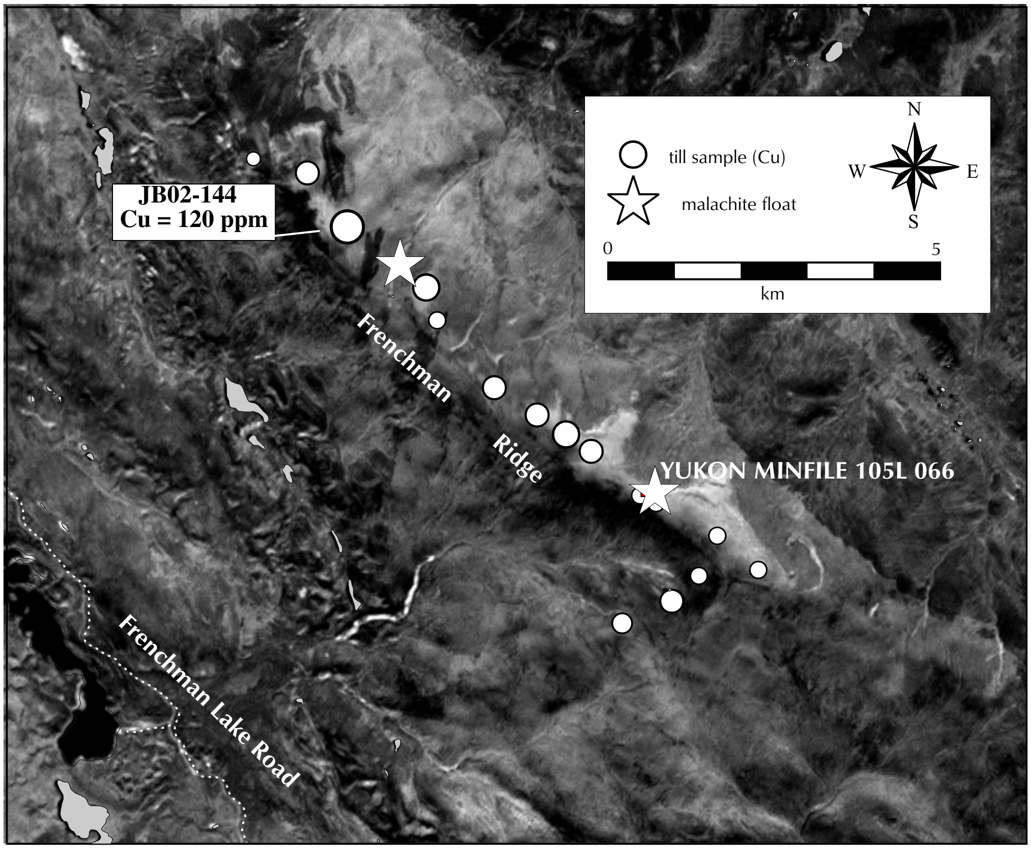

Figure 27. *Local scale map showing copper in till samples from Frenchman Ridge. Two occurrences of malachite float were found on the ridge in 2002. UTM = 466157E, 6894763N.*

CONCLUSIONS

The Glenlyon and eastern Carmacks map areas are located at the limit of the last glaciation. The Cordilleran Ice Sheet at this point was relatively thin, and isolated plateau nunataks protruded through the ice mass. Two ice lobes, the Selwyn and Cassiar, with differing flow trajectories, converged in the southwestern part of the study area. Local ice accumulations were limited to minor advances in the Glenlyon Range, and had no significant contribution to the regional ice sheets. Recessional features, widespread across the study area, indicate a complex ice retreat history. Large abandoned outwash channels and glacial lake deposits are common features.

An orientation study of till geochemistry at the Clear Lake SEDEX deposit indicates that lead, mercury, barium and silver are useful exploration indicators. Zinc is not a good indicator despite the high zinc grades in the deposit. Acid weathering may play an important role in the depletion of zinc in the till. The survey identified a dispersal train at least 600 m long that may be topographically controlled.

Regional till geochemistry results identify anomalies in gold, zinc and copper. Intrusion-related gold associated with mid-Cretaceous and Jurassic granite, and hydrothermal gold near Big Salmon fault are the primary precious metal settings. A base metal anomaly in Earn Group rocks of the Cassiar platform suggests SEDEX potential south of the Clear Lake deposit. Nickel-copper-chromium-copper values are anomalous in Mississippian rocks of the Little Salmon Range. Lastly, anomalies in zinc and copper were identified in Stikine Terrane in the southwest part of the study area.

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