Province of British Columbia
Ministry of Energy, Mines and
Petroleum Resources
Hon. Anne Edwards, Minister

MINERAL RESOURCES DIVISION
Geological Survey Branch

DRIFT EXPLORATION IN THE CANADIAN CORDILLERA

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PAPER 1995-2

1895 - 1995
100
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MINERAL RESOURCES DIVISION

Geological Survey Branch

Ryder, J.M. (1995): Recognition and Interpretation of Flow Direction Indicators for Former Glaciers and Meltwater Streams; *in* Drift Exploration in the Canadian Cordillera, Bobrowsky, P.T., Sibbick, S.J., Newell, J.H. and Matysek, P.F., Editors, *British Columbia Ministry of Energy, Mines and Petroleum Resources,* Paper 1995-2, pages 1-22.

Canadian Cataloguing in Publication Data
Main entry under title:
Drift exploration in the Canadian Cordillera
(Paper, ISSN *0226-9430* ; *1995-2)*

Issued by Geological Survey Branch.
ISBN 0-7726-2368-6

1. Drift - British Columbia. 2. Geochemical prospecting - British Columbia. 3. Prospecting - British Columbia - Geophysical methods. 4. Glacial landforms - British Columbia. I. Bobrowsky, Peter, T. II. British Columbia. Ministry of Energy, Mines and Petroleum Resources. III. British Columbia. Geological Survey Branch. IV. Series: Paper (British Columbia. Ministry of Energy, Mines and Petroleum Resources) ; 1995-2.

QE579.D74 1995 622'.1'09711 C95-960058-2

VICTORIA
BRITISH COLUMBIA
CANADA

FEBRUARY 1995

FOREWORD

Exploration for mineral resources in the mountainous regions of the Cordillera has changed considerably in the last decade. As the frequency of near-surface discoveries diminishes mineral exploration is more frequently focused on regions of high potential but mantled by unconsolidated sediments of varying complexity and thickness. This move to a different type of terrain, dominated by Quaternary deposits, requires a change in the exploration strategy. Successful mineral exploration in Quaternary dominated terrain requires an appreciation and understanding of the surficial sediment cover, glacial history, glacial dispersal theory and soil formation which can assist in the interpretation of the overburden cover.

This volume is a compilation of papers on various aspects of drift exploration using many examples from British Columbia. The number of glaciations, patterns of ice dispersal as well as thickness and types of deposits found vary throughout the province. Coupled with a variable topographic relief the region is highly suited for a compilation of drift studies focussing on mountainous terrain. Papers are grouped thematically beginning with Quaternary geology, followed by geochemistry and concluding with geophysics. Topics are diverse, and cover many principles of surficial geology such as recognition of paleo-flow direction, drift potential mapping, methods of drilling as well as glacial dispersal using indicator clasts. Geochemical contributions address various methods of till geochemistry and biogeochemical sampling, lake sediment research, laboratory techniques and new research interests such as partitioning studies. Topics covered in the geophysical papers include shallow seismic methods, borehole analysis and resistivity mapping. Case studies which elaborate on the above concepts are dispersed throughout the technical contributions.

The contributors represent a wide range of specialties and possess many years of experience in their particular fields of interest. Provincial and federal geological surveys as well as academia and the exploration industry are well represented. All of the authors worked hard to complete their papers for this volume and the editors acknowledge and appreciate their efforts. An earlier version of this text appeared as a companion to the Cordilleran Roundup 1994 Short Course on Drift Exploration in Glaciated and Mountainous Terrain held at the Hotel Vancouver, in Vancouver, British Columbia. The emphasis of the course and this volume has been on glaciated and mountainous terrain in keeping with our focus on Cordilleran activities. However, examples from outside the Cordillera are common to illustrate certain concepts and principles relevant to the Cordillera. We have deliberately tried to limit duplication of other successful volumes on drift studies which tend to stress 'shield' or 'continental ice' environments.

The papers have undergone critical review and editing by the Ministry of Energy, Mines and Petroleum Resources. We trust this volume will be of interest and use to a variety of mineral explorationists, particularly those bedrock and Quaternary geologists, geochemists and students who share a common interest in drift exploration and mountainous terrain.

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RECOGNITION AND INTERPRETATION OF FLOW DIRECTION INDICATORS FOR FORMER GLACIERS AND MELTWATER STREAMS

By J.M. Ryder
J.M. Ryder and Associates, Terrain Analysis Inc.

INTRODUCTION

Mineral exploration in glaciated terrain relies on the identification of dispersal trains of mineralized debris in glacial drift (Shilts, 1976; DiLabio, 1990). Debris was eroded from mineralized source rock and transported by ice or meltwater prior to deposition. Exploration involves discovery of dispersal trains by geochemical soil surveys and subsequent tracing to the source by following the glacial flow-path upstream. Early drift prospecting concentrated on the analysis of till, but more recently other types of glacial drift, such as glaciofluvial (meltwater stream) sediments and Holocene deposits have been used.

Drift prospecting relies heavily on knowledge of the former flow directions of late Pleistocene glaciers and glacial meltwater streams. Flow directions are indicated by a variety of erosional and depositional features. Many of these are landforms that are large enough to be visible on air photos (Table 1-1), and air photo interpretation is by far the fastest and most economical way to determine flow directions. Smaller landforms and other features, such as sedimentary structures, can only be seen on the ground (Table 1-2). Commonly, ice and meltwater flow directions can be reliably determined from air photos by an experienced interpreter, and less experience is required to identify some of the more clearly defined flow features. Additional information about the origin and processes of deposition of different types of surficial materials can also be interpreted from air photos, although for this purpose, some ground checking is usually necessary.

Even when clear directional features are identified, application of flow information to drift prospecting is not always straightforward. For example, flow directions may have changed with time during a glaciation, or observed flow direction indicators may not represent regional or typical patterns of ice or meltwater movement.

The objectives of this paper are: to illustrate and provide criteria for the recognition of landforms and other features that indicate the former flow directions of ice and meltwater with emphasis on air photo interpretation; and to discuss the factors that control flow directions and changes of flow direction, in both space and time, with regard to application to drift exploration.

Because this paper can provide only a broad overview of these two topics, it is recommended that persons attempting to develop skills in air photo interpretation of glacial features should read additional material on glacial geomorphology and air photo interpretation. Recommended reading includes the classic text by Flint (1971) and books by Easterbrook (1993), Sharp (1988), Sugden and John (1976), and Prest (1983). Guides to air photo interpretation of glacial landscapes are provided in air photo interpretation guides by Keser (1976) and Smith (1987).

To simplify the following descriptions, flow direction indicators are grouped by agent of formation (glaciers and ice sheets, meltwater), size, and composition (bedrock, glacial drift). Two size classes (large and small) are used to separate features that are visible on air photos from those that can only be identified on the ground. It is useful to distinguish erosional forms in bedrock from features composed of drift because the former can be expected in rocky areas, such as large parts of the Canadian Shield and the Coast Mountains of British Columbia, whereas the latter are characteristic of drift-covered landscapes such as the Interior

TABLE 1- 1
DIRECTIONAL LANDFORMS IN BEDROCK AND DRIFT CREATED BY GLACIERS AND MELTWATER

Agent of Formation	Bedrock Landforms	Landforms of Drift and Bedrock	Drift Landforms
ICE	*Alpine glaciation:* cirques troughs diffluent troughs		*End moraines:* terminal moraines recessional moraines *Small moraines:* (various types)
	Streamlined landforms: roches moutonnées rock drumlins whalebacks flutings glacial grooves	*Streamlined* drumlins crag and tail	drumlins drumlinoid ridges flutings fluted till plain
MELTWATER	*Meltwater channels:* lateral subglacial proglacial	*Meltwater* lateral subglacial proglacial	*Meltwater channels:* lateral subglacial proglacial
			Outwash landforms: plains terraces fans deltas
			Ice-contact landforms: eskers kames kame terraces

TABLE 1-2
SMALL LANDFORMS AND SEDIMENTARY STRUCTURES

Agent of Formation	Erosional Features	Depositional Features
ICE	striations grooves roches moutonnées transverse marks	*Sedimentary structures:* till fabric boulder trains, erratics glaciotectonic structures
MELTWATER	scour marks	*Sedimentary structures:* imbrication ripples crossbedding

TABLE 1-3
TYPICAL DIMENSIONS OF LANDFORMS

Landform	Relief	Length	Width (or dimension indicated)
Alpine glaciation:			
cirques	150-1000 m	0.5-2 km	0.3-1.5 km
troughs	150-1500 m	5-20 km	0.5-2 km
End moraines:			
of Laurentide ice sheet	up to 100 m	10's km	1-30 km
of alpine glaciers	up to 50 m	0.3-1.5 km	10-100 m
Small moraines:			
of Laurentide ice sheet	10-30 m	up to 1 km	(crests 100-300 m apart)
of alpine glaciers	up to 3 m	0.3-1.5 km	(crests 1-30 m apart)
Streamlined landforms:			
roches moutonnées	2-200 m	10-1000 m	0.2-0.8 of length
rock drumline	5-150 m	50-1000 m	0.2-0.4 of length
whalebacks	1-100 m	5-500 m	0.2-0.5 of length
flutings	1-10 m	up to several km	0.1 or less of length
fluted till-plain	1-10 m	up to several km	0.1 or less of length
drumlins	5-150 m	50-1000 m	0.2-0.4 of length
drumlinoid ridges	3-20 m	50-1000 m	0.1-0.3 of length
glacial grooves	1-10 m	up to several km	0.1 or less of length
crag and tail	5-150 m	50-1000 m	0.1-0.4 of length
Outwash landforms:			
plains	0-2 m local relief	up to 10's km	up to several km
terraces	scarps 2-50 m	up to several kms	up to several km
fans	2-50 m toe to apex	100-1000 m	
deltas	foreset slope 2-100 m high	100-1000 m	
Ice-contact landforms:			
eskers	2-50 m	1-10 km	10-100 m
kames	2-100 m	10-200 m across individual hillocks	
kame terraces	scarps 2-50 m	100-1000 m	5-500 m
Small landforms:			
striations	up to 1 cm deep	1-100 cm	few mm
glacial grooves	up to 1 m	0.1-10 m	0.05-2 m
roches moutonnées	0.1-5 m	0.5-10 m	0.2-0.8 of length
transverse marks	up to 5 cm deep		5-30 cm across
meltwater scour marks	up to 0.5 m deep	0.5-2 m	0.5-3 m

Plateau of British Columbia and the Yukon. Tables 1-1 and 1-2 show the classification of flow direction indicators that is used in this paper. Table 1-3 indicates the typical dimensions of the various landforms. Line drawings are used to illustrate the diagnostic characteristics of the various landforms and other features. Photographs were selected to illustrate typical glaciated landscapes, not "textbook" examples (these can be found in the books referenced).

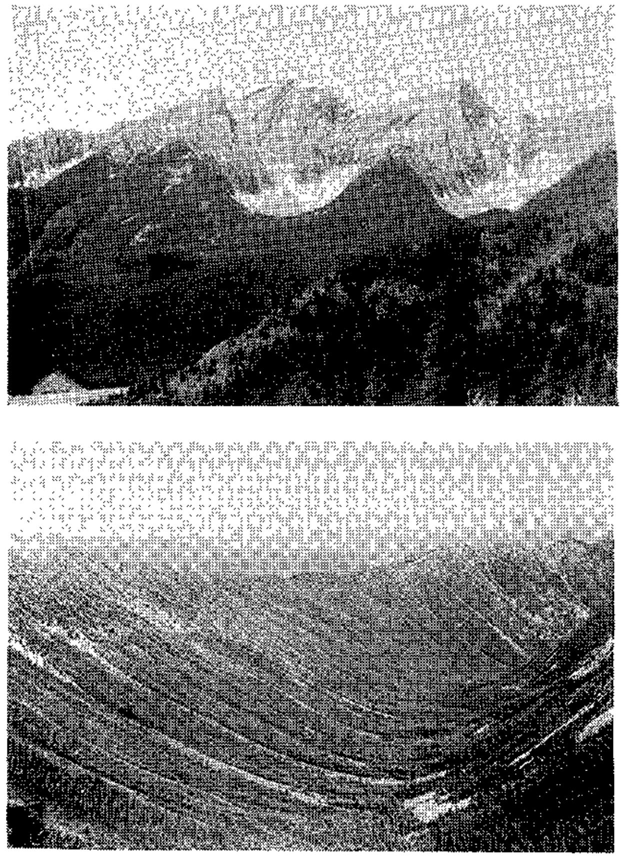

Photo 1-1. Landscape with cirques and troughs, showing diagnostic features for air photo identification of these landforms. (a) Cirques in the Wisukitsak Range of the Rocky Mountains: note U-shaped cross profile with gently sloping floor, much steeper side slopes, and steep headwall; "empty" cirques commonly contain small lakes. (b) Glacial trough in headwater valley of Stein River: this valley has slopes that are relatively gentle for a trough, but the U-shaped cross profile is clearly apparent (note alpine peaks with numerous cirques in the distance)

ICE-FLOW DIRECTION INDICATORS

ICE-FLOW DIRECTION LANDFORMS VISIBLE ON AIR PHOTOS

BEDROCK LANDFORMS OF MOUNTAIN GLACIATION

In mountainous regions where summits and ridge crests were sufficiently high that they were not buried by ice during glaciation, ice-flow directions can be reconstructed by observing the distribution and orientation of the large erosional landforms: cirques and troughs. Cirques mark the heads of former glaciers, and ice flowed from the cirques into and along the troughs, generally, although not invariably, moving in the present downstream direction. Tributary glaciers converged to form larger trunk glaciers, the whole system resembling the modern drainage network. Cirques and troughs are distinctive landforms that can normally be recognized easily on topographic maps and air photos. Criteria for their recognition are shown in Photo 1-1 and their typical dimensions are indicated in Table 1-3. Further information can be found in Easterbrook (1993), Sugden and John (1976) and other sources noted in the Introduction to this paper.

It is necessary to qualify the preceding paragraph, however, noting that this simple model of ice-flow direction should be applied with caution. It may be invalid for certain valleys because glaciers, unlike river systems, may split and diverge around major topographic obstacles and can flow against the gradient of the present land surface. The former characteristic, known as glacial diffluence (or divergence), develops when thickening ice in one valley overtops a relatively low divide and some ice spills into an adjacent valley. Glacial erosion along the new channel may ultimately turn it into a well defined glacial trough or U-shaped pass that connects two drainage systems. In some cases, ice-flow direction through the connecting valley can easily be determined from regional ice-flow patterns. In other cases, additional evidence of flow direction in the connecting valley must be sought on air photos or on the ground (*see* following sections). Examples of "up-valley" flow and glacial diffluence are illustrated in Figure 1-1.

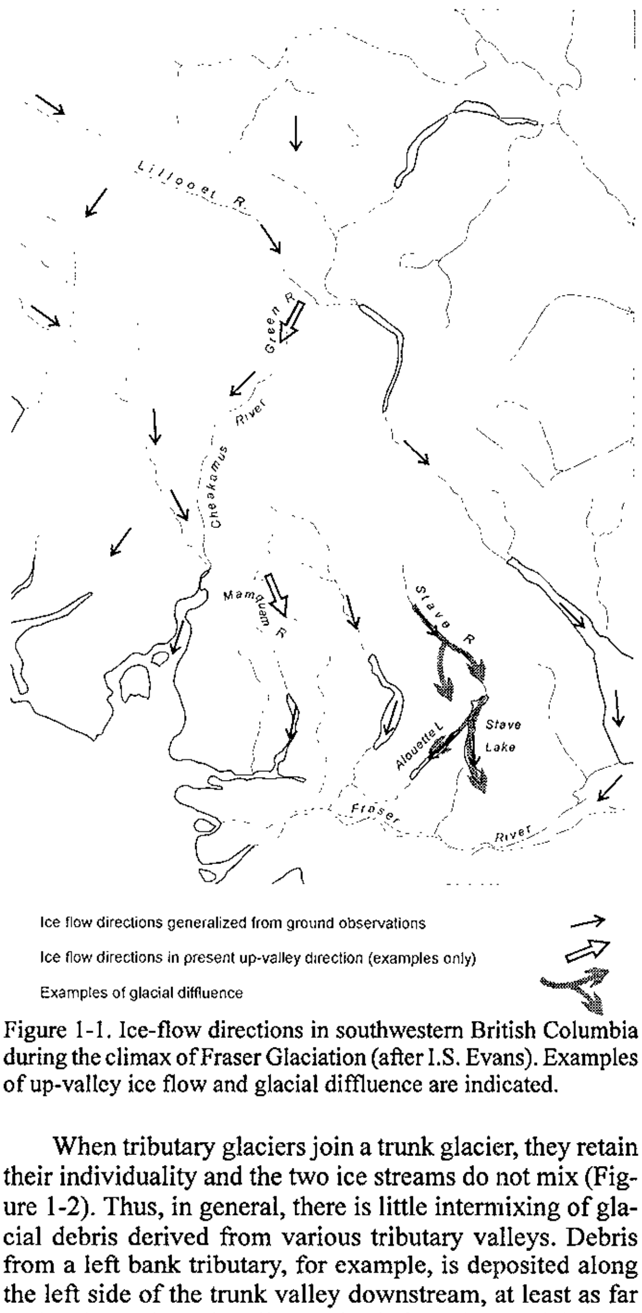

Figure 1-1. Ice-flow directions in southwestern British Columbia during the climax of Fraser Glaciation (after I.S. Evans). Examples of up-valley ice flow and glacial diffluence are indicated.

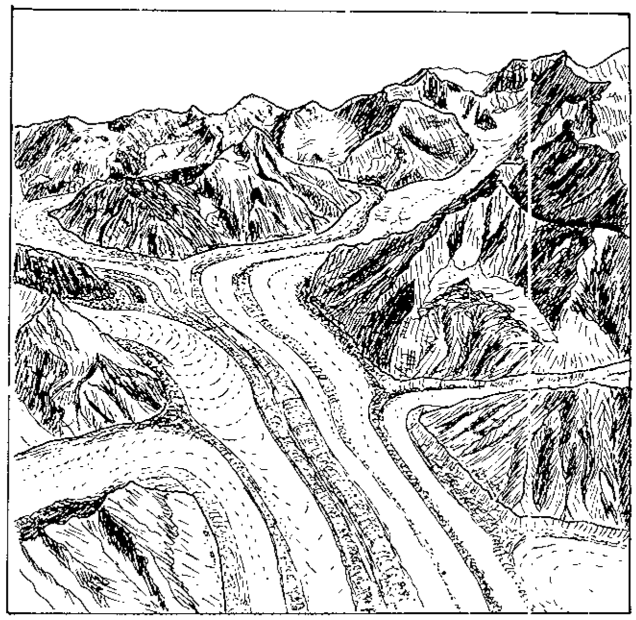

Figure 1-2. Mountain glacier system. Note that tributary glaciers maintain their identity within the trunk glacier: distinct streams of ice are separated by medial moraines (from photoraph by Austin Post).

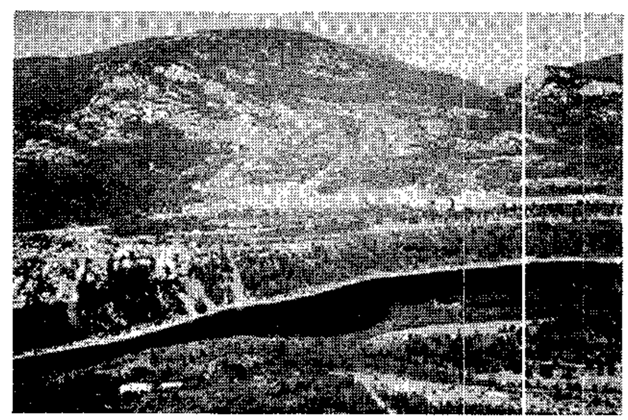

Photo 1-2. Roches moutonnées developed on coarse crystalline rocks on the west side of the Columbia River valley near Castlegar, British Columbia. Ice flowed southward (right to left) Note large, classic roches moutonnée (arrow) and numerous smaller ridges with roches moutonnée type asymmetry: steep slopes (with little vegetation) face down-flow. The influence of geological structure is clearly apparent.

When tributary glaciers join a trunk glacier, they retain their individuality and the two ice streams do not mix (Figure 1-2). Thus, in general, there is little intermixing of glacial debris derived from various tributary valleys. Debris from a left bank tributary, for example, is deposited along the left side of the trunk valley downstream, at least as far as the place where the tributary ice is forced toward the centre of the valley by subsequent tributaries (*e.g.* Hicock, 1986). Less commonly, this pattern may be modified by topographic irregularities, surges from tributary glaciers, or shifts in the relative size and position of glaciers during deglaciation. Medial moraines, which are a striking feature of large trunk glaciers (Figure 1-2), usually do not survive deglaciation intact, and are not commonly preserved in the postglacial landscape.

In mountainous regions where summits and ridge crests were overridden during glaciation, ice-flow directions during the glacial maximum may have been unrelated to present valley alignments.

LARGE STREAMLINED LANDFORMS IN BEDROCK

Streamlined (linear) erosional forms consisting of rock ridges and intervening depressions aligned parallel to the ice-flow direction are best developed in hard rocks that were resistant to glacial erosion, such as coarsely crystalline igneous and metamorphic lithologies and the harder sedimentary rocks. Details of the morphology of these landforms are strongly influenced by the alignments of planes of weakness such as joints, bedding and foliation. Relatively soft rocks were eroded by ice, giving rise to featureless lowlands.

Streamlined bedrock ridges and hummocks with distinctive morphology have been given specific names, such as "roches moutonnées" and rock drumlins (Figure 1-3; Photo 1-2), but glaciated ridges are commonly referred to more loosely as "whalebacks" (Photo 1-3), streamlined to-

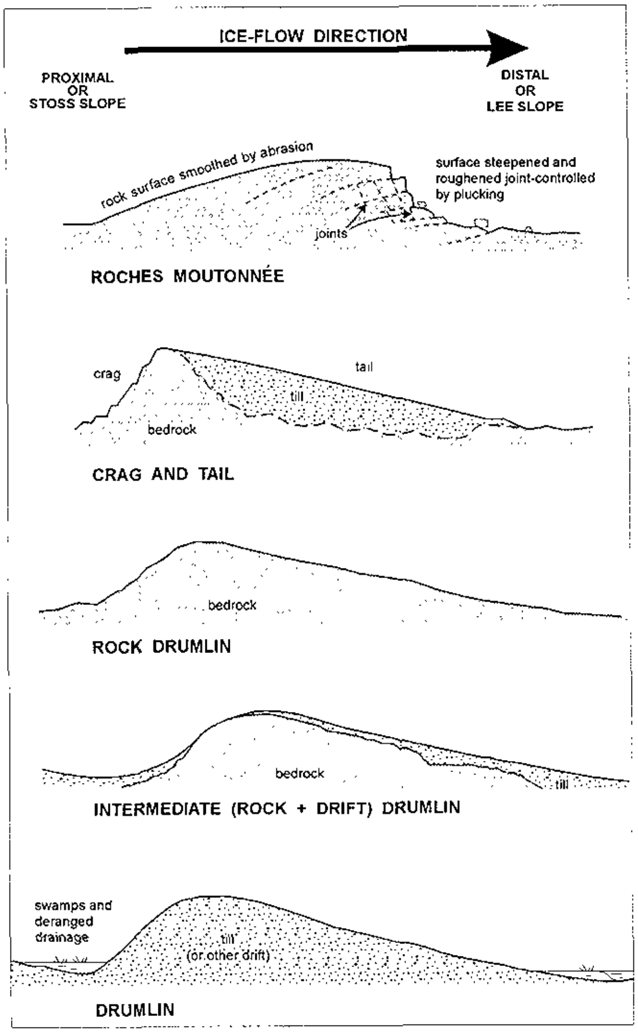

Figure 1-3. Schematic cross-sections of streamlined landforms with asymmetric longitudinal profiles. Ice flow direction and related terminology for all landforms are shown at the top of the diagram (not to scale).

pography, or simply "glacial lineations" (the latter term is also applied to linear features in till). If glacially eroded linear depressions are the dominant form, they are termed "glacial grooves" (Photo 1-4). Commonly, glacial grooves are best developed where ice flowed over obstacles, such as escarpments. Features such as roches moutonnées and glacial grooves may be too small to be visible on air photos (*see* Table 1-3).

Figure 1-3 indicates that roches moutonnées and rock drumlins have dissimilar asymmetry of longitudinal profiles with regard to ice-flow direction. The two forms can be distinguished by the sharp irregularities on the distal slope of the former feature. In areas of glaciated resistant rock, roches moutonées are typically much more common than rock drumlins, and they have a wider range of sizes (Table 1-3). Many rock knobs and irregular bedrock hummocks display a similar type asymmetry, with gentle stoss slopes and steep lee sides, although a ridge-like morphology (parallel to ice-flow direction) may be absent (Photo 1-2).

Streamlined landforms typically occur in groups, and the multiple ridges impart a distinctive grain (like wood grain) to the appearance of the landscape on air photos. This grain usually has topographic expression, but it is commonly emphasized by vegetation patterns that result from variations in soil moisture or soil thickness between the crests of ridges and intervening troughs.

All these linear forms indicate the trend of the former ice flow (*e.g.* northwest-southeast) but only those landforms with asymmetric longitudinal profiles (Figure 1-3) indicate the actual sense of ice movement (*e.g.* toward the southeast) of the ice. Very close inspection of air photos may be necessary to determine the typical longitudinal asymmetry of the rock ridges, and hence ice-flow direction, because a variety of irregular ridges is usually present. If the landforms are so poorly defined that direction of ice flow cannot be determined, it may be possible to use known regional ice-flow patterns to infer the sense of movement in a study area. In any case, it is always advisable to check the results of air photo interpretation against any existing regional information.

Streamlined bedrock landforms are best developed where ice-flow direction was parallel (or almost parallel) to bedrock structures because glacial erosion was most effective along structural planes of weakness (bedding, joints, foliation; *e.g.* Photo 1-3). However, weathering and erosion by nonglacial agencies are also most effective along the same structural weaknesses, and some landscapes have a pronounced grain that indicates only geological strike and NOT former ice-flow directions. Thus, structurally controlled linear topography can be mistaken for glacial lineations (Photo 1-5).

The following suggestions and criteria are offered to distinguish between linear topography of glacial and structural origins:

- Compare the trend of the bedrock lineations with that of any more reliable ice-flow directional indicators that are nearby, or with regional ice-flow direction if it is known. Crag and tail, or isolated examples of streamlined drift landforms may be found in predominantly bedrock landscapes. Eskers can be used as a general indicator of ice-flow direction.
- Is the alignment of the lineations in accord with the likely effects of topographic irregularities large enough to have locally affected ice-flow direction? For example, glacial flow-lines are likely to diverge and converge around prominent topographic features.
- Compare the trend of the lineations with that of any visible non-topographic features that are clearly of structural origin (*e.g.* streaky grey-tone patterns that represent foliation), or with structures shown on a bedrock geology map. If the supposed glacial lineations and the strike of bedrock structures are parallel, be suspicious: the lineations may be structural features (but *see* also below).
- Bedrock strike commonly changes alignment in a manner dissimilar to that of glacier flow lines. For example, in an area of low relief such as the Canadian Shield, rock ridges describing the arcuate patterns of fold structures typically have a smaller radius of curvature or change alignment

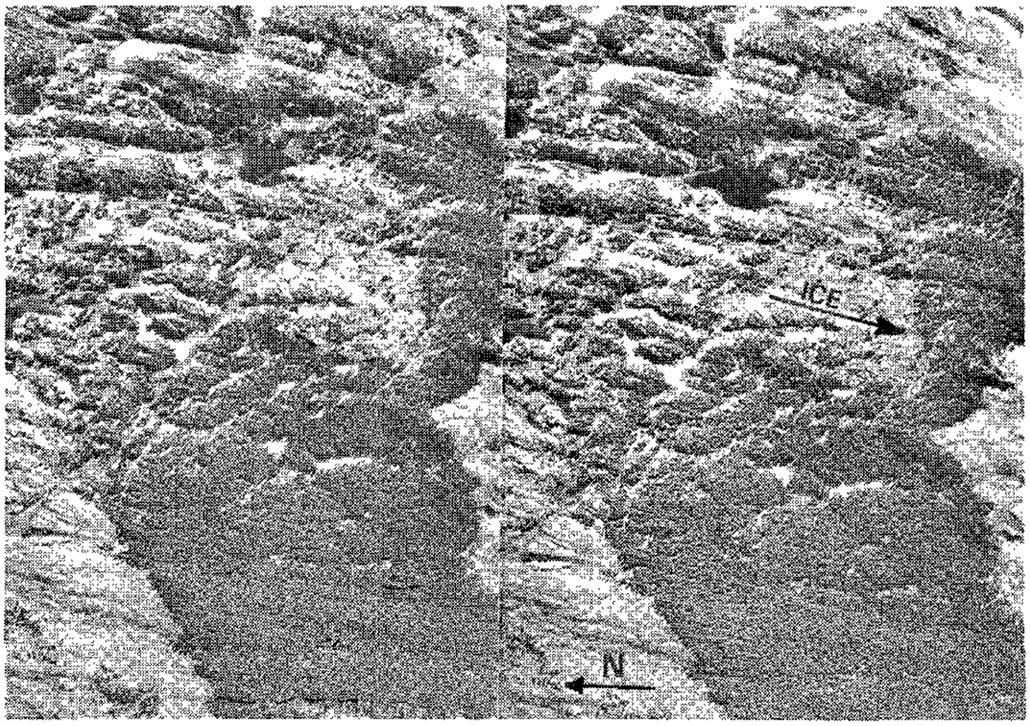

Photo 1-3. Whalebacks developed on the Mount Lytton batholith in the Cascade Mountains, British Columbia. Strong influence of north-trending master joints is apparent. Note variation in the shape of the landforms. White patches in the eastern part of the view are snowbanks. Nivation appears to have caused steepening of north-facing slopes, producing features which resemble roches moutonnées but with asymmetry reversed with regard to ice-flow direction (arrow) (Government of British Columbia air photos BC5212: 135-136).

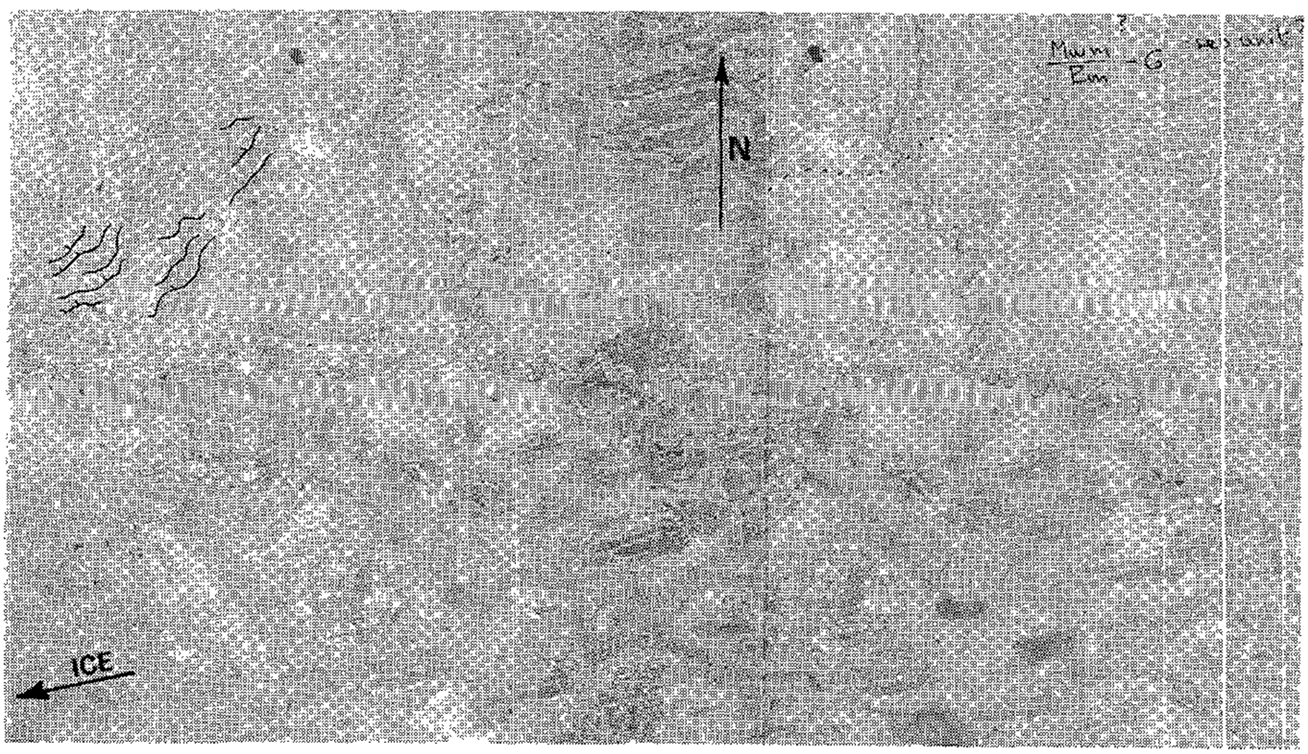

Photo 1-4. Weakly developed but clearly visible glacial grooves on the Kawdy Plateau in northern British Columbia; crag-and-tail ridges, rock drumlinoids and lateral meltwater channels (a few of which are mapped) are also apparent (Government of Canada photos A19604: 72-73).

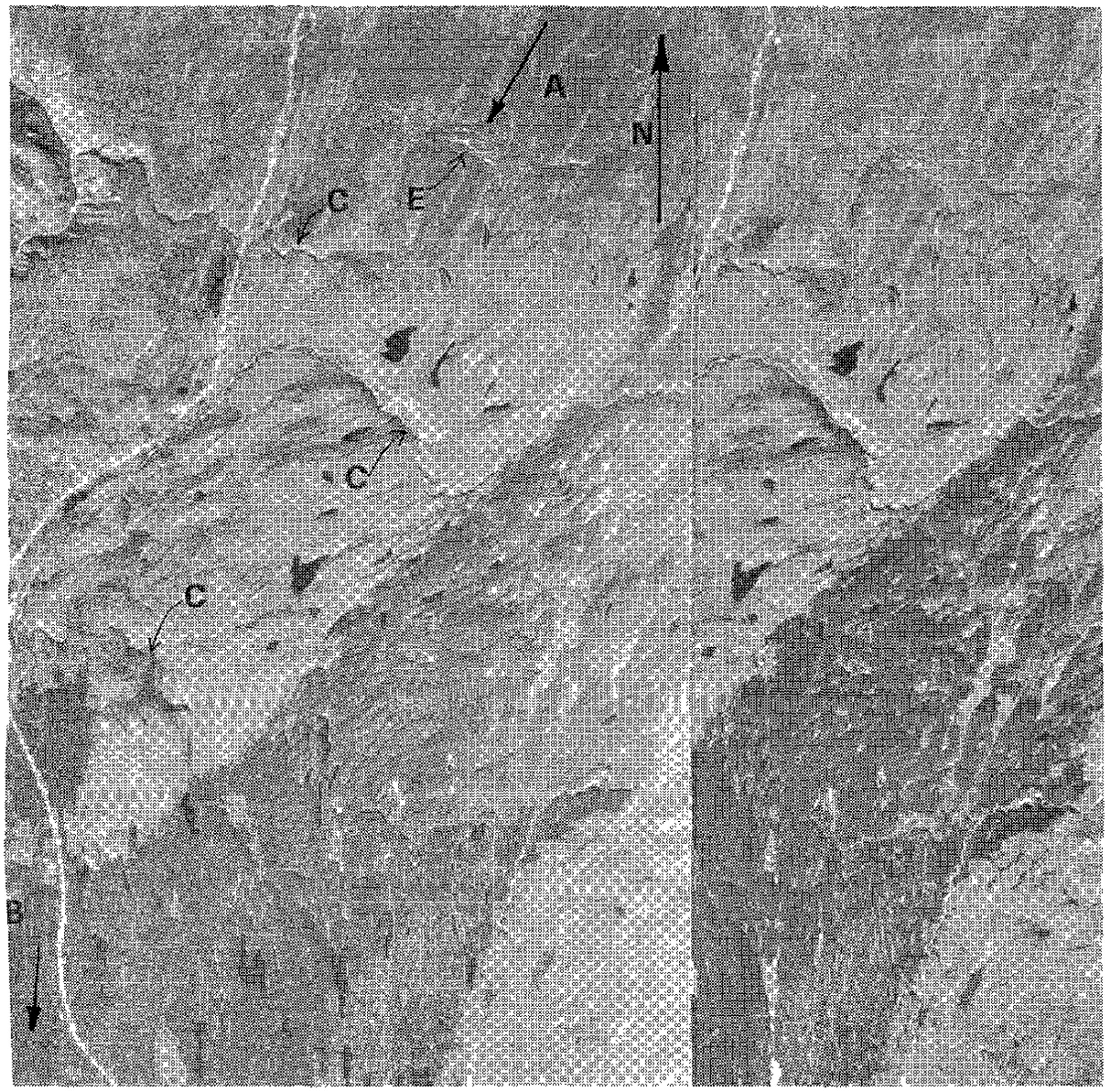

Photo 1-5. Stereo pair from Iskut River valley, northwestern British Columbia: True ice-flow direction is indicated by drumlinoid ridges at "A" and rocky ridges at "B". Ridges oblique to this trend are structurally controlled: note relatively abrupt changes in strike directions. *See* also meltwater channels (C) and series of small eskers (E). Pale grey tones in northwestern half of the area indicate the extent of the recent forest fire (Government of British Columbia air photos BC5612: 004-005).

more abruptly across faults than glacial flow lines. In low-relief terrain, glacier flow lines are most commonly straight. (There are some exceptions to these generalizations: where an ice-sheet margin was lobate, interactions of adjacent lobes resulted in curving or converging glacier flow-paths.)

- Closely examine details of the bedrock ridges. If glacial abrasion has been sufficiently effective to create linear topography, then it is likely that the rock surfaces will be smooth, rounded, and with either roches moutonnées or drumlin asymmetry. Some rock drumlin ridges are extremely long and narrow. In contrast, ridges formed by weathering of structural features are irregular and have sharply jutting protuberances.
- Use ground searches for striations and other features (small roches moutonnées and glacial grooves) to confirm the results of air photo interpretation.

Base conclusions on two or more independent lines of evidence.

LINEATIONS AND STREAMLINED LANDFORMS CONSISTING WHOLLY OR PARTLY OF DRIFT

The elongate, asymmetric hills known as drumlins are probably one of the best indicators of ice-flow direction. Drumlins are readily identified by their distinctive morphology (Figure 1-3, Photos 1-6 and 1-7) and their typical occurrence in groups, sometimes referred to as a "swarm of drumlins". "Basket-of-eggs topography" is another evocative term. Drumlin size (Table 1-3) is such that these land-

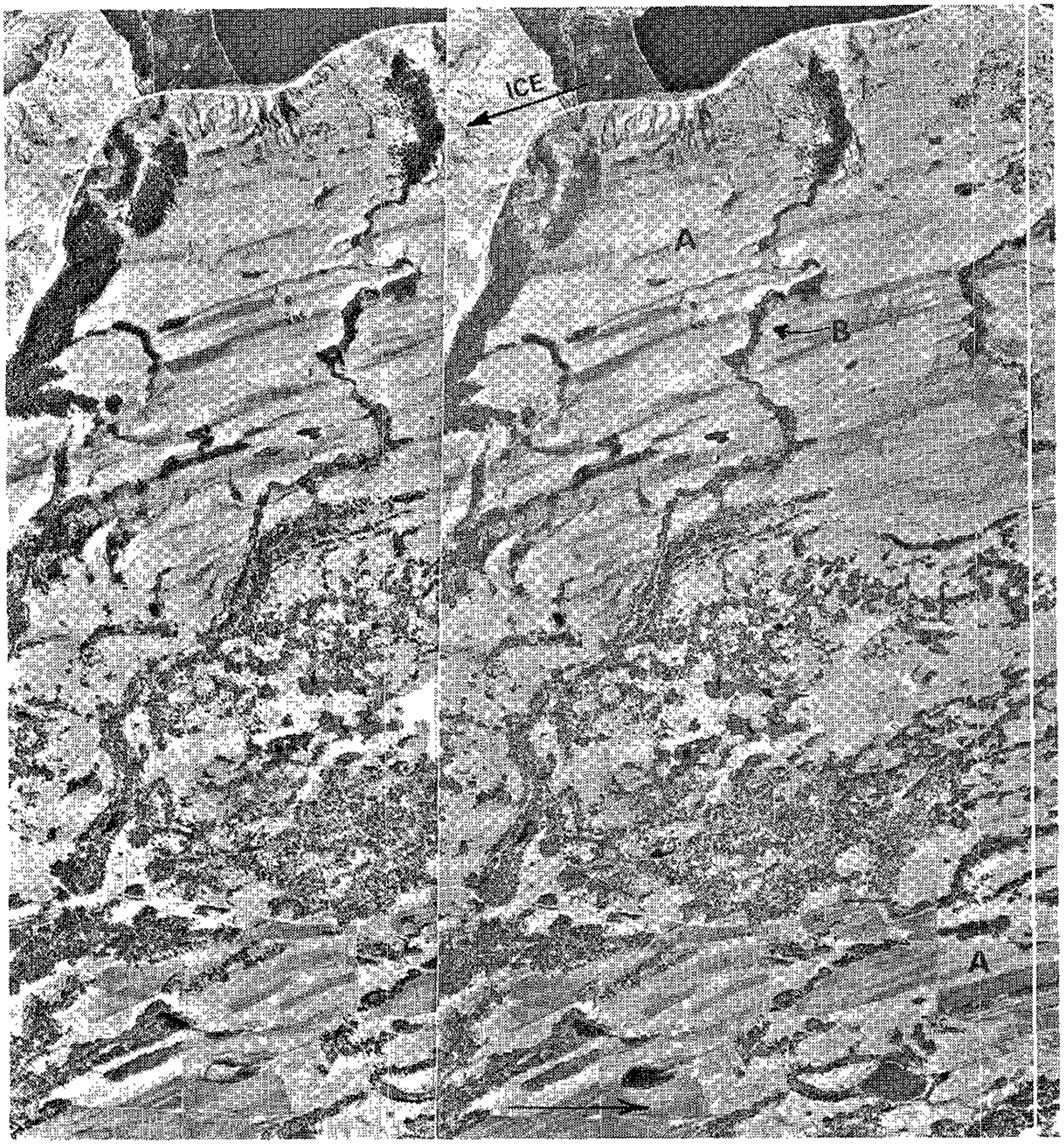

Photo 1-6. Stereo pair of Thompson Plateau near Merritt: streamlined landforms include weakly developed drumlins, and drumlinoid ridges (A); at "B", a meltwater channel was superimposed on a drumlin from downwasting ice, resulting in dissection of the drumlins (Government of British Columbia air photos BC 5188: 195-196).

forms are readily visible on most air photos. Surface drainage is commonly impeded by drumlins (sometimes called "deranged drainage") so that irregularly winding streams and swamps occupy intra-drumlin areas. Thus the visibility of drumlins on air photos is commonly enhanced by contrasting vegetation patterns that reflect variations in soil moisture.

Drumlins commonly consist of basal till, or till surrounding a rock core, or thin till covering an essentially rocky landform. There is a continuum of landforms of similar shape but varying composition extending from till drumlins to rock drumlins. Drumlins may also consist wholly or partly of glaciofluvial (outwash) sediments or other drift, the drumlin shape being a product of glacial erosion. Current knowledge of drumlin formation suggests that some are the result of till accumulation at the base of actively flowing ice while others are attributed to erosion (or remolding) by ice, or erosion by catastrophic floods of meltwater (in the latter case, meltwater-flow direction is indicated; *c.f.* Shaw *et al.*, 1989).

A typical drumlin has a distinctive streamlined shape that indicates both the trend and the sense of direction of ice movement (Figure 1-3), but all drumlins are not equally well developed (Photo 1-7). To identify ice-flow directions by air photo interpretation, it is usually necessary to examine carefully several drumlins within the swarm in order to determine a consistent arrangement of stoss and lee ends. Drumlins may also be composite features, for example, some have flutings (*see* below) superimposed on their distal slope, and twinned forms are common. In areas where ice

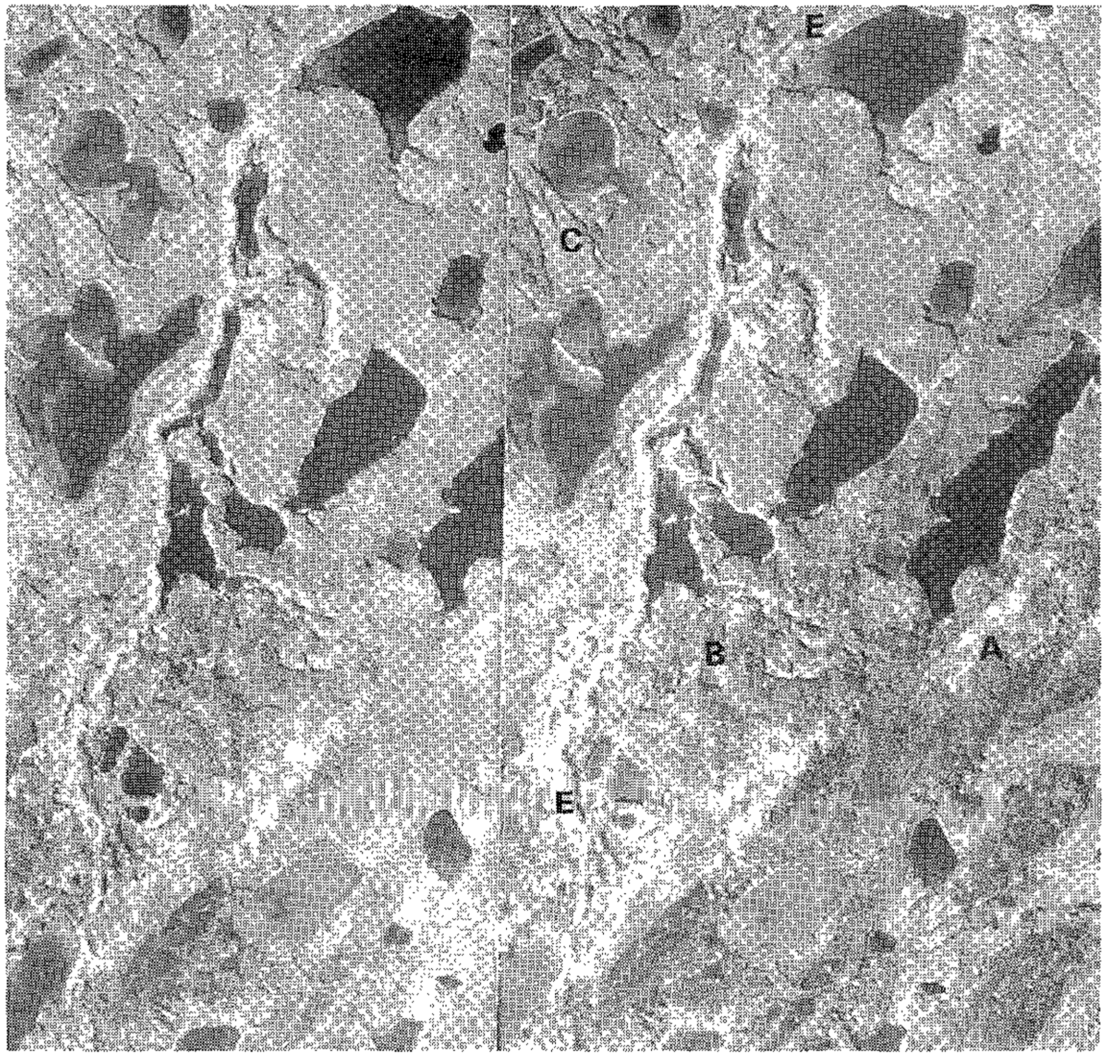

Photo 1-7. Liard Plain, northeastern British Columbia: complex esker (E), drumlins (A), hummocky ice-disintegration moraine (B), and ridges transverse to ice-flow direction (C) that may be crevasse fills (Government of Canada air photos A13022: 87-88).

stagnated at the end of the last glaciation, drumlins partly buried by ablation till, and hence with indistinct morphology, are common.

There is a continuum of forms between well defined drumlins and featureless till plains. Terminology such as drumlins, drumlinoid ridges, flutings and fluted till-plain is commonly applied to this sequence in order of decreasing range of relief and longitudinal asymmetry (Photos 1-7, 1-8 and 1-9). Sense of direction may be difficult to interpret for drumlinoid forms, and usually only ice-flow trend can be determined from flutings and fluted till-plain. Flutings (or flutes) are open-ended, parallel ridges of low relief. The low wave-like morphology of a fluted till-plain may be hard to see on the ground and even on air photos unless emphasized by low-sun shadows or snow drifts, although on air photos, alternating strips of better and less well drained soils and related vegetation can usually be seen.

"Crag-and-tail" is another landform which provides clear evidence of both trend and sense of ice-flow. The crag is a steep-sided bedrock hill, and the tail is a tapering ridge of drift, usually till, that was preserved or accumulated on the protected lee side of the crag during glaciation (Figure 1-3, and Photo 1-10). The tail points in the direction of ice flow. Crag-and-tail landforms occur both in groups and alone.

DEPOSITIONAL LANDFORMS TRANSVERSE TO ICE-FLOW DIRECTION

The edge of an ice sheet or the edge of a glacier at its terminus tends to be roughly perpendicular to flow lines in the ice. Morainal ridges that were deposited along the edge of the ice can be to used as indicators of approximate glacier flow direction. Some subglacial drift ridges also form roughly at right angles to the ice flow. Transverse landforms such as end moraines and subglacial ridges may provide the only evidence of ice-flow directions where there are no parallel features such as drumlins.

End moraines include terminal moraines, which mark the furthest extent of a glacial advance, and recessional moraines, which mark the position of temporary standstills or local readvances of the ice margin during general ice recession. The morphology and size of these landforms varies greatly with the size and type of the associated glacier. Mo-

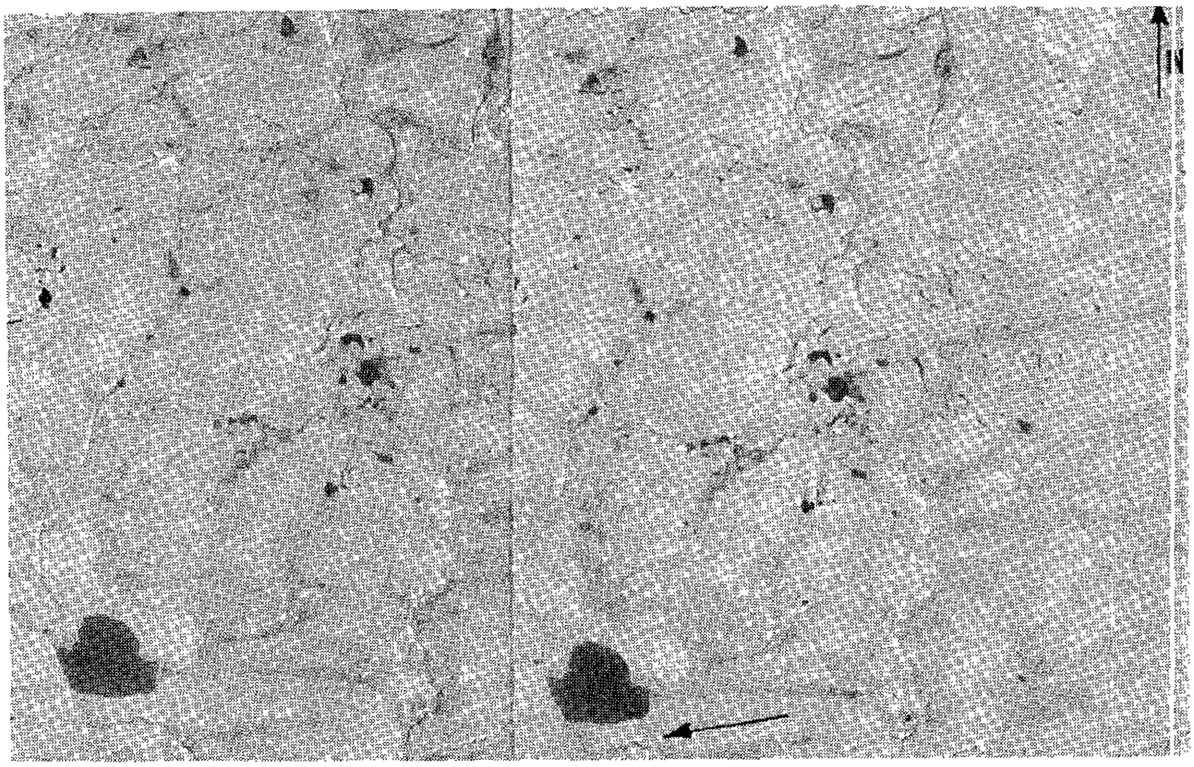

Photo 1-8. Stereo pair, Stikine Plateau, northern British Columbia: drumlinoids indicate the trend of ice flow, but sense of flow is harder to interpret unless crag-and-tail ridges are identified (careful analysis will reveal the latter). Note also the numerous small meltwater channels transverse to ice flow that were superimposed on the drumlinoids during deglaciation (Government of Canada air photos A19568: 11-12).

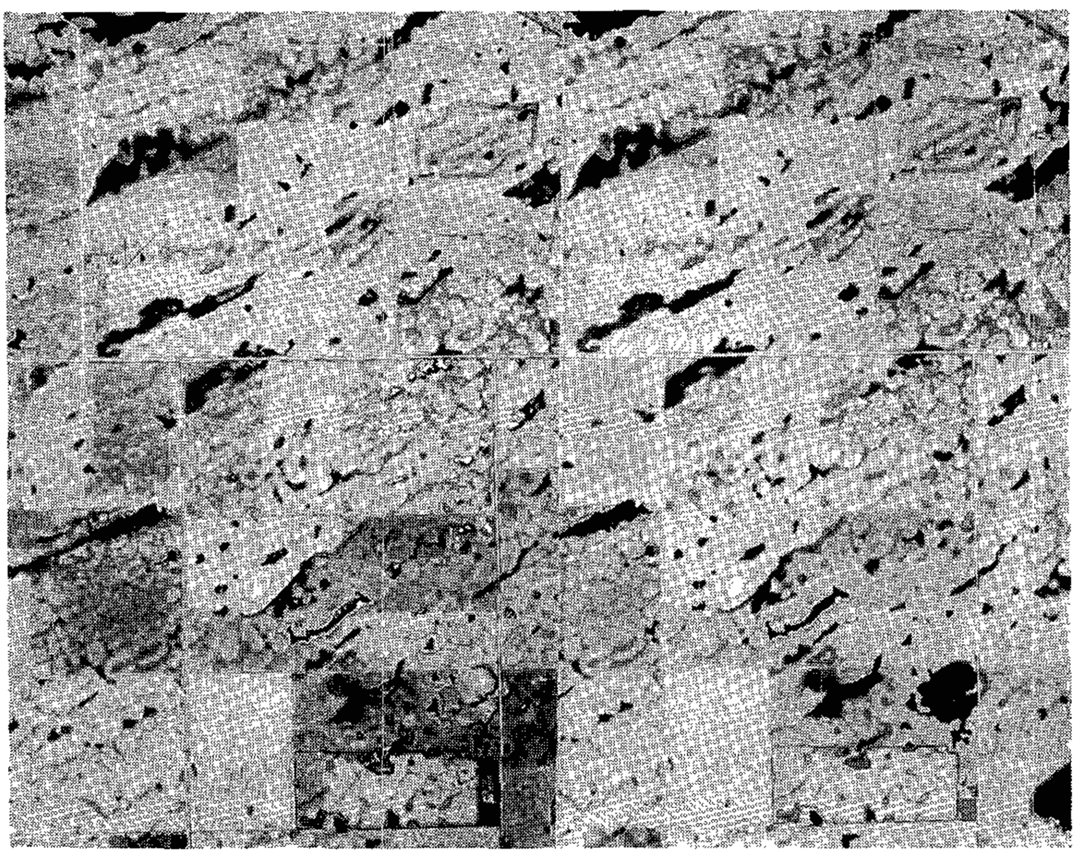

Photo 1-9. Stereo pair of a fluted till-plain, parallel ridges of very low relief, (Alberta) partly masked by superimposed hummocky ablation moraine (irregular small blobs and "donuts") Government of Canada air photos A131115: 75-76).

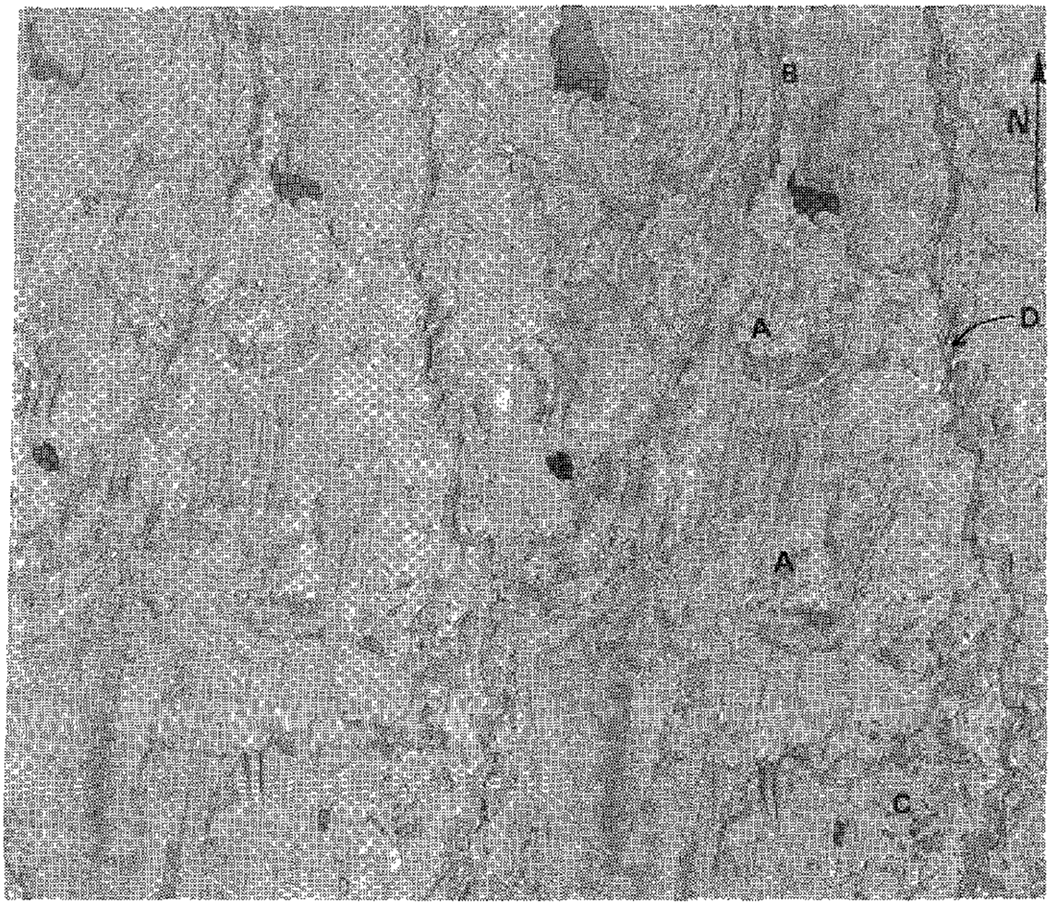

Photo 1-10. Stereo pair of crag-and-tail (examples at "A") indicating ice flow toward slightly east of north. Note also drumlinoid ridges, small eskers and meltwater channels at "B", hummocky ice-disintegration moraine at "C" and present day stream in meltwater channel at "D" (Stikine Plateau, northern British Columbia; Government of Canada air photos A19569: 75-76).

raines of the Laurentide ice sheet are belts of gently undulating to hilly topography many kilometres wide, whereas moraines of a valley glacier may be sharply defined ridges only a few metres wide. Many moraines, regardless of size, are arcuate in plan and convex with respect to the former ice-flow direction. Also, multiple morainal ridges are commonly nested in concentric arcs.

Caution is necessary when using end moraines for reconstruction of ice-flow directions. Due to irregularities of topography, melting of the ice margin by meltwater streams, and the effects of ice-marginal lakes, the ice edge was only perpendicular to ice-flow direction in a very general sense. Of more significance for drift prospecting is the fact that in many places, ice-flow directions near a receding ice margin differed considerably from the flow-direction of ice during earlier stages of the same glaciation (Figure 1-4). Flow directions determined from end moraines should thus be used circumspectly.

Small moraines of various types have been differentiated, but there is no general consensus as to terminology or specific mode of origin of some of these features. For reconstruction of ice-flow directions, it is useful to distinguish only two classes of small moraines; (i) those that formed at or close to the ice margin, and (ii) those that formed subglacially. The appearance, on air photos, of most small moraines of the first type is aptly summarized by the descriptive terms "corrugated moraine" and "washboard moraine" (Photos 1-11 and 1-12). Typically, numerous low ridges are visible on a single air photo, and commonly concentric arcs of small moraines mark the recessional stages of former ice lobes. Some of these small moraines formed subaqueously, in which case the curvature of the arcs may be concave with respect to former ice-flow direction, in accord with the typical configuration of calving bays in floating glacier termini. Reconstruction of ice-flow directions from the first type of moraine is subject to the same drawbacks as noted above for the larger end moraines.

Small moraines of the second type are known as "Rogen" or "ribbed" moraines (two names for the same feature). These small transverse ridges formed beneath moving ice, possibly at points where shear planes extended upward from

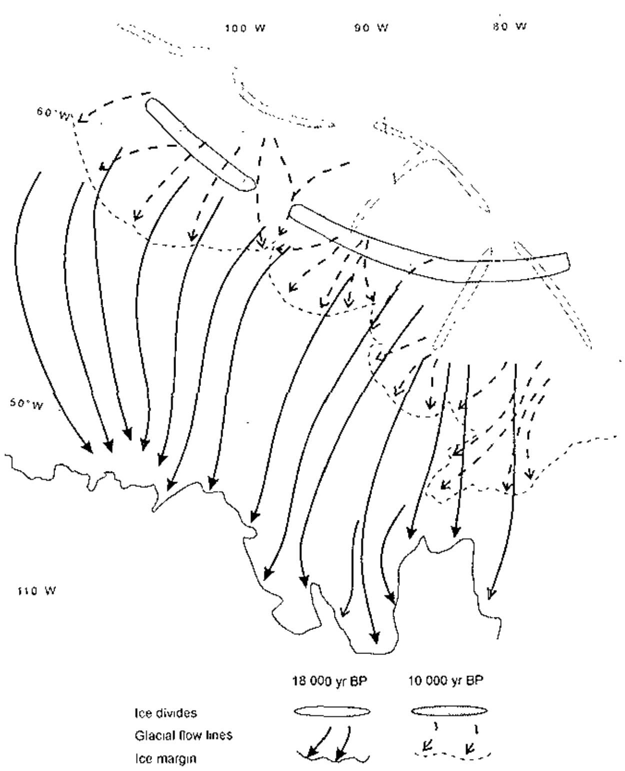

Figure 1-4. Relation between position of the ice margin and glacier flow directions. Note how parallel flow lines are later replaced by radial flow patterns near to the receding ice margin (from Dyke and Prest, 1986).

the subglacial bed (Photo 1-13). These moraines are transverse features formed at right angles to ice-flow direction. Because they formed farther up-ice than moraines described above, their configuration was not influenced by the local morphology of the ice margin. Consequently they are probably more representative of typical ice-flow directions. Rogen moraines are asymmetric in cross-section, with steeper sides facing down-flow. They are commonly associated with drumlins, either grading laterally into drumlin swarms or superimposed on drumlins, in which places, the drumlins should be used to reconstruct ice-flow direction. Excellent air photo illustrations of ribbed (Rogen) moraines and other ice-flow direction features are presented by Aylesworth and Shilts (1989).

OTHER LINEAR LANDFORMS

Several linear or ridged landforms that occur in till are not indicators of ice-flow direction, including crevasse fillings and iceberg scour marks.

SMALL ICE-FLOW DIRECTION LANDFORMS AND OTHER FEATURES

SMALL LANDFORMS AND SURFACE MARKS

Some features that are reliable indicators of ice-flow direction are sufficiently small that they can be identified on the ground. Other features, such as the rock slope asymmetry that is best exemplified in roches moutonnées, and glacial grooves, occur at a range of sizes in which smaller features can only be identified on the ground (Photo 1-14, Tables 1-2 and 1-3).

Striations (striae) are scratches made by rocks embedded in moving ice when they were dragged across a rocky glacial bed (Photo 1-15). A field observer must carefully differentiate glacial scratches, which are tiny grooves and not cracks, and usually do not penetrate more than a few millimetres into the rock, from the surface expression of planes of weakness (cracks) which are related to rock structure. Striations are found on surfaces which contain other evidence of ice abrasion, such as smoothing and glacier polish. They may be sufficiently small and shallow that they are invisible except under very oblique lighting or unless enhanced by brass-rubbing techniques (pencil shading on overlying paper).

Striations are best formed where relatively hard rocks in the glacier sole were scraped across relatively soft rocks, such as limestone. Late Pleistocene striations are best preserved, however, on relatively hard, fine-textured rocks that have undergone little weathering during the past 10 000 to 12 000 years, such as basalt and quartzite. Striations are less common on coarse-textured intrusive rocks and unusual on metamorphic and clastic sedimentary rocks, although small patches of striated rock may exist on small parts of an outcrop, such as on veins of aplite surrounded by weathered granodiorite. Whether or not striations are to be found depends upon a variety of local circumstances. Striations are common where glacially smoothed slabs have recently been exhumed from beneath a soil cover, for example by road construction.

Striations clearly indicate the trend of the former ice flow, but the direction is usually difficult to determine. Commonly other features that show sense of direction, such as smoothed stoss and steepened lee slopes, are present in the vicinity.

Both trend and sense of flow direction can be readily determined where differential abrasion of inhomogeneous rocks has resulted in the protrusion of knobs of hard rock from which tails of softer rock ("rat-tails") extend downflow.

A variety of small crescentic fractures in bedrock have been interpreted as friction cracks and attributed to the effects of large boulders dragged across the rock by moving ice. Multiple features commonly occur together in longitudinal trains that are roughly parallel to the ice-flow trend. The depressions that result from these cracks have been differentiated on the basis of their curvature (concave, convex) with respect to ice-flow direction, and described by terms such as chatter marks, crescentic gouges and sickle troughs. As fractures can be either concave or convex with respect to ice flow, they do not provide unequivocal evidence of sense of direction.

OTHER METHODS FOR DETERMINING ICE-FLOW DIRECTION

Information about ice-flow direction is preserved in the arrangement (dip and orientation) of elongate clasts in basal till, referred to as "till fabric". Most commonly, a majority

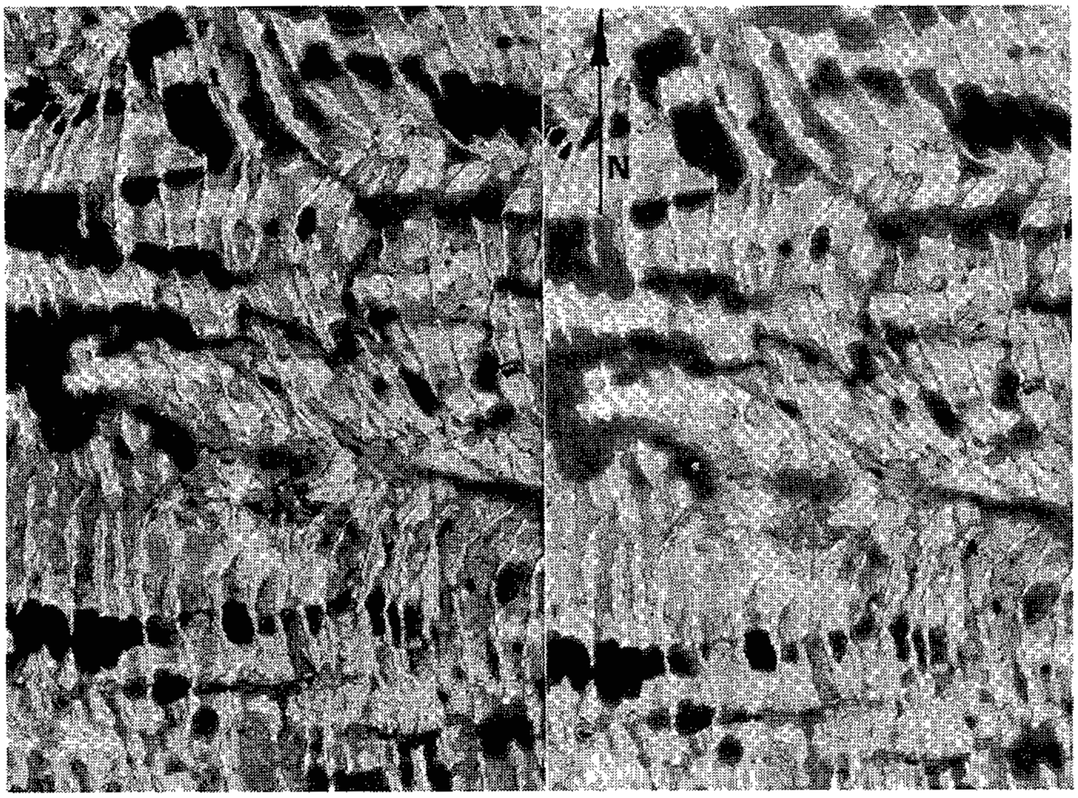

Photo 1-11. Stereo pair of small moraines (of the type known as de Geer moraines) near Rivière Koktak, Quebec; ridge crests are about 300 metres apart. Ridges were deposited along the slightly lobate margin of the ice sheet, thus arcuate moraines are concave with respect to ice-flow direction from east to west (Government of Canada air photos A14882: 90-91).

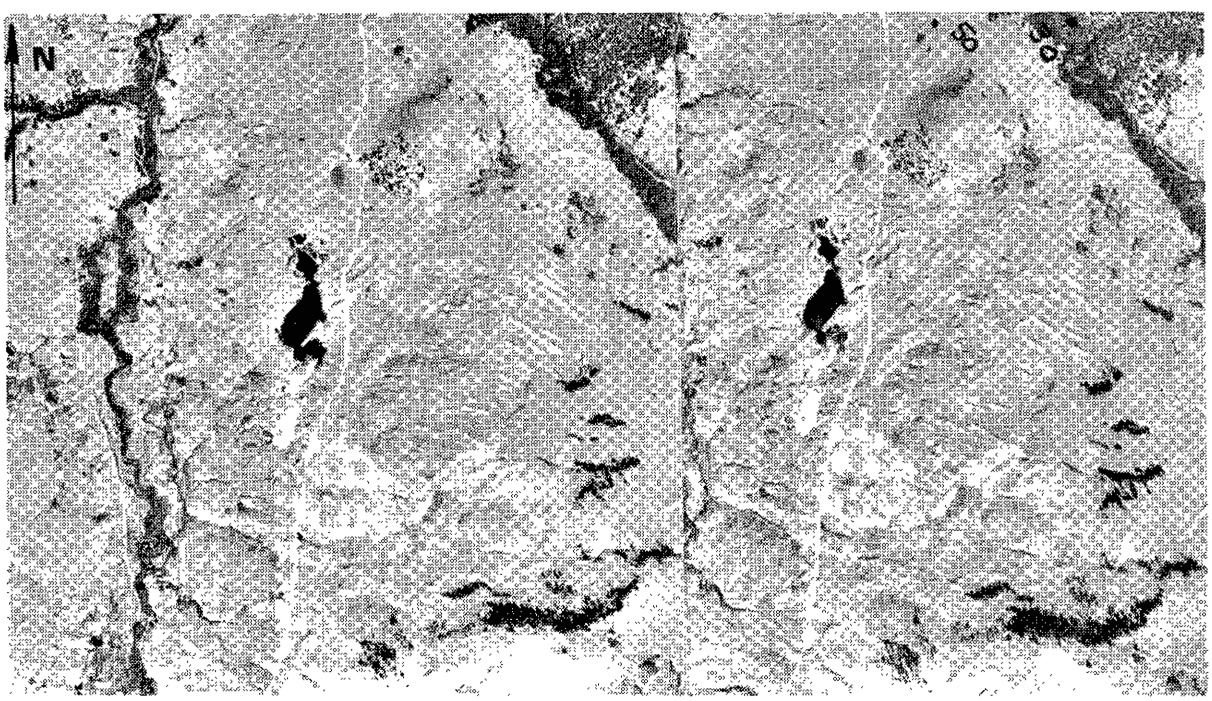

Photo 1-12. Stereo pair of small, transverse moraines in the Hat Creek valley, south-central British Columbia. Note faintly defined flutings on smooth, till-covered surfaces (Government of British Columbia air photos BC5213: 14-15).

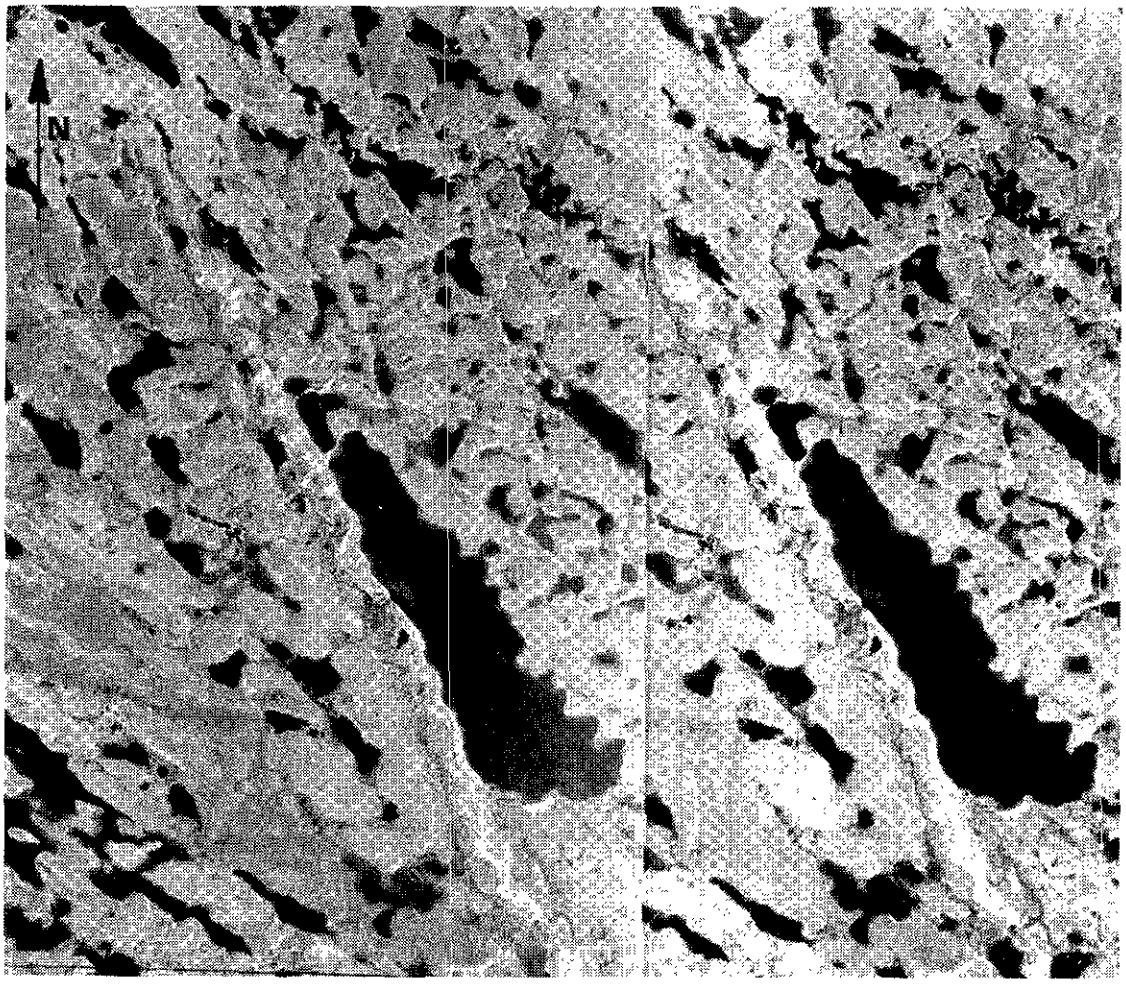

Photo 1-13. Stereo pair showing asymmetric small moraines (Rogen moraine) superimposed on low drumlinoid ridges deposited by southeastward-flowing ice. Note prominent and unusually straight esker (west of Rankin Inlet, N.W.T.; *see* also Aylesworth and Shilts, 1989) (Government of Canada air photos A14887: 2-3).

Photo 1-14. Small roches moutonnées in front of alpine glacier, Coast Mountains, British Columbia. Glacier flow from left to right.

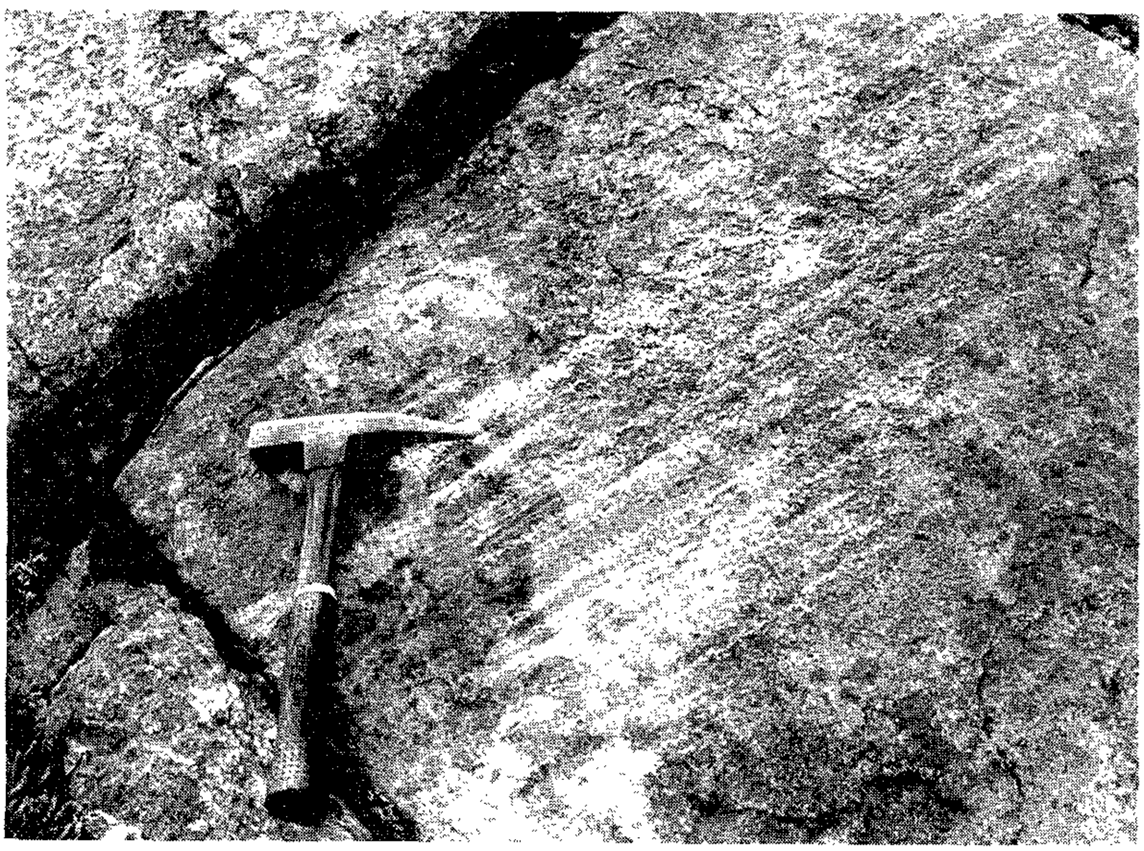

Photo 1-15. Glacial striations.

of clasts are aligned so that their long (a) axis is parallel to former ice flow and dips in the up-glacier direction. Thus analysis of data describing orientation and dip of a large number (50, 100) of elongate clasts may provide information about flow direction. Careful interpretation of till fabric data is necessary, however, because clast alignment is related to the mode of deformation and melting of glacier ice during till deposition. Less commonly than the case described above, most clasts may dip down-flow, or they may be aligned perpindicular to flow direction, or, in the case of melting of stagnant (stationary) ice, there may be no preferred alignment. A useful discussion of this topic is provided by Bolton (1971). The technique of till fabric analysis is described by Andrews (1971). Till fabrics have been widely used for drift exploration (*e.g.* Kerr and Bobrowsky, 1991).

In some circumstances, deformation of drift by overriding ice has resulted in "glaciotectonic structures" that can be used to reconstruct ice-flow directions. Such structures include faults, joints, clastic dikes, and ductile deformations. Glaciotectonic structures are not widespread, and description and analysis requires extensive exposure, such as a borrow pit (*c.f.* Broster and Clague, 1987). To date, the use of these features for drift exploration has been minor.

MELTWATER-FLOW DIRECTION INDICATORS AND THE ORIGIN OF GLACIOFLUVIAL DEPOSITS

Meltwater-flow directions can be interpreted from a variety of glaciofluvial landforms and sedimentological features, and some erosional landforms indicate possible sources of materials contained in landforms downstream.

LANDFORMS THAT INDICATE FORMER MELTWATER-FLOW DIRECTIONS

MELTWATER CHANNELS

The term "meltwater channel" refers to features ranging from gullies to small valleys and canyons that were eroded by glacial meltwaters. Meltwater channels can be broadly subdivided into three types: ice-marginal (or lateral) channels, subglacial channels, and proglacial channels. The following descriptions cover only the most basic and common characteristics of these channels.

Ice-marginal (lateral) channels developed where a meltwater stream occupied the shallow depression between glacier ice and an adjacent exposed hillside (Figure 1-5 and Photos 1-8 and 1-16). Thus a lateral channel is subparallel to contour lines, and has a gentle gradient in the direction of meltwater flow. In places, downwasting of an ice margin resulted in the development of several parallel channels at successively lower elevations. Ice marginal channels are best developed and preserved on moderately sloping hillsides that are blanketed by till: channels may be incised into the till by amounts ranging from a few metres to over 20 metres. Individual channels may continue for several kilometres, or may be discontinuous, or only isolated short segments may be present. Discontinuous channels with missing segments developed where alternate reaches of the stream were on the ice. Along some channels, there are strongly curving channel segments, sometimes deeply incised, marking places where the meltwater stream meanders impinged on the hillside (Photo 1-16).

The longitudinal gradient of an ice-marginal channel (or the linked segments of a discontinuous channel) indicates former meltwater-flow direction. As the gradient of a lateral channel also approximates that of the adjacent ice surface, meltwater channel configuration also provides information about contemporaneous ice-flow direction.

Subglacial meltwater channels are present where thermal and hydrologic conditions at the base of a glacier or ice sheet permitted the flow of meltwater in channels, and subsequent conditions favoured their preservation. Hydrostatic pressure at a glacier bed is capable of causing high flow velocities, leading to rapid erosion and development of incised channels, sometimes called "tunnel valleys" (Figure 1-5).

Subglacial meltwater channels can usually be recognized by some combination of the following features, although any one of these features may be lacking:

Distinctive morphology: subglacial channels tend to be relatively deep and narrow; many are flat floored, some are V-shaped in cross-section;

A clear relationship to other glacial (both ice and meltwater) features: commonly, subglacial channels are the continuation of other types of meltwater channels or subaerial channels, including eskers (*see* below); an esker may abruptly give way to an incised channel (or *vice versa*)

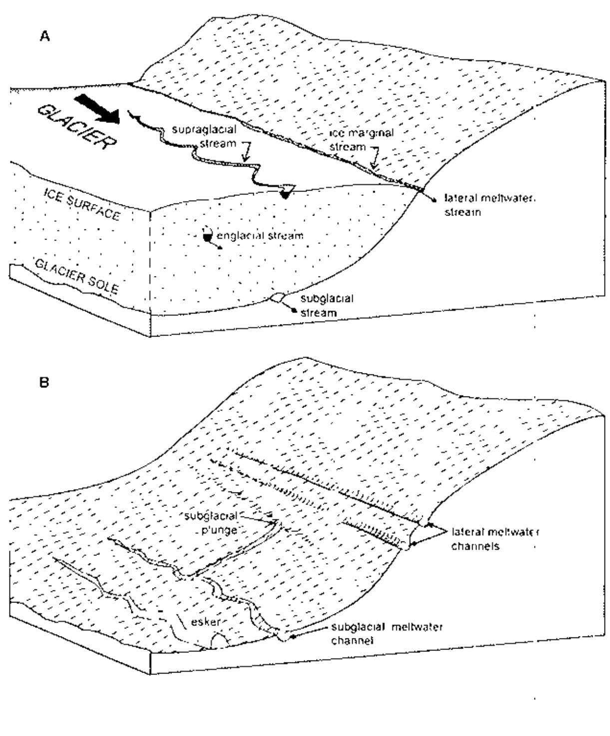

Figure 1-5. Block diagrams to illustrate lateral and subglacial meltwater channels: (A) landscape during deglaciation; (B) landscape after deglaciation.

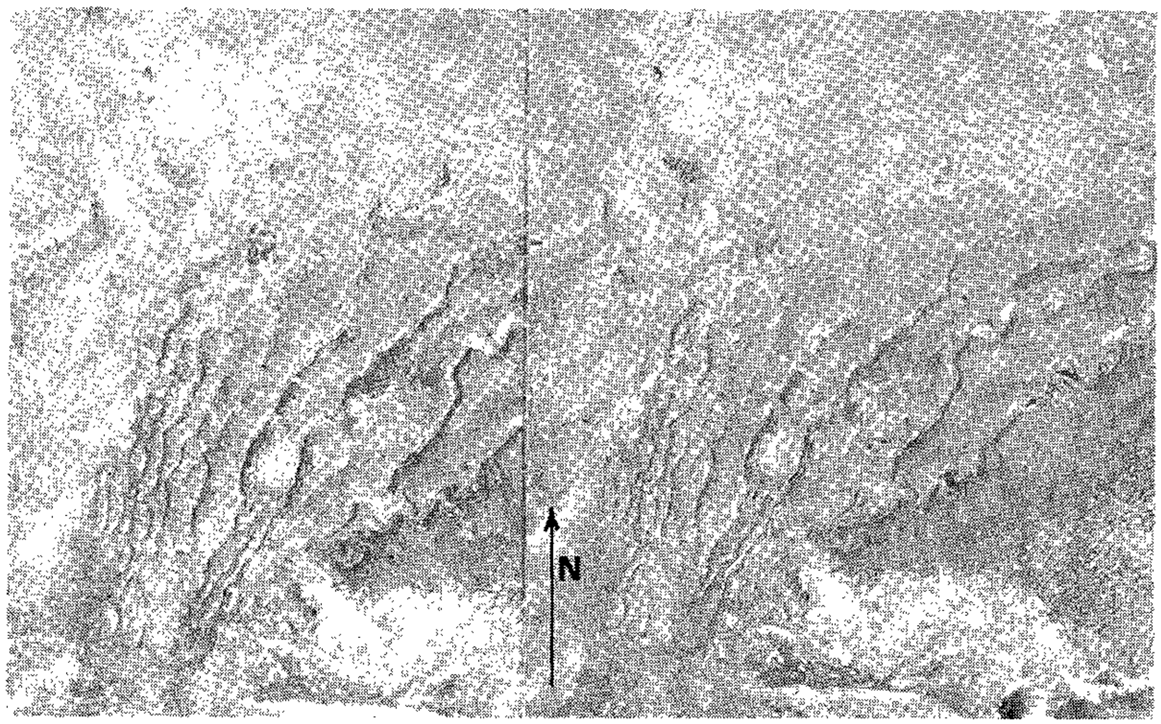

Photo 1-16. Stereo pair showing lateral meltwater channels on the Kawdy Plateau, northern British Columbia: channels have a gentle gradient down toward the northeast, suggesting a general northeastward movement of ice during deglaciation (Government of Canada air photos A19568: 17-18).

where subglacial hydrologic conditions dictated a change from deposition to erosion (or *vice versa*).

Distinctive spatial position and pattern: in regions where deglaciation occurred by downwasting of stagnant ice, shallow subaerial channels may suddenly change into deeply incised channels, or lateral channels may suddenly turn and plunge directly downslope; the point where the transition occurs marks the position of a former ice margin (Photo 1-14). An example of a distinctive pattern of subglacial drainage is illustrated by Photo 1-17).

The direction of flow of meltwater in individual subglacial channels is not always indicated by the present channel gradient because meltwater under hydrostatic pressure may have flowed uphill. In order to determine a flow direction, it is best to reconstruct the overall pattern of ice recession and meltwater flow from air photo interpretation of all late glacial features within a local area.

Proglacial meltwater channels carried water away from the ice. Although many such channels were in trunk valleys now occupied by modern streams, other channels were cut across drainage divides and represent remnants of drainage networks that were distinctly different from those of the present day.

Many meltwater channels are either not occupied by streams or now contain "misfit" streams (*i.e.*, streams that are very small in relation to the size of their valleys). These channels commonly contain small lakes and bogs in depressions that are kettles (holes left by melting ice-blocks) or depressions upstream from natural dams such as postglacial alluvial fans or landslides.

During the formation and incision of meltwater channels, bedrock or drift was eroded, transported by meltwater, and deposited as glaciofluvial sediments within landforms such as outwash plains and deltas. Thus reconstruction of meltwater flow paths may directly assist identification of the source of mineralized drift encountered in geochemical soil surveys.

ESKERS

Eskers are sinuous ridges of gravel and sand that mark the course of former meltwater tunnels in glacier ice (Figure 1-5, Photos 1-7 and 1-18). They are classed as "ice-contact glaciofluvial" landforms and are closely related to subglacial meltwater channels, as noted above. Eskers are the filled channels of englacial and subglacial streams. Because meltwater-flow direction was related to the hydraulic gradient within the ice, and because any esker may have been lowered from melting ice and superimposed onto the land surface, former flow directions cannot be unequivocally interpreted from present day topography. The flow directions of some short esker segments cannot be easily determined. As in the case of meltwater channels, reconstruction of the broader late-glacial drainage network may be necessary. Alternatively, because subglacial or englacial meltwater flow was generally in the same direction as ice flow, esker flow-direction can be inferred if ice-flow direction is known. For example, in areas of relatively subdued topography, such as

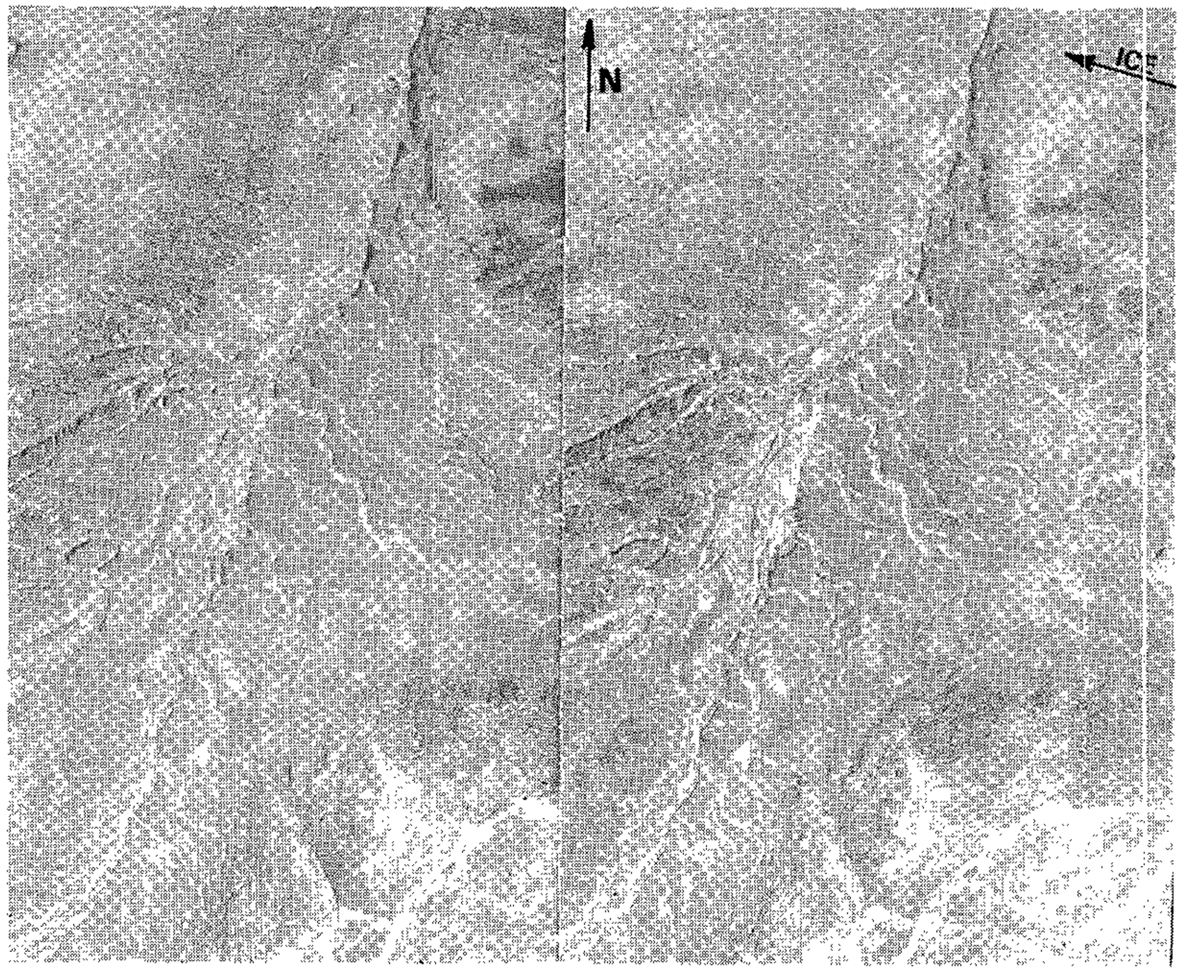

Photo 1-17. Stereo pair illustrating dendritic pattern of subglacial channels probably developed beneath stagnant ice; meltwater-flow direction is unrelated to ice-flow direction. Ice movement, as indicated by features immediately east of the field of view, was toward west-northwest (near Dease Lake, northern British Columbia) (Government of Canada air photos A19569: 57-58).

the Canadian Shield, the predominant alignment of major eskers closely parallels ice-flow direction (and can be used to approximate ice direction if other indicators are lacking or ambiguous).

OTHER ICE-CONTACT GLACIOFLUVIAL LANDFORMS

Other landforms resulting from meltwater deposition in contact with glacier ice, kames and kame terraces, are not particularly useful indicators of meltwater-flow direction, although flow directions can sometimes be inferred, and these landforms do provide information about the pattern and style of deglaciation that can be usefully applied to drift prospecting.

Kames are irregular mounds of sand and gravel commonly arranged in an apparently chaotic fashion. Kame terraces consist of sands and gravels deposited in the depression between the margin of a melting glacier and the adjacent hillside: they are the depositional equivalent of lateral meltwater channels. Flow direction may be inferred from the longitudinal gradient of a kame terrace *if* its surface is sufficiently continuous to convince the observer that the entire terrace developed more or less contemporaneously. The topography of kame terraces is commonly so irregular and fragmented that reconstructions of longitudinal gradients are not reliable.

LANDFORMS OF GLACIAL OUTWASH

Landforms that consist of sands and gravels deposited by glacial meltwater flowing away from the ice, commonly described as "proglacial" landforms and sediments, include outwash plains, terraces, fans, and deltas (Photo 1-18). The chief criteria for recognition of these landforms on air photos are:

- Morphology: Outwash plains are flat or very gently sloping; low terrace scarps and channel-like depressions may be recognizable. Kettles, enclosed depressions, either dry or with bogs or lakes, may be present, and the presence of kettles serves to distinguish outwash plains from younger fluvial plains. Outwash terraces are the tabular remnants

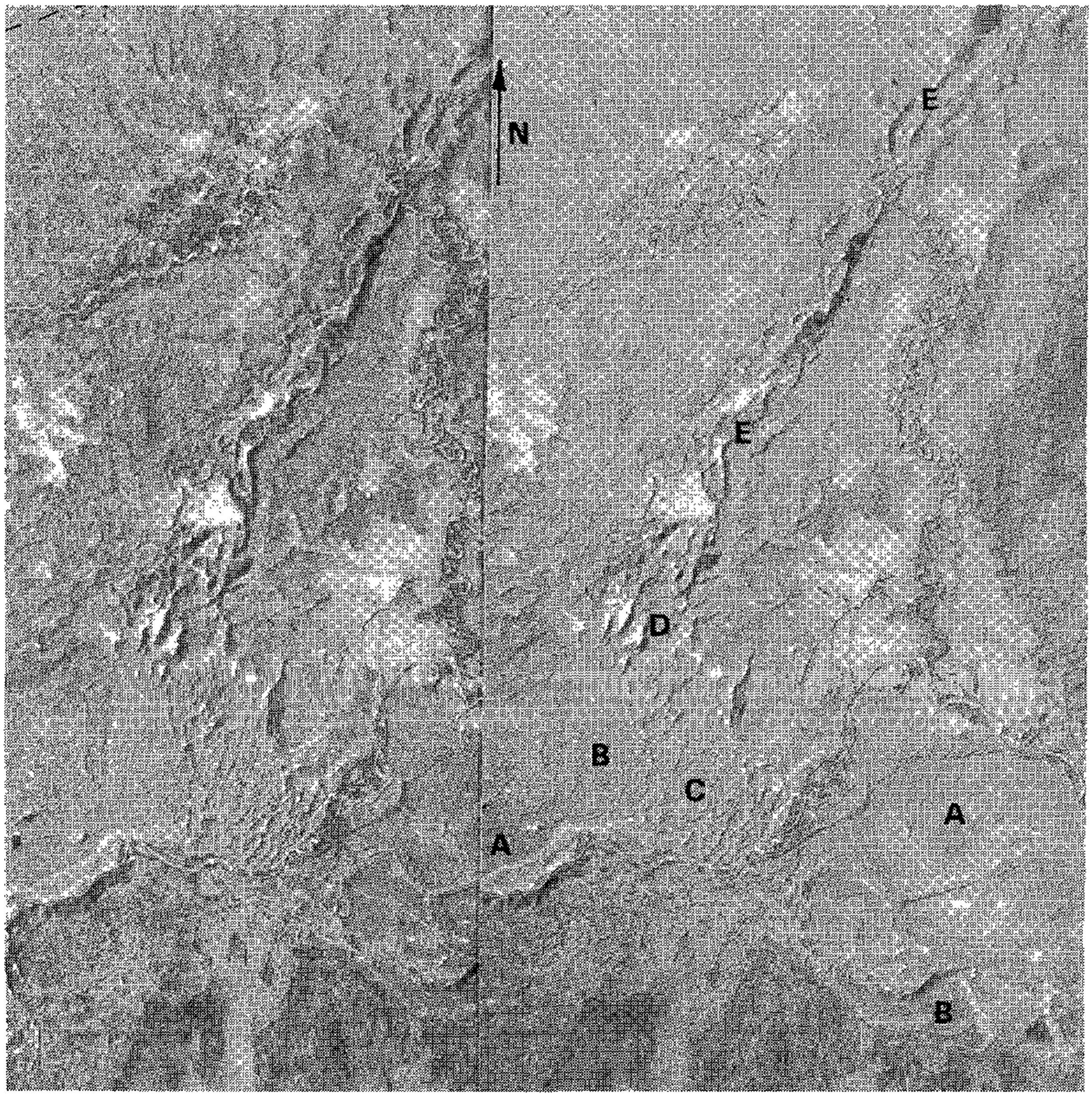

Photo 1-18. Stereo pair showing glaciofluvial outwash terraces (A), ice-contact (kame) deltas (B) and esker (E-E) near Dease Lake, northern British Columbia. Kettle depressions at D and collapse features (slumped ridges) at C indicate that deltaic sediments were deposited in contact with melting ice (Government of Canada air photos A19568: 20-21).

of outwash plains that have been dissected by stream erosion due to either the effects of meltwater or postglacial streams. Outwash fans are essentially alluvial fans; they are commonly located at the lower end of meltwater channels. Many outwash fans are graded to elevations above present valley floors (*i.e.* "raised fans) and have been dissected or terrace by postglacial streams. An outwash delta has a flat top (*i.e.* terrace) at the elevation of the lake into which it was deposited, and a steep foreset slope.

- Situation: Outwash deltas are located where meltwater streams flowed into lakes, typically where meltwater channels and tributary valleys emerge into a larger valley. Outwash deltas, fans and terraces may be difficult to differentiate, but for drift exploration, recognition of these outwash landforms as a group is sufficient for most purposes.
- Channel traces: The former channels (*i.e.* stream beds) of outwash landforms may be visible on air photos. Typically, they have a braided pattern, with channels splitting and rejoining around diamond-shaped bars.
- Postglacial modification: Outwash landforms are usually underlain by thick and uniform sands and gravels with high permeability. There is usually no surface runoff or gully erosion, other than the dissection noted above.

- Vegetation patterns: Soils are well drained and so vegetation is a uniform cover of whatever species are characteristic of relatively dry sites within the local vegetation zone. For example, in many parts of northern British Columbia, outwash surfaces are characterized by pine. Old channels may be less well drained and defined by contrasting vegetation.

Meltwater-flow directions can be reconstructed from channel patterns. Bars tend to point in the downstream direction, and bank erosion is concentrated slightly downstream from bends. If bars and channels are not visible on air photos, flow directions can be interpreted from the spatial arrangement of meltwater channels, outwash plains, fans, terraces and deltas, and local topography. Suface gradients on outwash landforms usually conform with flow direction, although in rare cases, gradients may have been reversed by glacio-isostatic tilting or by tectonic uplift.

SMALL MELTWATER-FLOW FEATURES

Meltwater-flow directions can be interpreted from a variety of sedimentary structures normally visible in exposures of stream-deposited sands and gravels. The most common structures are ripple marks, crossbedding, and imbrication. Flow directions indicated by these small features may vary considerably within a single body of sediment due to the commonly changing trends of channels on a braided outwash plain, and due to backwater effects which can result in structures locally dipping upstream. For a reliable assessment of flow direction, a number of measurements should be made at different sites and results plotted on rose diagrams or analyzed statistically.

PROBLEMS OF INTERPRETATION

Interpretation of flow direction data and its effective application to drift prospecting requires some basic understanding of the factors that controlled flow directions in ice and meltwater, and hence the variability of flow directions in space and time. In some regions, ice and meltwater-flow directions varied considerably -- flow may even have reversed direction -- in the course of the last glaciation.

ICE-FLOW DIRECTION

In the broadest view, flow paths within an ice sheet are outward from accumulation zones toward the ice margin. In the Cordillera of western Canada, accumulation zones were located in high mountains with heavy snowfall (these areas are approximated by the distribution of present-day glaciers). In the case of the Laurentide ice sheet, ice-flowed radially outward from accumulation zones that were located to the east and west of Hudson Bay. These generalized flow patterns are indicated on maps such as Prest's 1983 reconstruction of flow lines for the Late Wisconsinan ice sheets (Prest, 1984). These "regional" ice-flow directions can be used to check whether flow directions interpreted from air photos or from ground features are reasonable within the broader context.

More specifically, the physics of ice flow dictates that ice flows in a direction that is determined by the surface slope of the ice sheet. Thus flow lines are parallel to lines of steepest gradient and perpendicular to the contours of the ice surface. This explains the motion of an ice sheet that rested on an essentially horizontal surface, an explanation that eluded early glaciologists and, for several decades, retarded the general acceptance of the glacial theory. In a horizontally based ice sheet, ice flows from the region where the ice is thickest (the accumulation zone) toward the margins where the ice is thinnest and the surface is low. The Laurentide ice sheet fits this model.

In marked contrast, the Cordilleran ice sheet covered the irregular and rugged landscape of the western mountains and plateaus. When it was thickest and most extensive, most recently between about 18 000 and 15 000 years ago, ice buried all but the highest peaks of the mountain ranges. Flow outward from the accumulation zones was in accordance with the surface slope of the ice sheet and unrelated to buried subglacial topography. Ice flowed along only those valleys that were aligned in the same direction as the ice surface gradient. Ice flowed across transverse valleys, that is, valleys aligned parallel to the contours of the ice surface. The details of glacier motion in transverse valleys during the glacial maximum have not yet been worked out, but it is possible that significant motion was restricted to the upper part of the ice, that is, ice above the level of the subglacial drainage divides. Thus ice within transverse valleys may have been stationary during the glacial maximum, although valley glaciers may have followed local topography during the early and late stages of glaciation. The changing controls on ice flow during the several phases of a glaciation are discussed in detail by Davis and Mathews (1944) and Kerr (1936).

This concept, and its significance to drift prospecting, are illustrated by work reported by Alley and Chatwin (1979) from the mountains of southwestern Vancouver Island. They found that ridge-top drift includes material transported from the mountains of the mainland (the Coast Mountains) by southwesterly flowing ice, but drift on valley floors is derived entirely from within-valley sources. This implies that ridge-top materials relate to ice-flow at the glacial maximum, whereas valley-floor materials relate to down valley flow. Successful up-flow tracing of dispersal trains requires understanding of *changes* in ice-flow directions.

In general, ice-flow directions during the waxing and waning of an ice sheet were commonly dissimilar to those of the glacial maximum This was particularly true for the early and late stages of the Cordilleran ice sheet when drainage divides were exposed and ice-surface gradients, and hence flow directions, were in accordance with local topography. At the beginning of a glaciation, flow directions of expanding cirque and valley glaciers are completely controlled by local topography. As ice thickness increases, glaciers advance and thicken until divides are overtopped and flow-directions gradually shift as the control exerted by topographic features declines. The process of ice thickening and changing topographic control within the context of the Cordilleran ice sheet was discussed in detail by Davis and Mathews (1944) and summarized by Clague (1989).

During recession of the Cordilleran ice sheet, the emergence of drainage divides from beneath the thinning ice resulted in gradually increasing topographic control. Within the mountains (the former accumulation zones), the style of glacial recession may have been a mirror image of the glacier advance. Glaciers receded by frontal recession of actively flowing ice -- melting exceeded glacier flow and glacier snouts retreated up-valley -- until glaciers were restricted to the regions that they occupy today. At greater distances from the past and present accumulation zones, ice sheet decay over large areas was dominated by downwasting and ice stagnation (melting of stationary masses of ice), rather than frontal recession. A full description of downwasting and stagnation within the context of the interior plateaus of the Cordillera is provided by Fulton (1967; 1975).

Some glacial geologists have suggested that during the climax of the last glaciation, the configuration of the Cordilleran ice sheet was similar to that of the present Greenland ice cap (*e.g.* Fulton, 1975). They believe that a vast ice dome developed over the central plateaus of the Cordillera. Ice flow from this dome would have been radially outward, in accordance with its surface slope. If this was the case, sites on the plateau could have experienced complete reversal of ice-flow direction. For example, along the western side of the Interior Plateau, early eastward ice flow off the Coast Mountains would have been later replaced by westward outflow from the ice dome. Ice-flow direction indicators suggest that the concept of an ice dome is more likely to be correct for northern than for southern British Columbia (Ryder and Maynard, 1991). Forrest Kerr (1934, 1936) interpreted the distribution of erratics on the Stikine Plateau as an indicator of such flow reversal, and indeed, strongly abraded rock ridges along the Stikine valley just east of the Coast Mountains show no preferred sense of direction. Local flow reversals may well have occurred at many places along the eastern side of Coast Mountains.

During the waning of the Laurentide ice sheet, the retreating ice margin was made up of a series of semi-independent ice lobes (*e.g.* Dyke and Prest, 1986). Within each receding lobe, flow-directions radiated out from the lobe axis toward its margins, and thus differed from flow-directions in effect prior to ice recession (Figure 1-4). Also, periods of recession were commonly followed by resurgence of individual lobes. The configuration of a readvancing lobe was commonly dissimilar to that of the same lobe at an earlier point in time. Thus ice-flow directions changed with time. During recession, parts of the Laurentide ice sheet stagnated and downwasted *in situ*: this style of deglaciation was particularly prevalent on the Prairies.

These concepts have great significance for drift prospecting because they indicate that flow directions determined for any one glacial feature may not apply to all features or surficial materials within a local area. Evidence of changing flow directions during accumulation of basal till has been recorded from many areas, (*e.g.* Clague, 1975). Deposition of till by ice flowing in one direction, and subsequent reworking of that till by ice from another quarter was described by Shaw *et al.* (1989). Multiple flow directions are commonly recorded by criss-crossing striations on bedrock, and directions indicated by striations may be discordant with the direction preserved in the fabric of overlying till. Glacial deposits associated with stagnant ice are typically chaotically arranged ablation (supraglacial) tills, kames and kame terraces, and contain little or no information about ice-flow directions.

An excellent example of the effect of changing ice-flow directions on the shape and extent of dispersal trains is provided by Klassen and Thompson, (1989) from the eastern sector of the Laurentide ice sheet in central Labrador. As a result of numerous measurements of striations, bedrock streamlined forms and the distribution of glacially transported boulders over a wide area, they identified seven phases of ice-flow (Figure 1- 6). Significantly, they note that ice-flow directions cannot be reliably interpreted from measurement of lineations at any single site. Directions changed in accordance with shifts in the position of centres of outflow and changes in the control exerted by topographic features during the last glaciation. Glacial dispersal trains range from narrow ribbons developed where shifts in ice-flow direction were relatively minor, to broad fans developed as a result of transport during changes in ice-flow direction through as much as 120°. Clearly, establishment of regional patterns of ice-flow direction is necessary prior to interpretation of dispersal trains.

In general, where drift is thin and ice-flow direction is confirmed by more than one type of evidence, including the established regional pattern, then the significance to drift prospecting of changing ice-flow directions may be minor. However, where ambiguous indicators are found, former flow directions may be significant and complex.

MELTWATER-FLOW DIRECTION

Meltwater-flow directions are inherently less variable that those of ice because in any one area, most meltwater channels and glaciofluvial deposits were formed during the relatively short time span of deglaciation. Flow directions of sub- and en-glacial meltwater, however, may be dissimi-

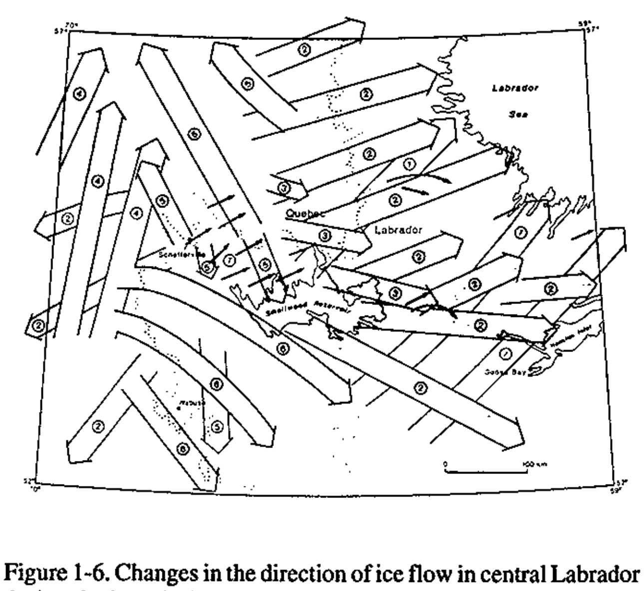

Figure 1-6. Changes in the direction of ice flow in central Labrador during the last glaciation (from Klassen and Thompson, 1989).

lar to that of ice-marginal or proglacial streams, and so this topic is worthy of some consideration.

Meltwater was present inside only those parts of ice sheets and glaciers that were "warm", that is, the temperature of the ice was at the pressure melting point (close to 0°C). In such a case, a water table would have been present, and flow directions of meltwater through channels in the saturated zone would have been in accordance with local hydraulic gradients. Dependent upon the configuration of the glacier's plumbing system, meltwater may have moved upward as well as down, although flow would generally be toward the glacier terminus. If a glacier terminated in a lake or the ocean, meltwater flow under high hydrostatic pressure may have occurred within the glacier but below the surface of the standing water. Subaqueous outwash could thus be deposited below lake or sea level. Above the water table in a glacier, meltwater flow was generally down-glacier, with local deviations determined by the morphology of en-glacial and subglacial channels and the glacier surface.

In the case of cold ice (temperature below pressure melting point), meltwater could exist only on the glacier surface and flow was in accord with surface morphology.

In general, meltwater in, on or under a glacier tended to flow in a direction that was parallel to the ice-flow direction. For example, large eskers in low-relief terrain are usually parallel to ice flow. Deviations occur where sub-glacial and en-glacial flow was affected by subglacial topography, and in stationary, stagnant ice. In the Cordillera, where ice-flow directions changed during deglaciation due to the control of emergent topography, meltwater directions changed in concert with those of the ice.

Flow directions in proglacial outwash were relatively constant, but changes may have resulted from changes in the position of meltwater streams brought about by ice recession, or from stream channels shifting due to differential build up of the outwash body.

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DRIFT EXPLORATION POTENTIAL MAPS DERIVED FROM TERRAIN GEOLOGY MAPS

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INTRODUCTION

Traditional surficial and terrain geology maps inherently contain and convey a wealth of information. Unfortunately, the scale, style, type and structure of these maps varies significantly as a function of user objectives and needs, study area size and location, availability of existing supplementary data as well as the conventional restrictions of time, funding and field access (*see* Church *et al.*, 1988). Another limiting factor, less commonly cited, is the influence of production format (*e.g.* report, hard copy colour *versus* black and white maps, digital file and so on). In fact, one recent compilation of surficial maps in British Columbia showed that more than 2000 maps are currently available for many parts of the province, scales range from 1:1000 to 1: 1 000 000, and the documented variations include about 22 types of surficial maps (Bobrowsky *et al.*, 1992). At an average cost of $50 000 per map (1994 dollars) to generate a terrain map, including salaries, field expenses and production costs, this database of 2000 maps may represent a $100 million investment.

The utility of surficial maps is not readily apparent to the non-specialist, especially as the information portrayed (relatively complex map symbols) does not often follow a set guideline or standard. Although the Province of British Columbia is active in the process of developing terrain geology mapping standards (Task Group on Terrain Geology, in preparation) the existing database of surficial maps will remain in their original diverse formats. Quaternary geologists have, nevertheless, shown that surficial maps serve many purposes ranging from waste management and hazard zonation to land-use classification and aggregate exploration (Varnes, 1974; De Mülder, 1989; Bobrowsky and Levson, 1993). The aim of this paper is to review the basic elements of all terrain and surficial geology maps, introduce the concept of derivative maps, and detail one type of derivative map termed a Drift Exploration Potential (DEP) map which may prove beneficial to the exploration community.

TERRAIN GEOLOGY BACKGROUND

Terrain geology and surficial geology are often used interchangeably for maps which portray information about unconsolidated deposits. One estimate suggests that about 70% of the terrestrial surface of the earth is covered by unconsolidated sediments (Goldberg *et al.*, 1965). A similar estimate (~75%) for surficial sediment cover can be applied to British Columbia, with the remaining 25% as generally representing bedrock, water and ice. This cover of sediment may mask underlying mineralized bedrock which makes the process of exploration and discovery a difficult task. However, the principles of surficial geology can be applied to make it easier to deal with drift-covered regions and increase the success of mineral exploration (Gartner, 1981). Moreover, interpretive DEP maps can be derived from basic surficial geology maps to assist in this process.

As noted by Mitchell (1991), terrain geology is nothing more than a surface expression of deeper bedrock geology. This relationship between surficial sediments and underlying bedrock is complex but interpretable, because the creation of terrain maps is based on knowledge of the association between landforms, sediments and geologic history (Eriksson, 1992). One of the first published accounts outlining the use terrain mapping for mineral exploration purposes in British Columbia was that of Maynard (1989). A typical terrain map shows a number of irregularly shaped areas termed "terrain polygons" which represent deposits of a similar nature (Task Group on Terrain Geology, in preparation). In British Columbia, the materials constituting a terrain polygon are classified according to the following criteria: type of surficial material (genesis), material texture, landform or material thickness and modifying processes (Howes and Kenk, 1988; Figure 2-1). Each polygon therefore contains information about the defining criteria listed above, and DEP maps capitalize on these data.

DRIFT EXPLORATION BACKGROUND

One of the keys to a sound mineral exploration program is a mineral deposit model. This model generally incorporates a set of geologic conditions that include rock types and associations, structural setting and features, as well as mineralogy. Similarly, an effective drift exploration program needs a surficial geology model that provides a predictive capability for sediment transport direction, relative transport distance from bedrock source, thickness of overburden and the probable integrity of samples. A relative ranking of the confidence with which samples from various sediment localities can be traced back to their bedrock source would also be useful. In this manner, a sampling program can be designed to economize by only sampling highly ranked sites. Regardless of the type of terrain sampled (high to low potential), however, it is important that the samples analyzed are of similar genesis, so that similar transport paths can be expected. Indeed, the consequences of facies vari-

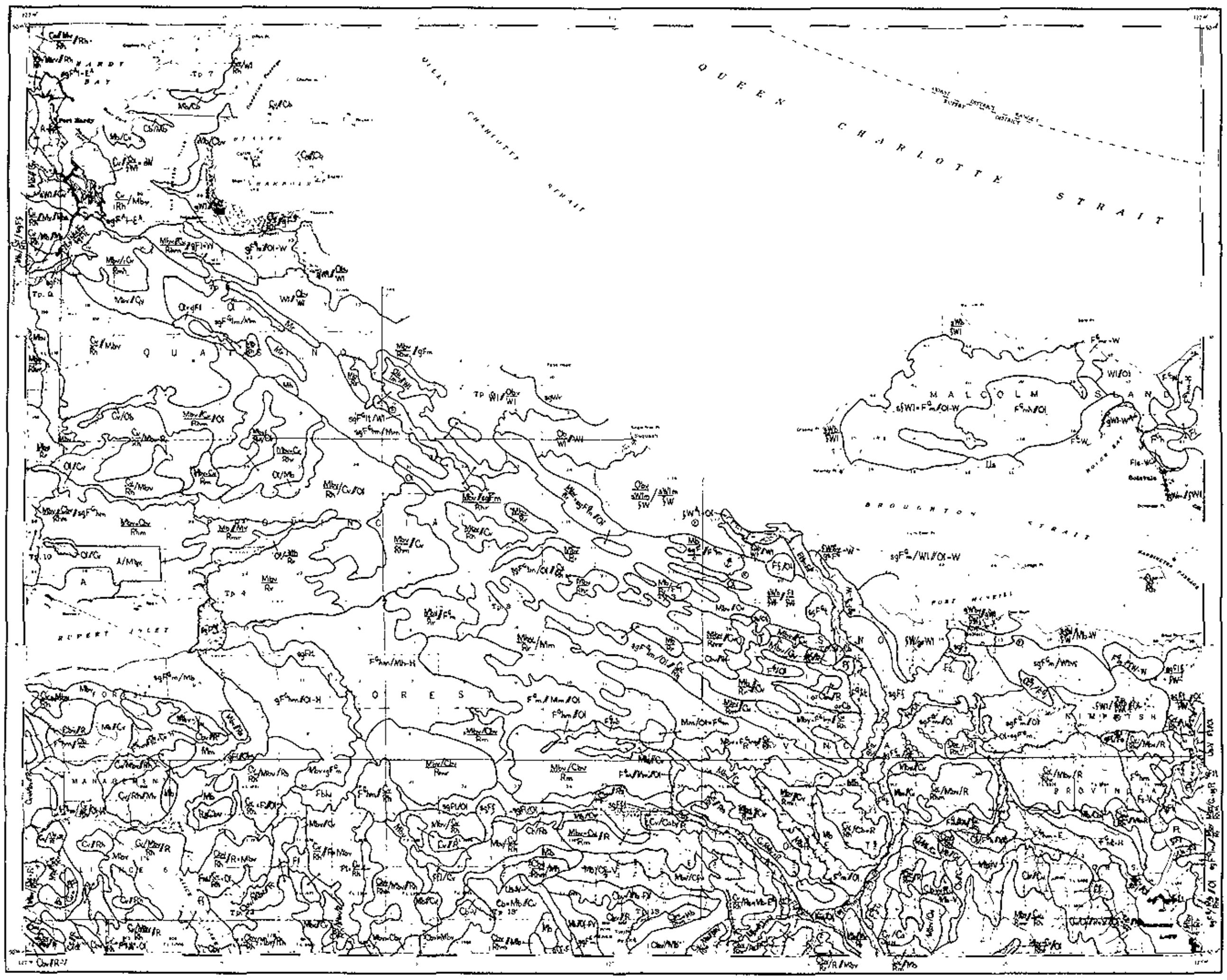

Figure 2-1. Terrain geology map of the Port McNeill area (NTS 92L/11), northern Vancouver Island.

ations to exploration was recently illustrated for several types of moraine by Aario and Peuraniemi (1992).

GENERAL CONCEPTS

The following discussion and all interpretations for sediment transport and deposition relate to sediment that has been transported as rock detritus. The resulting DEP map relates to clastic dispersal and is not intended for use in the interpretation of secondary hydromorphic anomalies.

The five main sets of processes of sediment transport and deposition important in this type of study are related to flowing and standing water as well as glacial ice, slopes and wind. Differences in sediment derivation and transport paths lead to different levels of potential for tracing geochemical anomalies and mineralized clasts back to their bedrock source. Some types of sediment are, therefore, less economical to sample because the likelihood of sourcing the parent bedrock is very low (Salminen, 1992).

The interpretation of the genesis of sediment is based on two major aspects: the surface geomorphology, particularly where surficial features are observed on aerial photographs and supported by ground verification, and the sedimentology of the material exposed at a site. These represent two different sets of data that can often be examined independently to arrive at corroborating genetic interpretations, thus increasing the reliability of the interpretation. For our purposes, this is most applicable to the genesis of glacial sediment.

Stratigraphic position of deposits provides considerable information on the sedimentologic history. In general, for thick till deposits, the upper till sediments are farther traveled than the lower sediments, whereas in the case of sediment veneers, it is assumed that the deposits are all shorter traveled. Since it is the near-surface sediment that is normally sampled in drift exploration, sediment thickness is an important criterion in the evaluation process.

One other factor which is important for ranking the potential of sediment for drift studies relates to transport-deposit processes. In glaciated terrain different modes of transport lead to different degrees of differentiation from a bedrock source (Shilts, 1975). Single cycles of erosion, transportation and deposition, such as weathering of bedrock and soil creep to form colluvium or glacier scouring and deposition to form till, are good examples of first derivative products (Shilts, 1993). However, melting of glacier ice and concomitant sediment redeposition by meltwater adds a second phase to the material. In this case, the resultant glaciofluvial deposits can be considered to be second derivative products. Further reworking of the sediment by rivers and subsequent deposition results in third derivative products. Additional reworking, including eolian and lacustrine processes, can result in fourth derivative products (Shilts, 1993). Each phase of reworking compounds the difficulty of interpreting the bedrock source. Sediments and clasts which have undergone multiple cycles of erosion, transportation and deposition progressively diminish in their ability to provide information on the parent bedrock (Shilts, 1991). As a result, the hierarchy for preferred sample media in drift exploration studies parallels the natural order of derivative products. In any area, lower order derivatives take preference over subsequent products.

GLACIAL DEPOSITS

The sediment that is deposited by glacial ice is normally referred to as 'till'. Till is typically an unsorted sediment that is composed of material that ranges from pebble to boulder-sized clasts, all supported in a finer grained matrix (Dreimanis, 1990). Deposits of till may be associated with or support a minor component of water-deposited sediment such as sand or gravel. Transport position of sediment in glaciers is particularly important because it can be used to infer distance of transport for various types of till. Figure 2-2 shows the three major positions of sediment transport in a glacier. In this discussion we assume that present-day glacial deposits retain an imprint of their transport history, thereby reflecting their relative paleo-position during glacier transport. Sediment that is carried and deposited near the base of a glacier is referred to as 'basal till'. Material transported above the basal debris-rich zone but well below the glacier surface is 'englacial' and if carried on or near the glacier's surface is referred to as 'supraglacial' (Dreimanis, 1989). The interpretation of transport position is important because it can be used to infer the relative distance of travel for various types of glacial sediment (Figure 2-3). Sediment deposited from a particular transport position may produce or be associated with a distinctive landform provided that there has been little post-depositional modification (Ashley *et al.*, 1985). Generally, the farther that sediment is carried by a glacier, the higher it rises in the ice to a maximum that is normally well below the surface (Figure 2-3). Exceptions to this include englacial incorporation as ice flows over and around promontories or high-relief topographic features (Figure 2-4). Other exceptions may occur where ice flows up an incline occasionally causing material to be thrust higher into the ice, or down a steep incline where material can be plucked into an englacial position from the lee side of the incline. However, unless there is evidence to the contrary, one normally assumes that the thinner a deposit of till, the more likely that the sediments at the base were locally derived.

GLACIOFLUVIAL AND FLUVIAL DEPOSITS

Glaciofluvial features may give an indication of the direction of sediment transport. For instance, eskers are formed by water flow controlled by a glacier and generally flow parallel to the glacier, often crossing modern topography such as valleys and ridge tops. Outwash plains are deposited by water flow controlled by topography beyond an ice margin. The paleo-flow direction of these second derivative deposits can be determined from crossbedding, pebble fabrics and bedform relationships and then traced upstream along local drainage from major to minor valleys (Lilli-

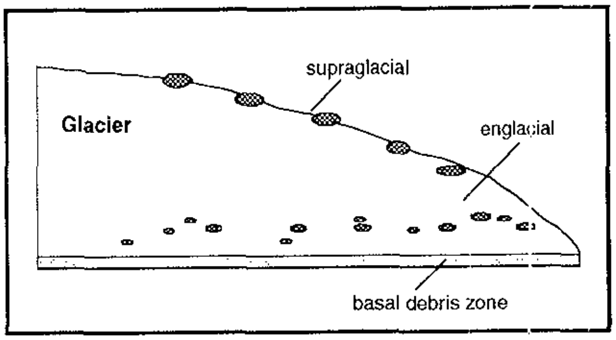

Figure 2-2. Schematic cross-section through a typical glacier showing three positions of sediment transport: basal, englacial and supraglacial.

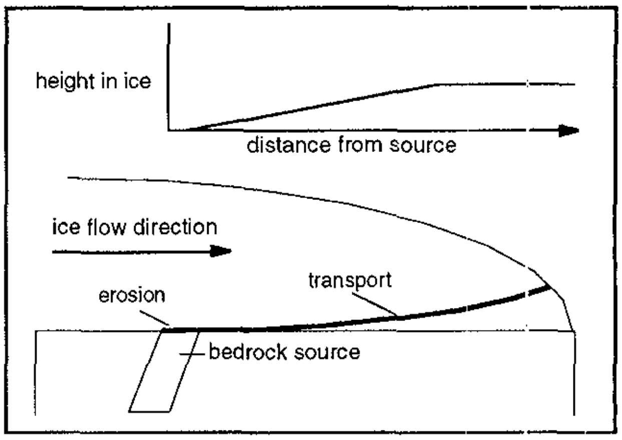

Figure 2-3. Schematic cross-section through a typical glacier showing the method of incorporating basal debris into the ice. Upper part of figure illustrates theoretical boundary for sediment uplift in a flowing glacier.

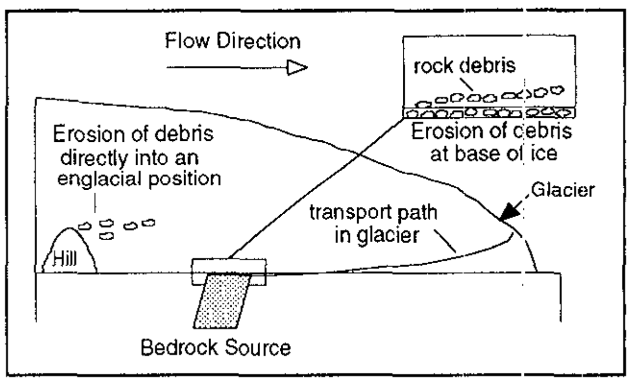

Figure 2-4. Schematic cross-section through a typical glacier shows sediment transport path in ice and an example of englacial incorporation of eroded debris as ice passes over a topographic high.

eskold, 1990). Although, fluvial deposits (*e.g.* terrace, fan) are third derivative products, they are ranked with glaciofluvial sediments because the process of transport and deposition is also flowing water. The sediment source for these waterlain deposits could be rock, till or other waterlain sediments, all of which may have had different source directions.

SLOPE PROCESS DEPOSITS

It is important to determine whether slope deposits are derived directly from upslope rock or sediment. Colluvium derived from bedrock is a first derivative product, whereas colluviated till is a second derivative product. Documenting the derivation of accumulations related to slope processes influences the ease of interpreting geochemical and pebble results. In general, colluvial sediments, whether veneers or blankets, rank high in their usefulness for drift prospecting studies.

OTHER PROCESS DEPOSITS

The deposits of glaciolacustrine, lacustrine, glaciomarine, marine, eolian and organic processes are grouped together under "other processes" and have very low potential for drift exploration sampling. The exception to this rule occurs in the use of lake sediments for reconnaissance survey work, where it can be shown that the sediments are derived locally from the contiguous slopes (*see* Cook, 1994, this volume).

DRIFT EXPLORATION POTENTIAL MAPS

A DEP map categorizes surficial sediments into levels of potential importance for drift exploration sampling before a field program is undertaken. In this style of map, drift exploration is assumed to include bulk sediment sampling for geochemical analysis and pebble/boulder collection for lithological provenance studies. The potential for obtaining primary, reliable, useful and easily interpretable results from either of the two sampling approaches can be ranked from very high to very low, according to five categories. The utility of this map is restricted to clastic glacial dispersal and is not applicable to the interpretation of hydromorphic anomalies.

The purpose of a DEP map is to assist explorationists to design sampling programs. The map should be consulted before fieldwork begins, as it identifies types of surficial sediment and categorizes each according to its potential for drift-related sampling. Potential refers to the suitability of the surficial deposits for geochemical analysis and clast lithology study. Potential also relates to the proximity of the sample to parent material or bedrock as well as the ease of interpretation of the data; it does not refer to the likelihood of encountering mineralization. The map provides cost-effective information as areas which contain poor or unreliable deposits can be avoided during sampling. Similarly, areas of exploration interest can be prioritized according to the five categories and sampled sequentially as results from higher potential categories are evaluated first.

Several factors are used in the characterization of surficial deposits including terrain unit, sediment thickness, transport distance (proximity to bedrock source), diagenesis (history of deposit from erosion to deposition), number of erosive/depositional cycles, and ease of interpretation of analytical results. Geological data characterizing paleoflow are also documented and illustrated to meet the purpose of the map. Collectively, these inter-related factors can be used to categorize all surficial sediments identified on a traditional terrain map to generate a DEP map. This map can then be used to develop a sampling strategy for various levels of drift prospecting. Specific bulk and clast sampling designs can be structured to fit changing project objectives which may rely on data comparisons between different facies. Analytical results can be confidently interpreted and further action can be taken.

DETAILS

As discussed in the preceding sections, several factors must be considered in the assessment of sediment potential for drift exploration study. Collectively, all the variables can be summarized in a Drift Exploration Potential Matrix (Figure 2-5).

Very high potential (I) deposits include bedrock and colluvial veneers or morainal veneers which directly overlie bedrock. Such deposits are usually less than a metre in thickness and are derived from bedrock within a few tens of metres. As a first derivative product, the history of the sediment and clasts since erosion is easily interpreted. Similarly, geochemical and pebble results are easy to interpret. The second category of high potential (II) deposits to sample in order of preference consist of colluvial blankets over bedrock, col-

DRIFT EXPLORATION POTENTIAL MATRIX

	I	II	III	IV	V
TERRAIN UNITS	R Cv/R Mv/R	Cb/R Cv/M Mb	Cbv Mbv Combined	FG F Combined	L, LG, E, O, A, W, WG Combined
TOTAL SEDIMENT THICKNESS	< 1 m	> 1 m	> 10 m	> 10 m	> 10 m
TRANSPORT DISTANCE	generally 10s metres	10s to 100s metres	10s to 100s metres	usually 100s metres but also 10s metres	often 100s to 1000s but also 10s metres
POST-EROSIVE DIAGENETIC INTERPRET	Very Easy	Easy	Moderate	Difficult	Very Difficult
DERIVATIVE PHASE	1st	1st	1st 2nd	2nd 3rd	3rd 4th
GEOCHEM/ PEBBLE SAMPLING INTERPRET	Very Easy	Easy	Moderate	Difficult	Very Difficult

Figure 2-5. Drift exploration potential matrix shows the relationship between the five drift potential categories, types of terrain units, generalized sediment thickness, estimated sediment transport distances, number of derivative phases, and interpretation capabilities for genetic history and sample results.

luvial veneers over moraine and morainal blankets. Colluvial blankets over bedrock differ from veneers over bedrock only in total thickness of the deposit (1 m but rarely 3 m) as distance to bedrock source is still in the order of tens of metres. Colluvial veneers over moraine are usually thin, so that the underlying diamicton can be sampled as a first derivative product. Transport distance is often in the order of tens of metres. Finally, morainal blankets, which normally consist of supraglacial and basal till facies, are good sediments to sample. Although sediment thickness often exceeds a metre, bedrock source is close, usually in the order of tens or hundreds of metres. As first derivative products, the transport history since erosion for these three sediment associations is easily interpreted, as are geochemical and clast analysis results.

Terrain units of moderate potential (III) include some first and second derivative products which consist of complex associations of colluvium and morainal sediments. Deposits are moderately thick, often in excess of 10 metres and distance to bedrock source can be tens to hundreds of metres. Interpretation of both the history of transportation and analytical results is generally moderately easy. The fourth category of low potential (IV) deposits consists of glaciofluvial and fluvial sediments. These second and third derivative products often overlie till or bedrock and are variable in thickness. The added phase of transportation increases distance to bedrock source so that transportation in the order of hundreds of metres is common although tens of metres is possible. Interpretation of the sediment history since initial bedrock erosion is difficult as is the interpretation of the analytical results. The final category represents the very low potential deposits (V) consisting of glaciolacustrine, glaciomarine, lacustrine, marine, eolian, organic and anthropogenic deposits. As these terrain units often overlie complex sequences of other sediments, total deposit thickness can be in excess of ten metres. The third and fourth derivative products in this category have very complex transport histories and, as such, distance to bedrock source can be several kilometres, although short pathways as little as tens to hundreds of metres are encountered. In many cases analytical results are very difficult to interpret.

Drift Exploration Potential maps contain fewer polygons and simpler map unit symbols than their corresponding surficial geology maps. They combine aerial photograph interpretation, field observations, sample analyses and sediment deposit theory to provide a predictive tool for the relative confidence with which samples from different map units can be traced to their bedrock source. Map units are ranked to provide the best possible opportunity for the success of a sampling program to find the origin of a geochemical anomaly or exotic boulder train.

CASE STUDY

Quaternary geological investigations were undertaken in NTS sheets 92L/6 (Alice Lake) and 92L/11 (Port McNeill) as part of an integrated resource assessment program on northern Vancouver Island (Panteleyev *et al.*, 1994; Figure 2-6). The objective of the Quaternary geology aspects of the project was to provide surficial geology data

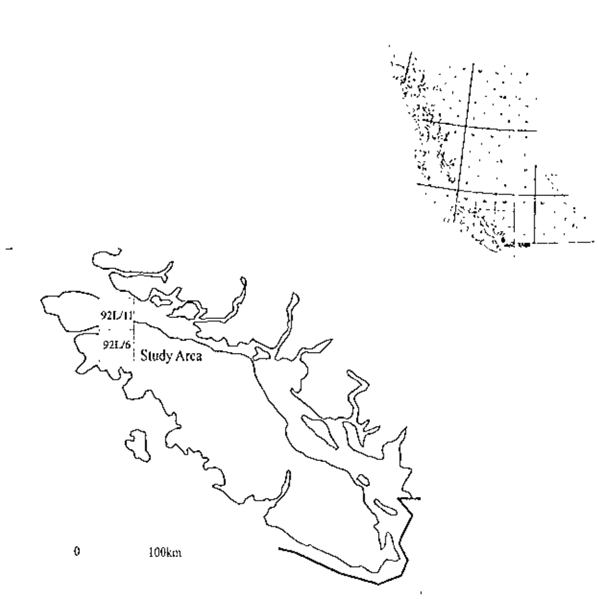

Figure 2-6. Location map of the 1993 northern Vancouver Island surficial geology field project.

that would be useful in expanding current areas of exploration as well as stimulate long-term exploration activities (Bobrowsky and Meldrum, 1994a, 1994b, 1994c). Surficial mapping, drift sampling for geochemistry, pebble lithology analysis, facies analysis and paleo-flow documentation characterized much of the drift prospecting project. As part of the data management program, a Geographic Information System (GIS) was adopted; specifically, a commercial package called Terra Soft.

Terrain geology maps for the study area were submitted to LANDIS Incorporated for digitization (Figure 2-1). Map data consisting of line-work of the terrain unit polygons were first digitized, stored as a TSF file and then imported into Terra Soft. Polygons were individually identified with a descriptive label stored in a dBase file. The terrain unit descriptions for each polygon were also entered into this same dBase file. A second dBase file was created for 187 sample site locations. This file contained UTM coordinates, geochemistry results for 42 elements, pebble lithology and textural data. Both files were interactively manipulated within Terra Soft to process data.

One product of the study involved the simplification of terrain maps to generate DEP maps (Meldrum and Bobrowsky, 1994a, 1994b; Figure 2-7). The illustrated DEP map is a derivative product of the terrain map shown in Figure 2-1. The very high potential areas (category I) in the corners of the DEP map correspond to high-relief areas consisting of bedrock outcrop and colluvial veneers over bedrock. Category II high potential areas tend to border the first category regions and represent blankets of moraine and colluvium. A very small region supports moderate potential (III) deposits in the centre of the map sheet and reflects some small but complex sediment associations. Low potential

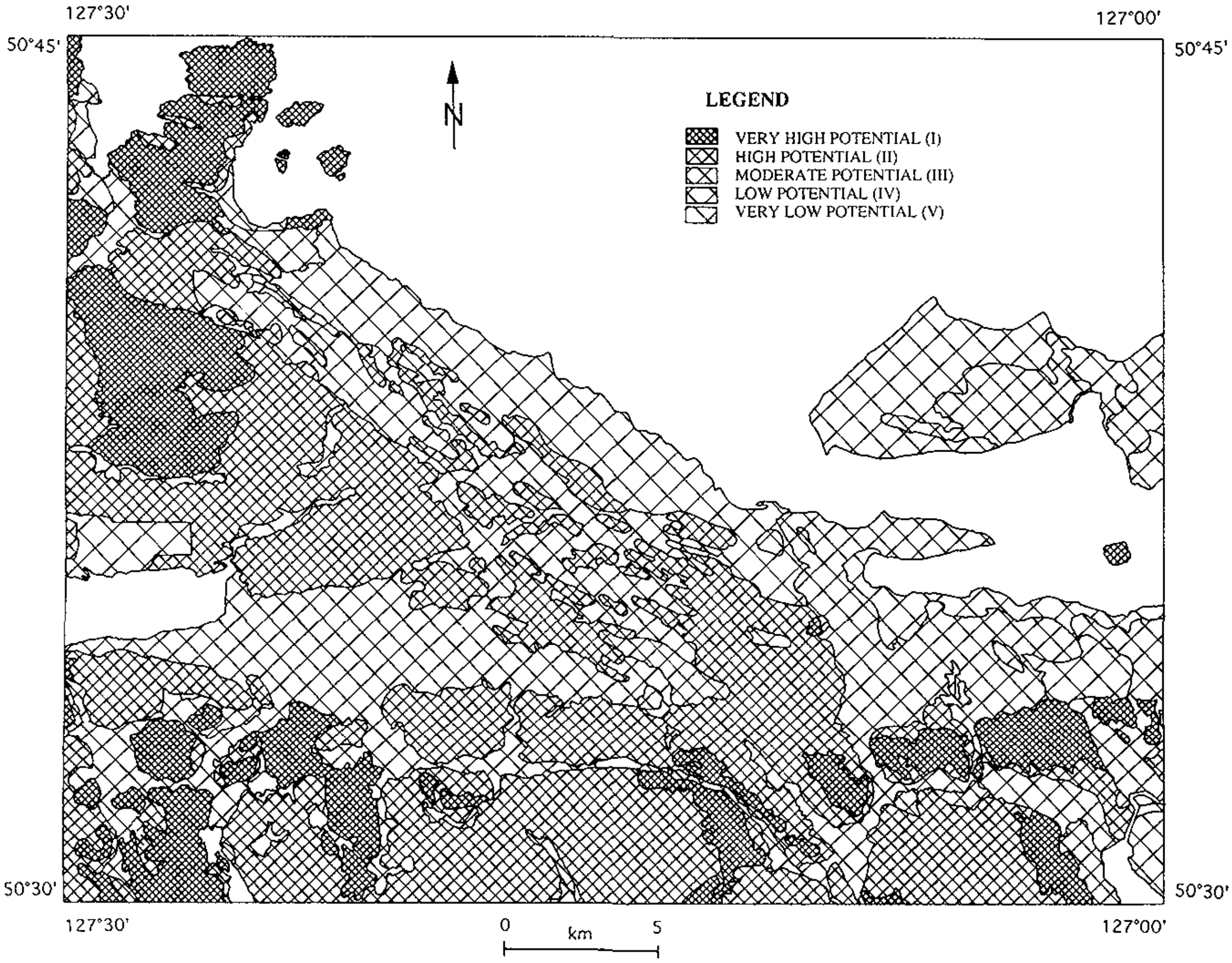

Figure 2-7. Drift Exploration Potential map for NTS 92L/11 (Port McNeill area), adapted from Meldrum and Bobrowsky (1994b). All five potential categories are represented by sediments on this derivative map. Most of the drift samples obtained in 1993 in the west half of the sheet corresponded to the very high to moderate potential terrains. Arrows indicate ice flow direction. *See* Legend Details.

glaciofluvial and glaciolacustrine deposits in category IV are distributed along an east-west belt through the centre of the map sheet eastwards from Rupert Inlet. Finally, category V glaciomarine, anthropogenic and organic deposits parallel the coastal region of the study area. Paleo-flow directions illustrate a dominant trend to the west and north-west. As sampling during the 1993 field season was restricted to the western half of the sheet, the majority of the samples were obtained from deposits categorized as very high to moderate potential. Geochemical results and lithological data can now be related to the bedrock map using the GIS. Data manipulations also allow interactive queries of point locations and regional trends for geochemical anomalies and significant pebble trends.

CONCLUSIONS

Quaternary geology principles and basic surficial mapping data can be used to design drift sampling programs. Information regarding sediment genesis, thickness, cycles of deposition and ability to derive bulk and pebble samples can be combined to generate interpretive maps we term Drift Exploration Potential Maps (DEP maps). Staff with the British Columbia Geological Survey Branch have now used these maps in study areas on the coast and in the interior of the province.

The general principles outlined here apply to all levels of mapping, however, the specifics and categories of the matrix discussed in this paper will change depending on the scale of the map. The accompanying matrix applies only to 1:50 000 scale maps, so the matrix and principles of categorization can be applied to any other terrain map of a similar scale. One important aspect is knowledge of paleo-flow direction of the sampled sediment, whether from pebble fabric data in till, crossbedding in outwash, or striae on underlying outcrop. Although some paleo-flow directions are often illustrated on a map, detailed paleo-flow must be determined at each station during sampling. Complex flow vectors result by compounding several cycles of transportation. For example, a down-slope component in colluvium may be overprinted upon an oblique ice-flow direction found in the till. Because any number of compounded flow-vector paths may occur, generalizations on the shapes, size and orientations of geochemical and clast anomalies are inappropriate. Finally, it is critical that samples from different terrain units not be compared in the analysis of any data set obtained during drift studies. Although, several types of deposits can occur within any single "potential" category, this association does not imply genetic affinities in the sediment.

LEGEND DETAILS

VERY HIGH POTENTIAL (I)

Consists of bedrock and some first derivative terrain units such as till veneers and colluvial veneers (<1 m thick) over bedrock. Terrain units have a simple genesis, deposits are very thin and transport distance is minimal. Sediment and clasts in these units are generally close to their bedrock source indicating short down-ice or down-slope transport distance, generally on the order of tens of metres. Origin and post-erosive history for sediment in this category is very easy to interpret. In general, the interpretation of results from geochemical and pebble samples from these units is very easy.

Mv which is material deposited directly by actively moving or stagnating glaciers (various facies of till) or Cv which are materials produced by the rapid down-slope movement of dry, moist or saturated debris derived from surficial morainal material and/or bedrock falling, toppling, sliding or flowing. All unconsolidated sediments in this category occur as thin mantles of material which have no constructional form of their own, but derive their surface expression from the topography of the underlying unit which is assumed to be bedrock. The sediments reflect minor irregularities of the underlying surface, are generally between 10 and 100 centimetres thick, and outcrops of the underlying bedrock are common.

HIGH POTENTIAL (II)

Consists of some first derivative terrain units including till blankets and colluvial blankets or colluvial veneers over till (<1 m thick). Terrain units have a simple genesis, deposits are thick and transport distance is moderate. Sediment and clasts in these units are usually close to their bedrock source, but given greater thickness of some deposits, transport distance is generally on the order of tens to hundreds of metres. Origin and post-erosive history for sediment in this category is easy to interpret. In general, the interpretation of results from geochemical and pebble samples from these units is easy.

Mb which is material deposited directly by glaciers (various facies of till) or Cb which are materials produced by the rapid down-slope movement of dry, moist or saturated debris derived from surficial morainal material and/or bedrock falling, toppling, sliding or flowing. All unconsolidated sediments in this category occur as thick mantles of material which derive their surface expression from the topography of the underlying unit which is usually not bedrock but probably till in the case of colluvial cover. The sediments mask minor irregularities in the underlying unit and are generally greater than 1 metre thick.

MODERATE POTENTIAL (III)

Consists of some first derivative terrain units including complex deposits of till and colluvium which may have undergone a second phase of transport. Composite terrain units are common and therefore units have a complex genesis, deposits are generally thick (>10 m thick) and transport distance is moderate. Sediment and clasts in these units can be proximal or distal to their bedrock source and of variable thickness, transport distance is usually on the order of tens to hundreds of metres. Origin and post-erosive history for sediment in this category varies from easy to difficult to interpret. In general, the interpretation of results from geochemical and pebble samples from these units is moderately easy to difficult.

Mv, Mb, Cv and Cb units same as above, either alone or in varying combinations, but underlying units are variable and not easy to verify or interpret. All unconsolidated sediments in this category occur as veneers or blankets, generally masking underlying topographic irregularities and total thickness is usually greater than 10 metres.

LOW POTENTIAL (IV)

Consists of some second and third derivative terrain units including glaciofluvial and fluvial deposits. Terrain units in this category have a complex genesis, deposits are of variable thickness (>10 m thick) and transport distance is large. Sediment and clasts in these units are generally distal to their bedrock source, indicating two or more phases of erosion and transportation, with transport distances usually on the order of hundreds of metres, but also tens of metres. Origin and post-erosive history for sediment in this category is difficult to interpret. In general, the interpretation of results from geochemical and pebble samples from these units is difficult.

F^G are materials deposited in association with glacier ice; generally consisting of sand and gravel and sometimes showing evidence of ice melting. Sorting, stratification, texture and shape are variable; includes all types of outwash and ice-contact deposits. F are materials transported and deposited by rivers, alluvial materials; generally consisting of gravel, sand, silt and clay. Gravels are often well rounded, contain interstitial sand, sediment is usually well sorted and stratified, includes flood plain, terrace, deltaic, and some alluvial fan deposits.

VERY LOW POTENTIAL (V)

Consists of some third and fourth derivative terrain units including glaciolacustrine, lacustrine, eolian, organic, anthropogenic, marine and glaciomarine deposits. Terrain units in this category have a complex genesis, deposits are of variable thickness (10 m thick), transport distance from original bedrock source can be very large and underlying units are variable in nature. Sediment and clasts in these units are generally very distal to their bedrock source indicating three or more phases of erosion and transportation, with transport distances usually on the order of hundreds to thousands of metres but also tens of metres. Origin and post-erosive history for sediment in this category is very difficult to interpret. In general, the interpretation of results from geochemical and pebble samples from these units is very difficult.

L are sediments deposited in lakes or reworked by wave action around lake shorelines; generally consist of stratified and well sorted sand, silt and clay. L^G are lacustrine sediments that were deposited in lakes associated with glacier ice; generally consists of stratified and well sorted sand, silt and clay. E are eolian materials transported and deposited by wind action; generally consisting of medium to fine sand and coarse silt that is well sorted. O are organic materials resulting from the decay of vegetative materials. W are sediments deposited by marine waters or reworked by wave action along marine shorelines; generally consisting of sorted and stratified gravel, sand, silt and clay. W^G are sediments deposited in a marine environment in close proximity to glacier ice; generally consisting of poorly sorted stony marine drift.

ACKNOWLEDGMENTS

Research by D.N.P. was funded under contract No. 93-661 with the British Columbia Ministry of Energy, Mines and Petroleum Resources. P.T.B. and D.G.M. appreciate the assistance of the Northern Vancouver Island research team in the collection of the case study data. Wade Noble was instrumental in seeing the paper to production.

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GLACIAL GEOLOGY APPLIED TO DRIFT PROSPECTING IN BUTTLE VALLEY, VANCOUVER ISLAND

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INTRODUCTION

This paper presents an example of low-elevation, alpine glacial ore dispersal along a large finger lake (Hicock, 1986). Buttle Valley is a long, narrow glacial trough now occupied by lake water at 215 metres elevation and flanked by mountains up to 2200 metres above sea level. Dispersal was traced in till from the source of the ore at the Westmin Resources Limited Lynx orebody on the north side of Myra Creek (central Vancouver Island; Figure 3-1) into and along the west side of the main Buttle valley. The ore comprises massive kuroko-type sulphides (Cu, Zn, Pb, Au, Ag, Cd) hosted in the seritic schist of the Myra Formation (Muller 1981).

Locally, the till is up to 8 metres thick, commonly stony, sandy, fissile, compacted and truncates underlying sandy to silty glaciolacustrine sediments. The till contains lenses and blocks of the glaciolacustrine sediment and striated boulder pavements; its stones are mostly locally derived, subrounded, striated and faceted. Sub-till sediments and bedrock are often brittly deformed and display striated surfaces in places. These criteria indicate that the till was formed mainly by plastering under dynamic glacial ice and is classified as lodgement till. Lodgement till was sampled in this study, because it is mainly locally derived, first derivative material and, therefore, usually the best for tracing ore dispersal by glacial transport. The till is overlain by deltaic, alluvial and colluvial deposits.

This paper consists of three parts. First, a section on useful methods for determining the direction of ice flow is presented. Knowledge of the ice-flow direction is essential for tracing ore anomalies in till back to source in drift exploration programs. This section is followed by a brief examination of geochemical analyses of till matrices which reveal the character of the dispersal train. Finally, a list of conclusions regarding this case study is offered.

GLACIAL MOVEMENT CRITERIA

A variety of paleo-ice-flow indicators were observed in the study area. Examples and discussion of several of these are presented below.

BEDROCK

LARGE SCALE (TENS TO HUNDREDS OF METRES)

Roches moutonnées (Photo 3-1) give the direction of ice flow responsible for their formation. In plan view (Photo 3-1a) the features are commonly elongated, streamlined rock mounds that parallel the direction of glacial flow. In longitudinal profile (Photo 3-1b) they have smoothed, striated, gently sloping ends that faced against the ice flow (up-glacier or stoss sides) and steep, rough, truncated ends facing in the direction of ice flow (down-glacier or lee sides). **Rock drumlins**, are essentially mirror-image forms of **roches moutonnées**. Their smoothed, striated ends face against glacier flow (stoss side) but are blunt and steep; their gently sloping tails point in the direction of ice flow (lee side). Rounded and grooved **rock sills** were observed at the mouths of some cirques and indicate that ice flowed directly over the sill from the cirque into the tributary valley below (Photo 3-2).

MEDIUM SCALE (METRES TO TENS OF METRES)

Stoss-lee features are very common on outcrops and appeared as smoothed, striated edges on the down-ice (stoss in this case) walls of fractures (P 3) or on the up-ice (stoss) ends of rock knobs and ridges (Photo 3-3, marked by solid triangles). Conversely, the up-ice (lee in this case) fracture walls or down-ice (lee) ends of knobs and ridges tend to be jagged (rough) and steep (Photo 3-3, arrows). These features were observed on outcrops along valley sides and in valley bottoms.

SMALL SCALE (CENTIMETRES TO METRES)

Crescentic fractures and gouges (Photo 3-4) give ice-flow direction over a bedrock surface. They are nested arc-shaped fractures probably caused by repeated impact on bedrock by clasts held in the glacier's sole. Ice-flow was in the direction bisecting the concavity of fracture arcs. These features were observed in a number of locations where bedrock was exposed on the surface.

A second type of small-scale feature described in the field are **till injections** into bedrock fractures (till wedges; Broster *et al.* 1979; Photo 3-5) which dip in the direction of ice flow. Wet till was squeezed down into fractures caused by the frictional drag of over-riding ice. Displaced angular blocks of bedrock commonly accompany till wedges and also indicate the direction of ice flow that dislodged and displaced them.

Finally, **striae and grooves**; which give the sense of ice flow, but not the actual direction (*i.e.* the alignment but not which way; Photo 3-6) are also present.

GLACIAL DRIFT

LARGE SCALE (TENS TO HUNDREDS OF METRES)

Drumlinoids are elongate streamlined ridges of drift and/or bedrock that parallel ice flow and were observed in high mountain passes above Buttle Lake (Photo 3-7). In

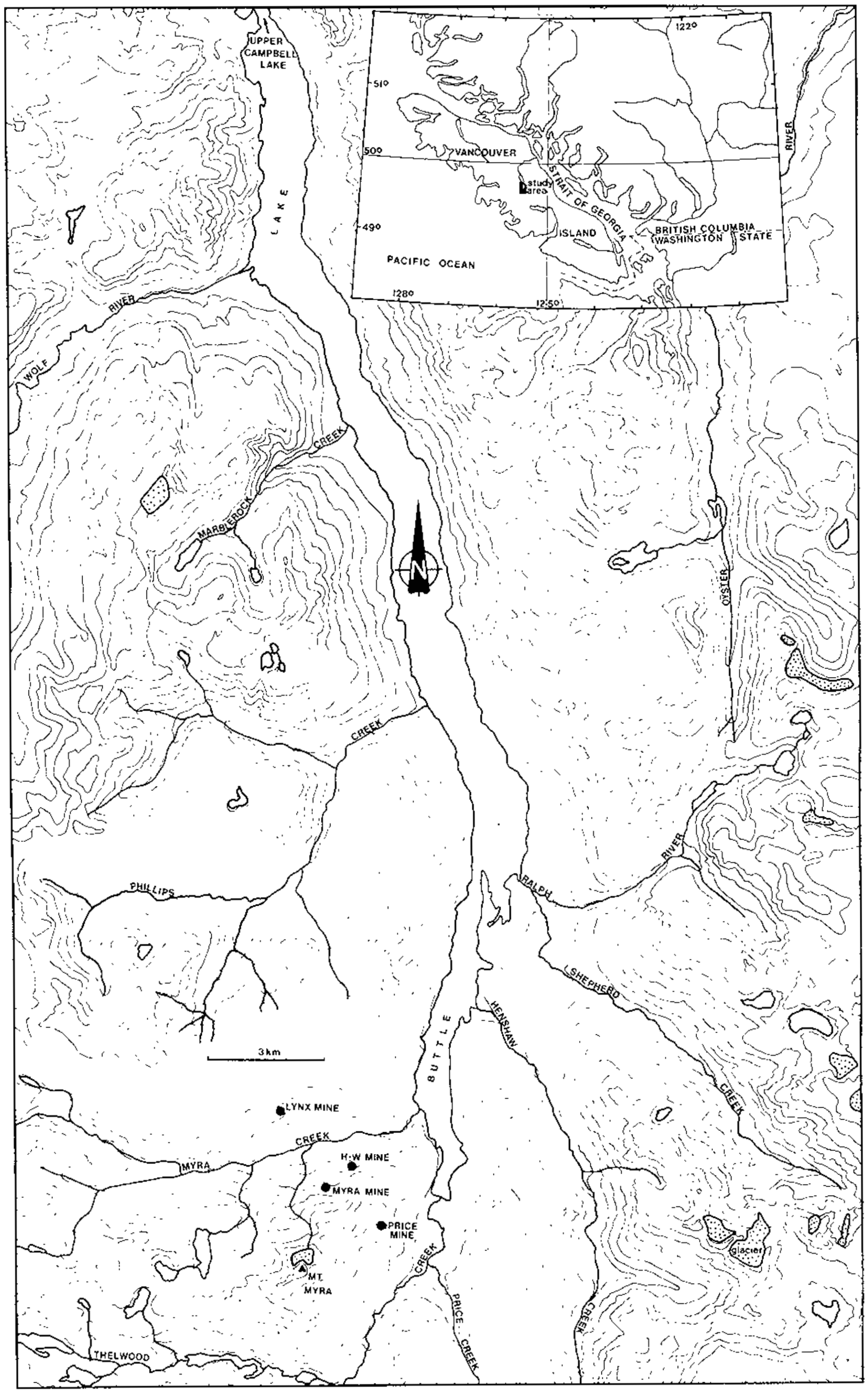

Figure 3-1. Topographic and location maps of Buttle Valley study area. Contour interval 150 m.

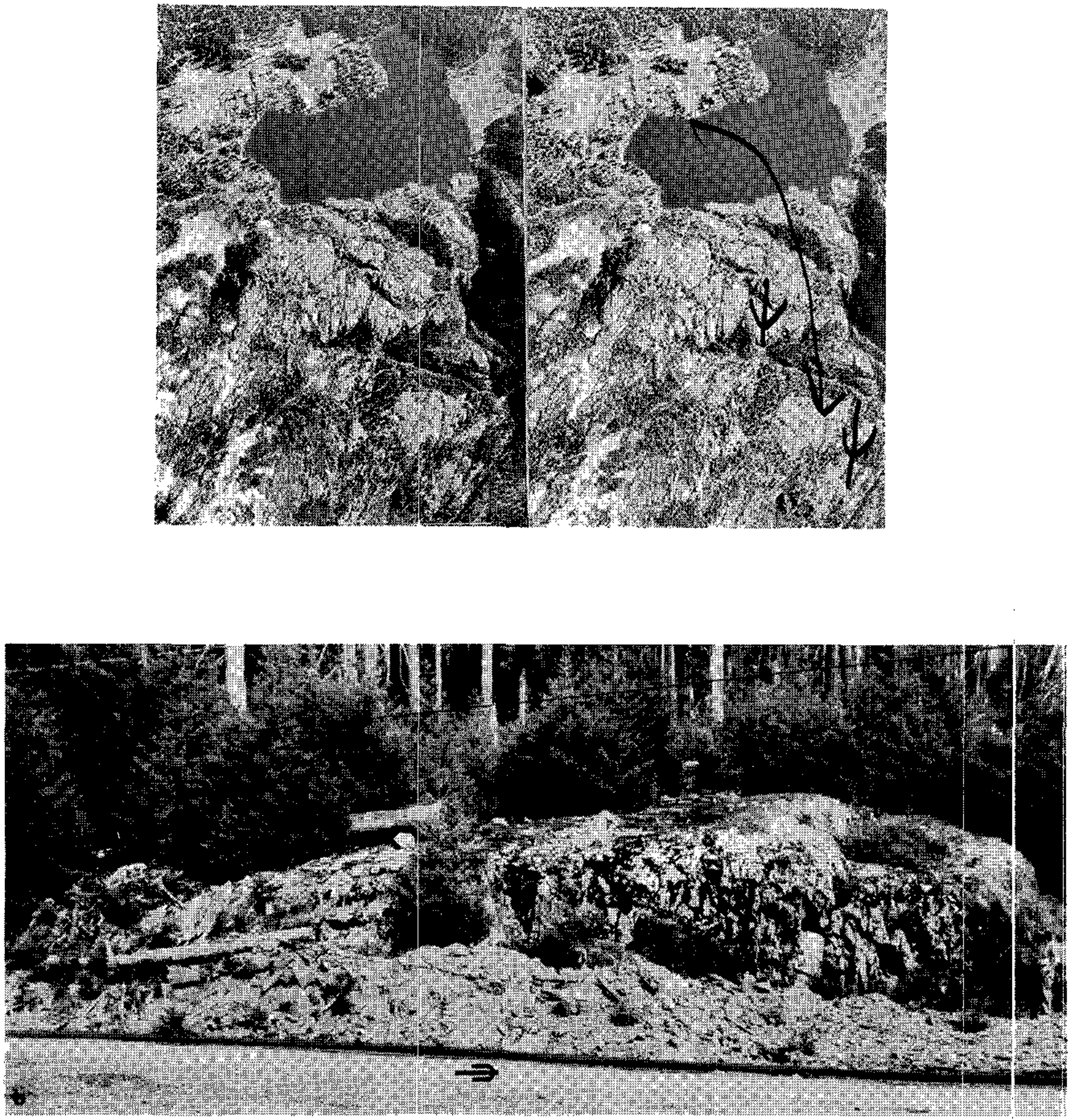

Photo 3-1. Examples of roches moutonnées. a) from the air in a stereo pair, ice direction indicated; b) on the ground, side view, ice movement symbol indicates flow from left to right, man for scale at extreme right.

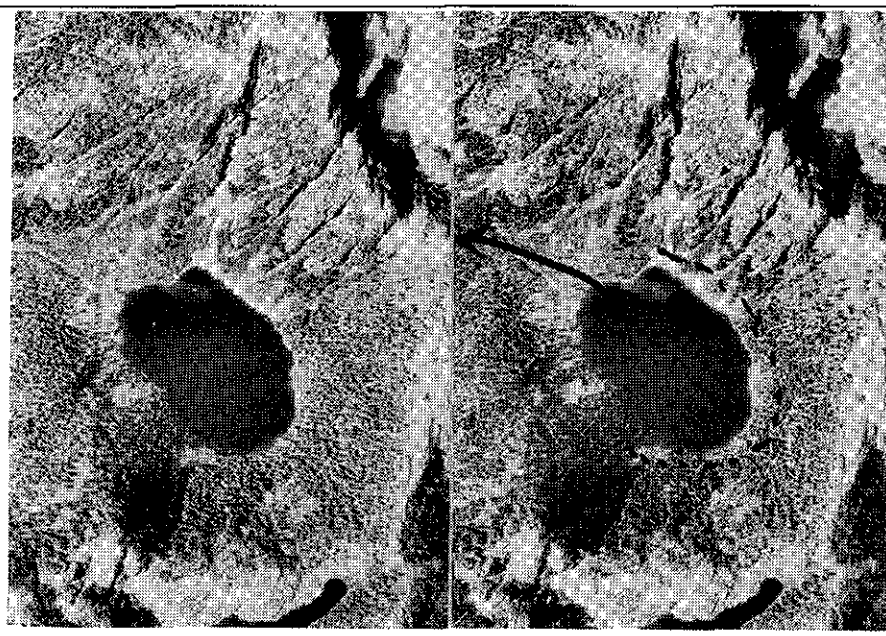

Photo 3-2. Stereo pair of a debris-covered rock sill at the mouth of a water-filled cirque. Ice flow indicated.

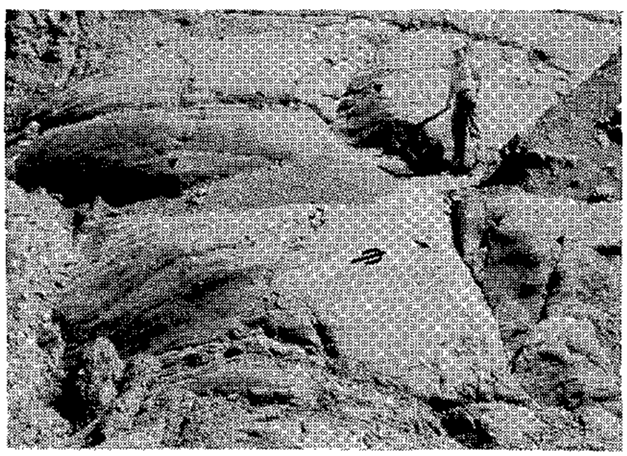

Photo 3-3. Examples of glacial stoss-lee features on a hillside bedrock outcrop at Lynx open pit mine; ice flow from left to right. Man is standing above a glacially quarried fracture with a plucked lee side on the left fracture wall (the down-glacier end of that part of the outcrop to the left of the fracture), and a rounded, smoothed, striated stoss side on the right fracture wall (which presented a surface facing against glacial flow over it). Another fracture to the left of the man exhibits similar stoss-lee relations. Bottom points of black triangles mark rounded, blunt stoss ends of rock knobs and ridges, whereas open arrows mark steep, jagged lee ends of these features.

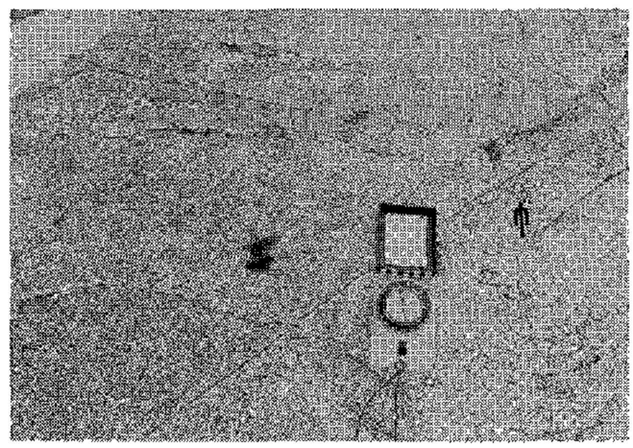

Photo 3-4. Example of arcuate crescentic fractures in a granodiorite outcrop, Ice flow was in the concave direction of the fractures. Compass is 18 cm long.

Photo 3-5. Example of a till wedge infilling fractured bedrock left of pick (pick is 43 cm long). Wedge and fractures dip steeply in the direction of ice flow (right to left). Blocks of bedrock have also been lifted by glacial ice and displaced to the left, on the right side of the photo.

Photo 3-6. Striae on bedrock surface in the bottom of Lynx open-pit mine. Stoss-lee features indicate ice flow was into the photo. Pick head (at top of outcrop) is 28 cm long.

most cases a steeper, rounded, blunt end (marked in Photo 3-7) indicated the stoss direction, whereas the lee end gently slopes to the level of surrounding terrain.

MEDIUM SCALE (METRES TO TENS OF METRES)

Glaciotectonic fractures and folds are caused by ice over-riding and deforming underlying sediment (and bedrock; Hicock and Dreimanis, 1985; Dreimanis, 1993). In the study area they include the following:

Shears are commonly gently dipping listric faults (Photo 3-8). They strike transverse to ice flow; dip directions parallel ice flow.

Tension fractures also strike transverse to ice flow but they usually dip steeply in the down-glacier direction (Photo 3-9). Where a tension fracture opens by continued sub-glacial drag and is filled from above with till, a **till wedge** results that also dips steeply downglacier.

Folds in sub-till silt (Photo 3-10) have fold axes that trend transverse to ice flow and axial planes that dip parallel to ice flow (either up or down-glacier).

SMALL SCALE (CENTIMETRES TO METRES)

Boulders in till can reveal ice movement direction, especially if they occur in concentrations (*i.e.* pavements; Hicock 1991) that commonly appear as subhorizontal stone lines in till exposures (Photo 3-11) with consistently oriented surface striae and stoss-lee relationships among stones (*see* below).

Similarly, **bullet-nosed stones** (not necessarily in pavements) with smoothed, striated stoss ends and rough, plucked lee ends (Photo 3-12) consistently facing the same way are excellent indicators of ice movement direction and usually imply till deposition by plastering (lodgement) under active ice.

Finally, **structures around boulders in till** may reveal where the stone was ice-pressed into wet till on the lee side (Photo 3-13, solid triangle), creating a cavity filled by sediment on the stoss side (Photo 3-13, hollow arrow).

STONE AND MINERAL PROVENANCE

Stones in till may reveal ice flow sources by their lithologies. Possible source lithologies for till materials in Buttle Valley are shown in Figure 3-2a. Provenance indicator lithologies in the study area are confined to the southern part of the valley. They include the Myra Formation (volcanic ash and tuffs interlayered with chert and argillite) and especially the Buttle Lake Formation (grey crinoidal limestone) which occurs as thin ribbons that are very good (restricted) sources for indicator tracing.

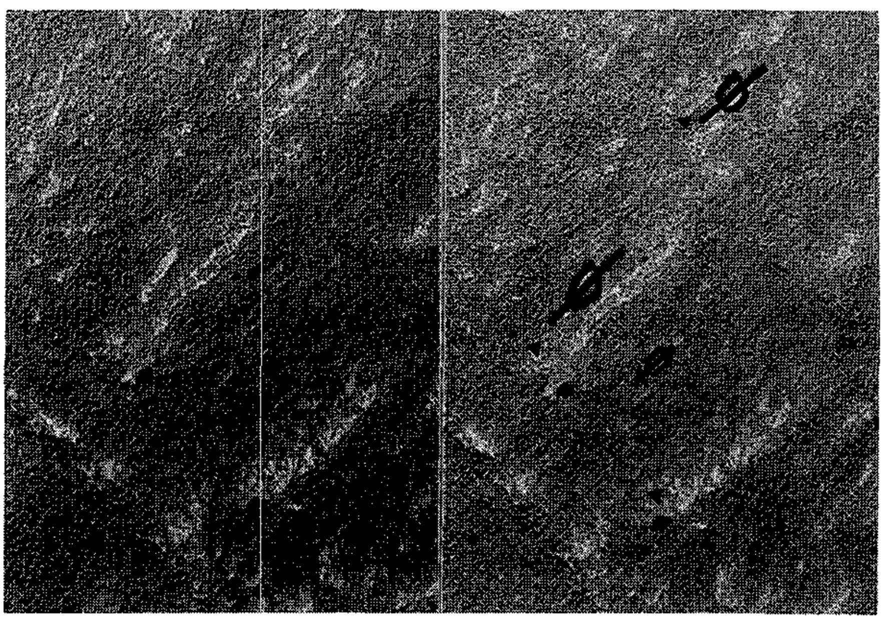

Photo 3-7. Stereo pair example of a drumlinoid ridges with three blunt stoss ends marked by bottom points of black triangles. Ice flow toward upper right.

Photo 3-8. Example of shears in till that rise gently in the direction of ice flow (right to left). Traces of shears on exposure surface are marked in five places by botttom points of black triangles.

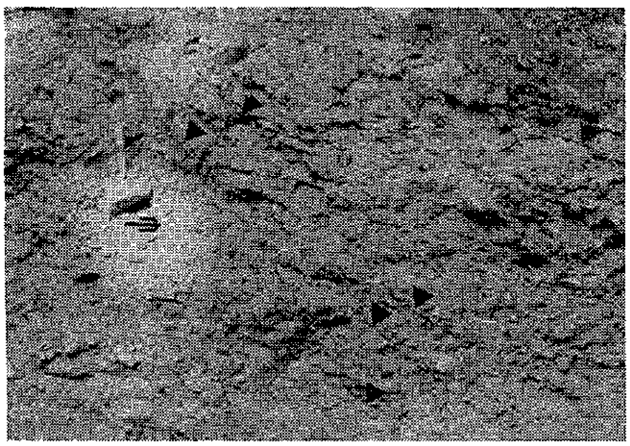

Photo 3-9. Example of tension fractures in till that dip steeply in the direction of ice flow (left to right). Traces of fractures on exposure surface marked in six places by left points of black triangles. Knife is 20 cm long.

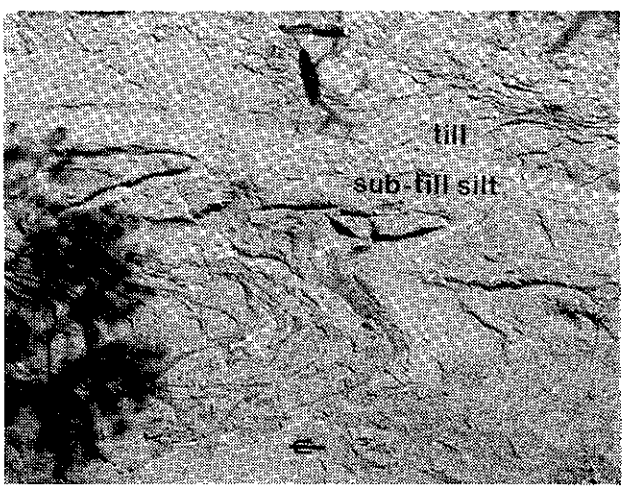

Photo 3-10. Example of folds in sub-till silt caused by ice overriding silt from right to left.

Photo 3-11. Example of a stone pavement in a till exposure on the west shore of Buttle Lake. Pavement boulders marked by bottom points of black triangles.

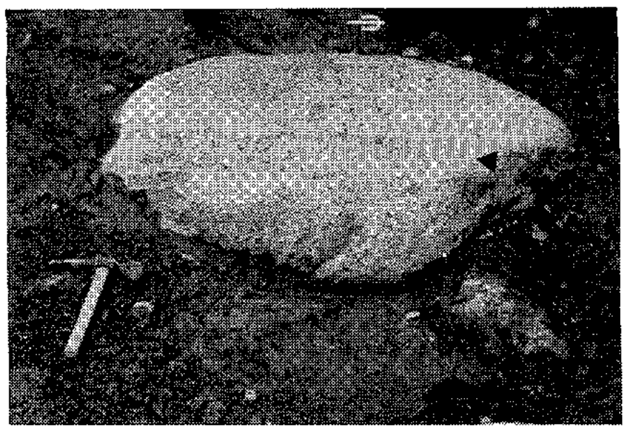

Photo 3-12. Example of a striated, rounded, bullet-nosed boulder in till. Plucked lee side is indicated under black triangle. Pick is 43 cm long.

Photo 3-13. Examples of ice-press structures around two boulders in till. Curved till-pressure structure (marked by black triangle) wraps around the downglacier lower right side of the left boulder where it lodged in till. Sediment infilling around the lower pressure up-glacier side of the right boulder is indicated by the hollow arrow. Cavity infilling probably occurred as the right boulder was being lodged into till while being released from overriding ice. Pick is 43 cm long.

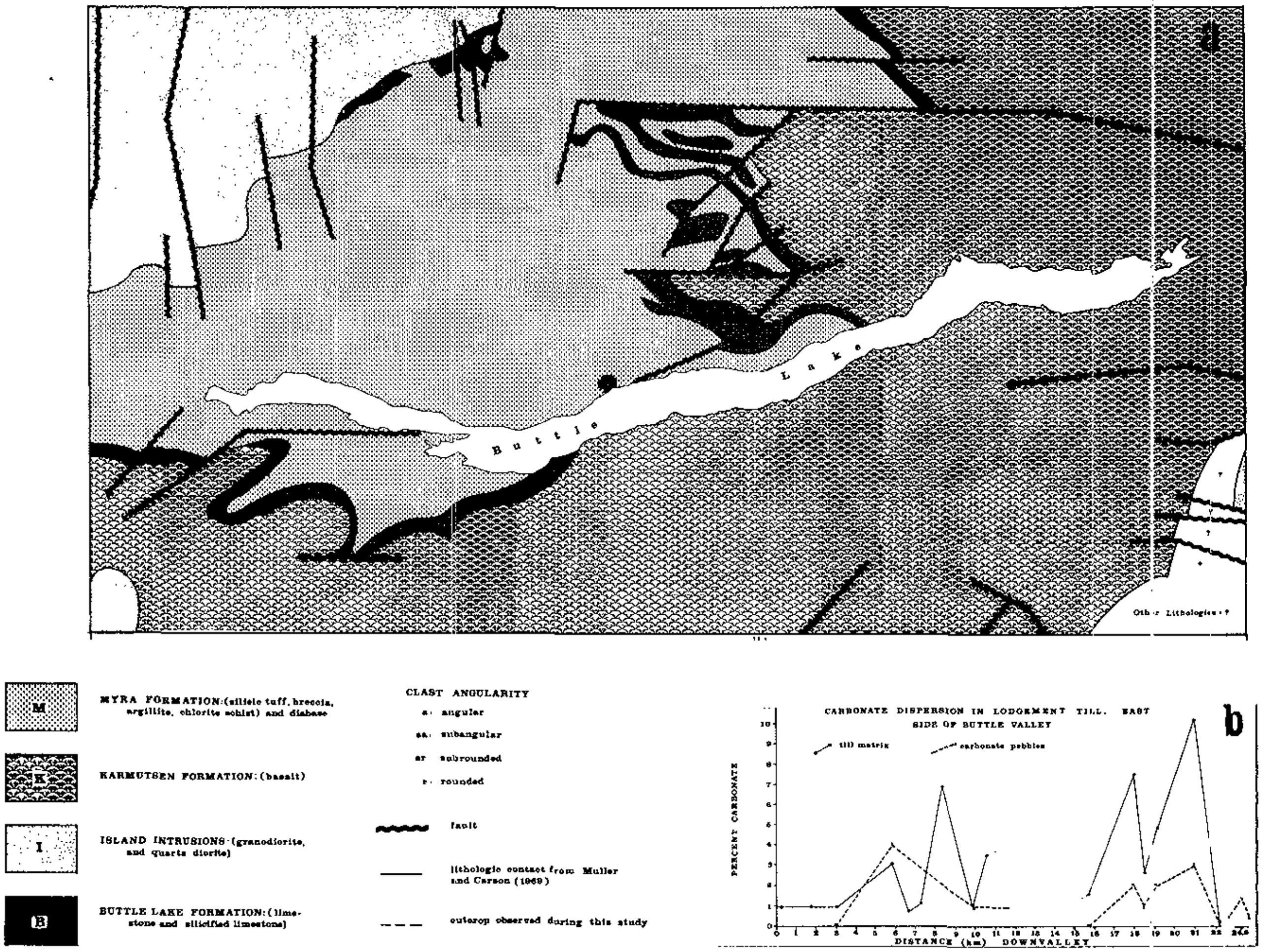

Figure 3-2. a) Simplified bedrock geology map of study area (modified from Muller and Carson 1969), and b) comparison of carbonate clast and matrix abundances in lodgement till along the east side of Buttle Lake. Distance downvalley is measured from the shoreline outcrop of Buttle Lake Formation (black in Figure 3-2a).

Stones 0.5 to 5 centimetres in diameter were identified under a binocular microscope. Selected stones were also thin sectioned and identified under transmitted polarized light. Myra Formation clasts dominate the pebble assemblages, indicating that glacial transport of the clasts was down-valley to the north. Till on the west side of Buttle Lake contains a higher percentage of Myra Formation clasts than till on the east side, in which Karmutsen basalt clasts are abundant. Roundness of Myra Formation clasts generally increases down-valley, further suggesting northward glacial transport.

Buttle Lake Formation pebbles were found only in east-side till samples, mainly down-valley from the shoreline outcrops of the formation, indicating northward ice transport. Buttle Lake Formation indicator stones in till permit a good estimation of basal glacial transport distances in the study area by comparing their proportion in pebble assemblages with abundance of till-matrix carbonate down-glacier from the source outcrops (Figure 3-2b). Limestone clast content generally decreases northward to zero within 20 kilometres of the source outcrops, whereas matrix carbonate generally increases before disappearing at about 20 kilometres transport distance. Carbonate matrix was produced by comminution of carbonate clasts during basal glacial transport along the east side of the valley. This implies that soft, Westmin ore clasts may also not have survived as much as 20 kilometres of basal transport. Indeed, no clasts of ore were found in pebble samples from anywhere in the study area.

The provenance of sand from till matrices collected on both sides of the lake generally reflects the mineralogy of local bedrock, which implies basal glacial transport and comminution of glacial debris down-valley. The 0.125 to 0.250-millimetre sand grain fractions from till matrices were separated into light and heavy mineral fractions using liquid sodium polytungstate (specific gravity 2.90). Separates were then mounted in Canada balsam, analyzed under transmitted polarized light and the opaques by reflected light microscopy. Only two grains of Westmin ore were found in this fraction, directly down-glacier from the Lynx orebody. This suggests that any ore entrained and transported basally was comminuted to the finest till-matrix fraction within a short distance down-glacier of the source. In addition, detrital ore grains would have been easily removed by leaching in the weathering zone (to about 1 m below ground surface), in places where sampling below the weathering zone was not possible.

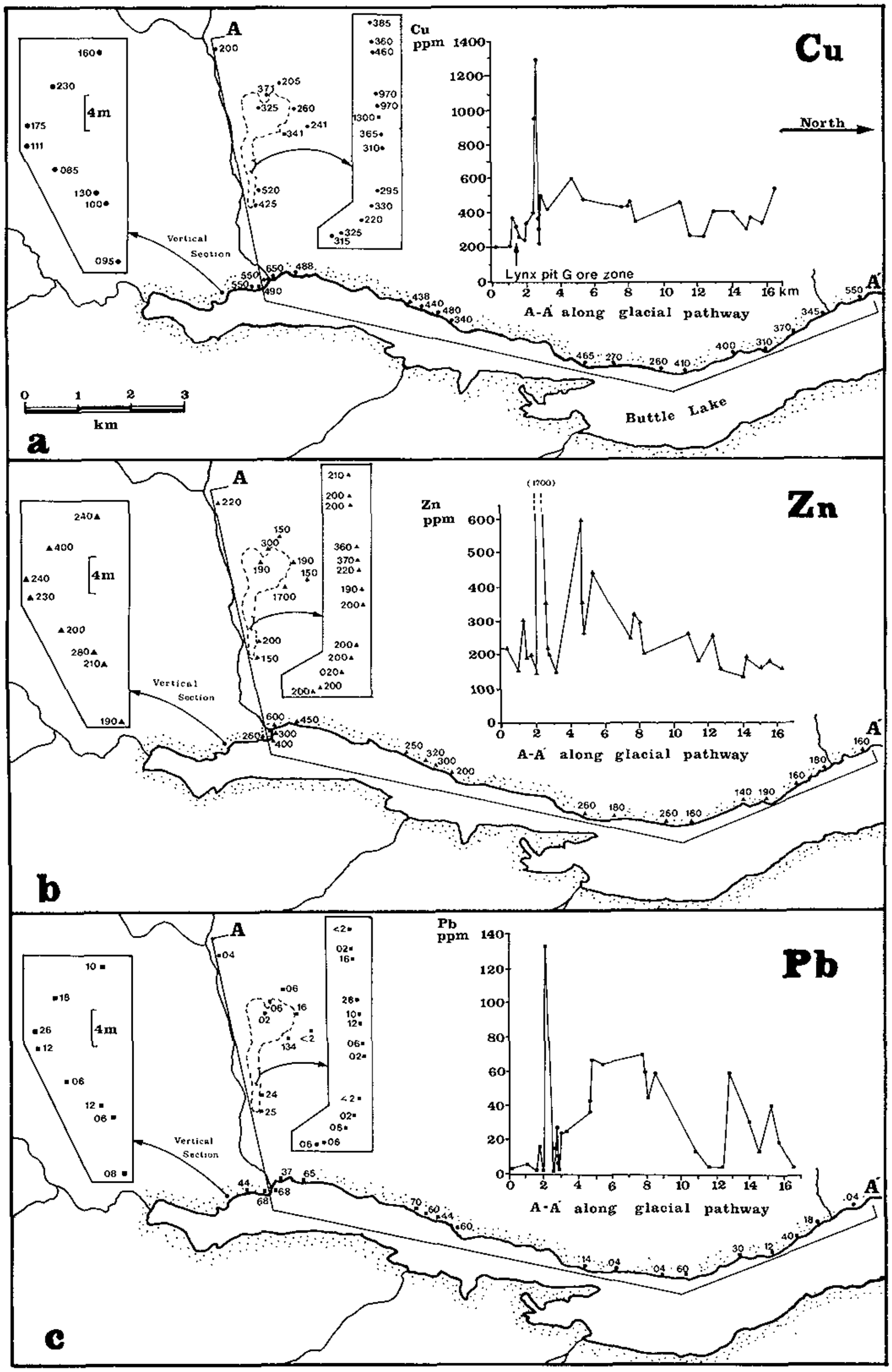

Figure 3-3. Glacial dispersal maps and curves of three detectable metals from the Westmin property. Dispersal was by the glacial lobe issuing out of the Myra valley (Figure 3-1). Also plotted is a vertical geochemical profile in till deposited by the Thelwood glacial lobe near the south end of Buttle Lake (Figure 3-1).

GEOCHEMICAL GLACIAL DISPERSAL OF WESTMIN ORE

Based on lithologic comparisons of stone and sand samples on both sides of the Myra and Buttle valleys, tributary ice lobes entering the trunk Buttle valley apparently did not mix (Hicock, 1986). Thus, glacial dispersal of Westmin ore occurred along the north side of the Myra valley (where the source orebody is located), then rounded the corner along the west side of Buttle valley. Metal concentrations were found only in till matrix clay fractions (<0.002 mm). The clay fraction was separated by centrifuging under the assumption that it would most likely retain the original proportion of metallic ions in the preoxidized till. Atomic absorption analyses (complete digestions) of copper, zinc and lead were performed on the clay separates. The results of these analyses and the glacial dispersal pattern are presented in Figure 3-3.

Copper, zinc and lead indicate that dispersal by subglacial transport was less than 20 kilometres in the finest fraction of the till matrices. Copper displays the highest values (Figure 3-3a), followed by zinc (Figure 3-3b) and lead (Figure 3-3c). All three metals display a sharp peak about 1 kilometre down-glacier from the Lynx orebody which probably represents the head or peak of the dispersal fan. A second peak appears about 5 kilometres from the orebody, near the mouth of Myra Creek. Beyond this point, metal values decrease unevenly down the Buttle valley in the tail of the fan and eventually approach background values. These results, together with the preceding ice-flow evidence from bedrock and till, confirm that glacial transport was mainly basal and deposition of till was subglacial by dynamic ice processes (*i.e.* mainly lodgement).

CONCLUSIONS

Based on this case study in central Vancouver Island:

- Where a mineral or geochemical anomaly is found in an alpine valley, it is best to trace it up-valley following the same valley side into tributary valleys.
- If a source of ore is to be found, it will probably be within a few tens of kilometres, and the head will probably be directly down-valley from the source. This is supported by another study of a subglacially dispersed geochemical fan in till in northern Ontario (Hicock and Kristjansson, 1989).
- Geochemical prospecting is the best method for exploration, because soft ore will probably be glacially comminuted to the finest till material (<0.002 mm) over a short distance from the source, and surviving mineralized grains may be leached from the weathering zone.
- Glaciotectonic deformation structures are useful for determining ice-flow directions. They can be more reliable than stone orientations (long axis fabrics) in tills that are susceptible to postglacial reorientation by mass movements on mountainsides.

ACKNOWLEDGMENTS

The author acknowledges the assistance of R.R. Walker and Westmin Resources Limited for allowing access to its property and for geological advice.

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DRIFT-PROSPECTING SAMPLING METHODS

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INTRODUCTION

Most orebodies in Canada have been found in areas where bedrock is near the surface or where outcrops are abundant. Unfortunately, much of Canada is covered by thick deposits of unconsolidated sediments, so there is an increasing need to conduct mineral exploration in drift-covered areas. Because much of this sediment was transported glacially over a short distance from the bedrock sources, drift sampling methodologies have become an important tool in the geochemical and indicator mineral tracing of mineral deposits.

In contrast to soil sampling, where leached and oxidized samples from the B-horizon are intentionally collected, drift prospecting, as defined here, attempts to sample unleached sediments which more closely represent the primary composition of the bedrock from a source area. Drift sampling is utilized if: subtle geochemical anomalies related only to clastic dispersal of mineral grains are sought; the provenance of soil parent materials, as indicated by mineral grains and rock fragments, is to be determined; or if indicator mineral tracing methods are required. Drift samples are often taken from the C-horizon at depths of 0.75 metre or deeper in order to obtain material which has not been effected by soil formation, which has not been leached of carbonate, and in which mineral grains have not been significantly altered.

Till and glaciofluvial sediments are most commonly sampled during drift prospecting because they most often reflect composition of a source area. Till, composed of crushed bedrock and reworked older sediments, can be recognized by a suite of diagnostic criteria. As a sediment directly deposited from glacier ice, Shilts (1993) refers to till as the **first derivative** of bedrock. This implies that the composition of till can usually be related to the ice-flow history. On the other hand, glaciofluvial sediments, which were first transported by ice and later by glacier meltwater, are considered **second derivative** products of bedrock; reflecting two or more cycles of transport. The sampling methods reviewed here are applicable to both sediment types.

In drift exploration, samples are collected in an area with the intent of defining the shape, extent and eventually the bedrock source of a geochemical dispersal train (DiLabio, 1990; Shilts, 1976; 1982; 1984). Local conditions (surficial sediment thickness, topography, accessibility) and the primary objective of the exploration program will dictate the choice of sampling methods.

Drift prospecting may be successfully applied if the genetic classes of the sampled sediments are properly identified, and sample collection is consistent (*e.g.* below the B-horizon). Therefore, sampling is a crucial stage of an exploration program, having cumulative effects on analytical methods and interpretations to locate mineralization. The purpose of this paper is to present and describe the five most commonly used overburden sampling methods, followed by a brief discussion on the advantages and disadvantages of each. These methods are hand excavation, trenching with a mechanical excavator (*e.g.* a backhoe), and drilling with portable, reverse-circulation and sonic drills. A summary of information is given in Table 4-1.

HAND EXCAVATION

The use of a pick and a shovel is certainly the simplest method to collect surficial sediment samples. It is very efficient in ditches along forestry roads where the organic cover and part of the solum have often been removed during road construction (Photo 4-1). In areas which lack cultural or natural exposures below ground surface, pits can generally be dug to a depth of about 1 metre with limited environmental damage. Depending on the local conditions, this may

Photo 4-1. Example of a till section commonly exposed along forestry roads in central British Columbia (GSC-1993-281-C).

TABLE 4-1
FEATURES OF SUBSURFACE SAMPLING METHODS

	Hand digging	Trenching (Backhoe)	Small Percussion and Vibrasonic Drills (various)	Auger Drills (various)	Reverse-circulation Drills (Longyear or Acker) (Nodwell Mounted)	Rotasonic Drills (Nodwell or Truck Mounted)
1. Production cost estimate per: - day (10 hrs) - metre	$100 per sample	$500-$1000	$500-$1000 $20-$40	$800-$1500 $25-$50	$1800-$2000 $25-$40	$3000-$4000 $50-$80
2. Penetration depth	1 to 1.5 m	3 to 5 m	10 to 20 m (greater?)	15 to 30 m (boulder free)	Unlimited (125 m?)	Unlimited (125 m ?)
3. Environmental damage	minor	5 m wide cut trails	nil	2-3 m wide cut trails (Nodwell, muskeg, all terrain vehicle mounted quite manoeuverable)	5 m wide trails (may have to be cut in areas of larger trees)	5 m wide cut trails
4. Size of sample	no limitation	no limitation	300 g (dry), or continuous core	3-6 kg (dry or wet)	5 kg (wet)	Continuous core (9 cm)
5. Sample of bedrock	Yes (chips), if bedrock reached	Yes (chips), if bedrock reached	Yes (chips), if bedrock reached	Unlikely, if hollow auger; split spock sampler can be used for chips	Yes (chips)	Yes (core)
6. Sample recovery a) till b) stratified drift	excellent excellent	excellent excellent	good good	good poor to moderate	good moderate	excellent excellent
7. Holes per day (10 hrs.)	10-15 (1 m deep, close spacing)	10-15 trench (short and close spacing)	5 @ 6-10 m	1 to 3 @ 15-20 m	4 @ 15-20 m 1 @ 60-80 m	4 @ 15-20 m 1 @ 60-80 m
8. Metres per day	10 to 15	30 to 50	30 to 50	20 to 60	60 to 80	60 to 80
9. Time to pull rods	N/A	N/A	30-60 min @ 15 m	20-40 min @ 15 m	10 min @ 15 m	10 min @ 15 m
10. Time to move	5-10 min	10-20 min	30 min	15-60 min	10-20 min	15-30 min
11. Manoeuvrability	good	good	good (poor if manually carried on wet terrain)	good to reasonable	good	moderate
12. Trails required	no	yes, may have to be cut in areas of larger trees	no	yes and no	yes, may have to be cut in areas of larger trees	yes, must be cut
13. Ease in collecting sample	excellent	good	sometimes difficult to extract from	good (contamination?)	good	excellent, continuous core
14. Type of bit	N/A	N/A	flow through, split spoon or piston samplers	auger with tungsten carbide teeth	milltooth or tungsten carbide tricone	tungsten carbide ring bits
15. Type of power	human	tractor	hydraulic percussion (gas engine percussion, vibrasonic)	hydraulic-rotary	hydraulic-rotary	hydraulic-rotasonic
16. Method of pulling rods	N/A	N/A	hydraulic jack, hand jack or winch	winch or hydraulics	hydraulic	hydraulic
17. Ability to penetrate or move boulders	very poor	excellent	poor	poor to moderate	excellent	excellent, cores bedrock
18. Texture of sample	original texture	original texture	original texture	original texture (dry) to slurry (wet)	slurry (disturbed sample)	original texture (core can be shortened, lengthened and/or contorted)
19. Contamination of sample	nil	nil	nil (tungsten)	nil to high (tungsten)	nil, fines lost (tungsten)	nil (tungsten)

Modified from Coker and DiLabio (1989). Drilling costs based on 1985 data.

be deep enough to reach unleached and unoxidized sediments. Hand trenching can occasionally be augmented with hand augers, in areas where large clasts are not abundant.

In this sampling method, as with all others, samples must be large enough to yield sufficient material for geochemical or mineral indicator analyses. Sample size will often be limited by accessibility (*i.e.* the number and amount of samples which can be back-packed to the nearest road, lake or helicopter pad).

Sampling should only be done by individuals capable of distinguishing between various sediment types. Proper notes must be taken (*e.g.* depth, texture, colour, oxidation level, mineralized clasts, lithologies *etc.*) which will aid in the interpretation of the analytical data. As part of the sampling program, notice should be given to striations on bedrock surfaces and unique boulder lithologies, which can then be related to a specific source indicating a direction of glacial transport. Similarly, in areas of good till exposures

Photo 4-2. Till fabric: to measure the orientation of elongated pebbles in the till, a pencil in this case, was placed parallel to the long axis. Its trend and plunge are measured with a compass.

(along a river, a creek or a road), till fabrics (measurement of pebble orientations in the till; Photo 4-2) should be measured, and pebble counts should be obtained (*cf.* Hirvas and Nenonen, 1990).

One common problem is to determine the best sample interval. The distance between every sample is dependent on the size of the anomaly expected in the till. For example, most studies on gold dispersal trains show that distances of transport of detectable material are rather short (Table 4-2). Consequently, if the source is thought to be small (*e.g.* veins a few metres wide) and as two or more consecutive samples are required to define any anomalous areas, samples should probably be spaced less than 100 metres apart.

Air photo interpretation should clearly complement the sampling stage. Apart from contributing information about the glacial history, it can be used to identify areas suitable and unsuitable for sampling. For instance, areas covered by thick glaciolacustrine sediments or organic deposits should be avoided.

The depth of hand-dug pits is a serious limiting factor which can represent a major impediment to a successful exploration program conducted in areas covered by thick drift. For those areas, other methods are more appropriate, such as trenching and drilling.

TABLE 4-2
REPORTED DISTANCE OF GOLD TRANSPORT IN TILL IN SELECTED REFERENCES

Reference	Reported distance of Au transport
DiLabio (1982)	600 and 1900 m
Sopuck *et al*. (1986)	less than 500 m
Stewart and Van Hees (1982)	354 m
Sauerbrei *et al*. (1987)	greater than 400 m
Parent (1992)	4000 m

TRENCHING

A variety of excavator types, mounted on tracks or tractors, are widely available in Canada. These machines can dig trenches from 3 to 5 metres deep, which then permits profile sampling units at greater depth (Photos 4-3 and 4-4). Interval sampling till at different depths may be important, especially in areas of thick till accumulation, as dispersal trains are generally relatively thin (DiLabio, 1990). The best sampling results will be achieved in areas where surficial sediment cover does not greatly exceed 5 metres (*i.e.* the reachable depth of most digging devices). In areas of exploration where sediment exceeds 5 metres in thickness, overburden drilling (*see* below) would be more appropriate.

The mobility and manoeuvrability of heavy digging devices will depend on topography, nature of the terrain, and the experience of the operator. Roads or trails are not necessary but in their absence, the environmental impact is more severe. Narrow trenches to depths greater than 2 metres can represent a serious hazard to workers. Trench walls are unstable and dangerous. Special care should be taken to support walls with timbers or to use a metal cage to protect the workers if they must descend into the trench. Wider trenches can be excavated by stepping the slope if detailed work has to be done at a particular site (*e.g.* till fabric or detailed sampling). Samples can be collected by the backhoe as the trench is dug. This practise is common in areas prone to collapse or areas with high water tables.

The cost of renting an excavator varies regionally and depends also on the type of machine that is required; costs average \$50.00 to \$100.00 per hour, and mobilization costs are often supplementary.

PORTABLE DRILLS

A wide variety of portable drills are available on the market. The most common ones are the Cobra, Pionjär and Vibra Corer (percussion) (Photos 4-5 and 4-6) and the Stihl (rotary; Photo 4-7). Veillette and Nixon (1980) present a good overview of portable drilling equipment suitable for drift exploration. Their report also contains technical information about portable drills and planning of a drilling program with this type of equipment. Good results can be achieved with portable drills, especially in areas where environmental damage is severely restricted, where unconsolidated sediment is to be sampled underneath a veneer of sand and silt or where large clasts are rare. For traverses, a three-person crew is usually necessary to carry the drill, the rods and rod puller to extract rods from the hole.

Although the maximum depth of penetration claimed by the manufacturer may be promising, practical results can be disappointing. For most drift prospecting programs, till has to be sampled and this sediment type is commonly bouldery and cobbly. A boulder or a large cobble embedded in till cannot be penetrated or overpassed by portable drills. Consequently, several attempts may be necessary to reach the desired depth of sampling. Nevertheless, a depth of 44.8 metres (148 feet) in fine sand and silt has been attained with some portable drills (J. Archibald, personal communication, 1993). The rate at which a portable percussion drill pene-

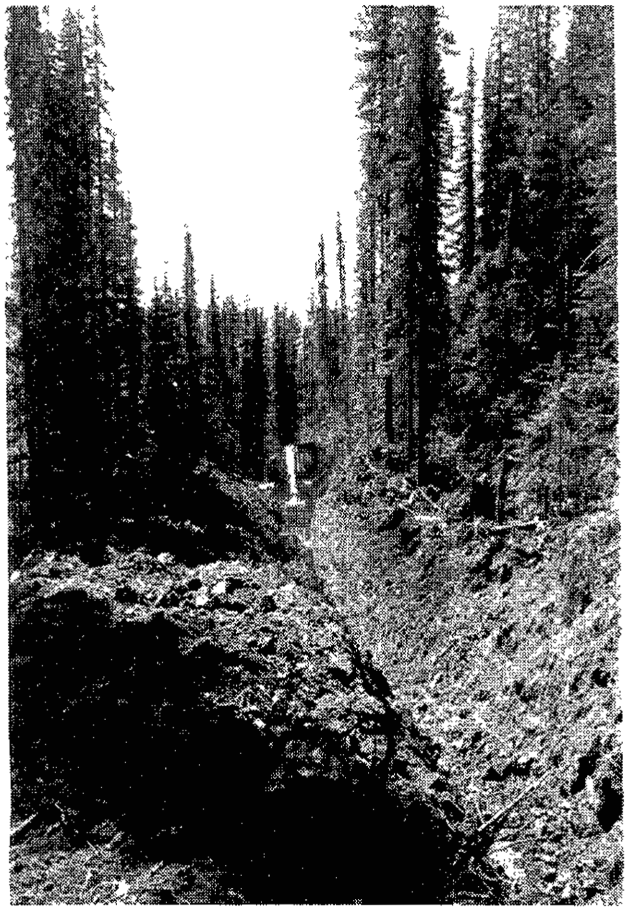

Photo 4-3. Two-metre deep trench dug down to bedrock. Note the excavator in the background.

Photo 4-4. Backhoe (GSC-1993-277-A).

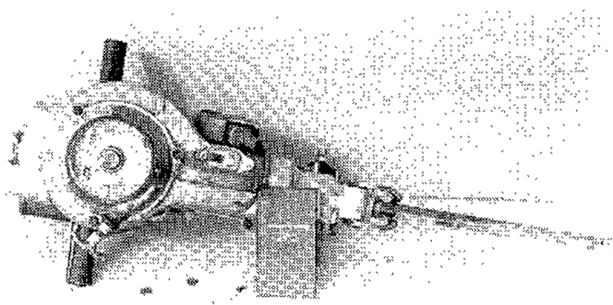

Photo 4-5. Cobra drill (GSC203205-J).

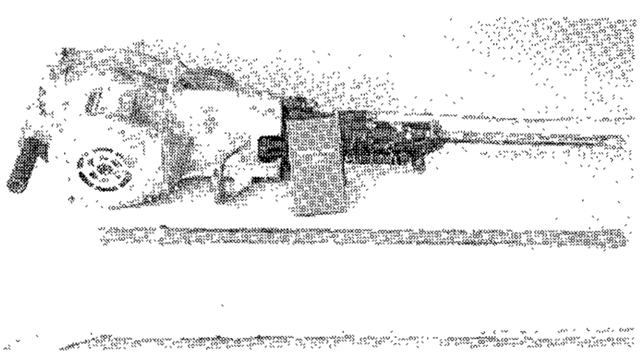

Photo 4-6. Pionjär drill (GSC 203205-B).

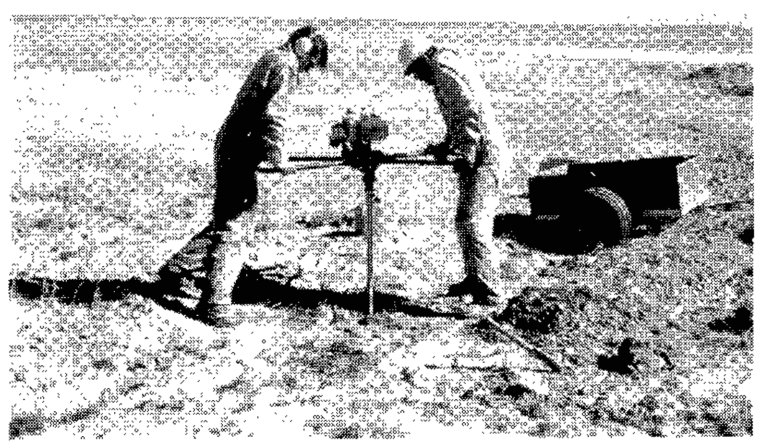

Photo 4-7. Stihl drill used by GSC in the high Arctic for permafrost sampling (GSC 202921-H).

trates hard compacted sediment (*e.g.* till, dry varved clay) may be slow. However, according to Archibald *et al.* (1983) who tested the Vibra-Corer, the greatest amount of field time was spent on retrieving the drill rods, recovering the sample and reinserting the drill sections into the hole. They also indicated that the penetration rate is dependent on the moisture content of the sediments.

Different types of sampling devices can be installed on portable drills: piston, split-spoon or flow-through sampler. For most of these the samples are small and disturbed to the point where it is difficult to distinguish between crushed bedrock and till. If a large sample is needed, as for indicator mineral separations, more than one hole must be drilled. With the flow-through sampler, contamination of the bit with material from shallower depth is also possible. Bedrock samples can be collected at the bedrock-sediment interface with portable percussion drills only in areas where the bedrock is crushed, loose or weathered. The stratigraphy of unconsolidated sediments can be established with portable drills, but requires the recovery of material for every depth interval equivalent to the length of the core barrel or sampler.

Portable drills can be rented at the cost of $800 per month. On the other hand, a Pionjär can be purchased for about $5000 (Table 4-1). Other types of semi-portable drills not discussed here have been developed by geologists, mostly for work in high Arctic regions (Veillette, 1975a, 1975b, 1975c). These drills would also prove useful for drift prospecting in the Cordillera.

REVERSE CIRCULATION

At a more advanced stage of exploration, when a significant geochemical or geophysical anomaly has been identified, controlled overburden drilling is appropriate. Many projects use diamond drilling to pierce the overburden (generally without sampling it) in order to gain the needed information about the bedrock. Bedrock can only be sampled where the drill bit makes contact with the subcrop. Instead, an overburden drilling method which allows sampling of both bedrock as well as till at different levels in the hole is preferred. In this case, data (geochemistry, lithology, mineralization etc.) gathered are not only representative of the site of drilling but also provides information regarding the up-ice-flow direction.

In 1970, during exploration for volcanogenic massive sulphide (VMS) deposits, Texas Gulf Sulphur Company and Bradley Brothers Drilling designed the first reversed-circulation drill for sampling till in areas covered by thick drift (Averill, 1993). Three years later, a small copper deposit (Currie-Bowman) was discovered by another company using the same technology (Thompson, 1979). Later, other important discoveries were facilitated with the use of the reverse-circulation drill: Gulf Minerals' Collins Bay B and Eagle Point uranium deposits in the Athabasca Basin, Saskatchewan and Inco's Golden Pond deposits in the Casa-Berardi gold district, Québec (Sauerbrei *et al.*, 1987).

The reverse-circulation rotary drill (Figure 4-1 and Photo 4-8) uses dual-tube rods in which water and compressed air are carried down the hole in the annulus between the outer and inner pipe. The drill cuttings are then brought to the surface through the inner tube. Cutting at the bottom of the hole is accomplished by a tricone bit which is specially designed (Photos 4-9 and 4-10) to direct the compressed water-air mixture, through ports, directly into the bit. Other drill bits, such as the 4 $^7/_8$ used for rock drilling are not a good substitute, as water is deflected around the bit resulting in sample carryover (Averill, 1993). Because the process does not involve coring, drilling can be completed without having to pull rods and re-enter the hole to recover the core samples.

As drill cuttings are returned to the surface, they enter a cyclone (Photo 4-11) which reduces the water velocity and permits the sampling of the slurry which passes through a sieve. A two-bucket retention system is used to retain fines. According to testing by Overburden Drilling Management (Nepean, Ontario), at this stage, most of the clay and approximately 30% of the silt is lost. In the case of gold exploration, where a large fraction of the gold is known to reside in the silt size fraction, this factor has to be taken into account in the interpretation of the results.

Recovery is generally good in all varieties of sediments. Sample loss typically occurs in the first 1 to 3 metres of the hole, prior to the formation of a sediment seal (Averill, 1990). Nevertheless, such sediment loss can be avoided with good drilling practices (S.A. Averill, personal communication, 1993).

The type of sample returned to the surface (slurry) and the single chance to describe sediment types as the drill rapidly penetrates the ground, complicates the stratigraphic interpretation. Although it is possible to decipher the surficial sediment stratigraphy, the quality of the interpretation is strongly dependent on the expertise of the driller and the experience of the on-site Quaternary geologist. Criteria such as lithology type and percentage content, particle size and colour of the matrix, and behaviour of the drill rods can all serve to improve interpretation.

With the rotasonic (*see* below) and reverse-circulation drills, till samples should be collected over depth intervals of 1 to 1.5 metres because: dispersal trains are usually thin (DiLabio, 1990); till units vary in thickness from one to tens of metres; and the variability of the gold content in the till through two or more consecutive samples can be used to distinguish between anomalous and background gold concentrations (Averill, 1990).

Contamination of samples may occur with the rotasonic or reverse-circulation drills from the tungsten and cobalt present in the tungsten carbide buttons of the bits and from the nickel and molybdenum present in the steel (Averill, 1990). The grease used on the drill rods can also represent a problem if geochemical analyses are done on fine grain-size fractions. Some brands contain high levels of copper, lead or molybdenum. Averill *et al.* (1986) reported analyses on two kinds of grease suitable for drilling (Table 4-3).

Levson *et al.* (1993) report results on the recovery of gold particles with a reverse-circulation drill, from buried placer deposits using low level radioactive gold particles (radiotracers). Four sizes of gold radiotracers including 0.18

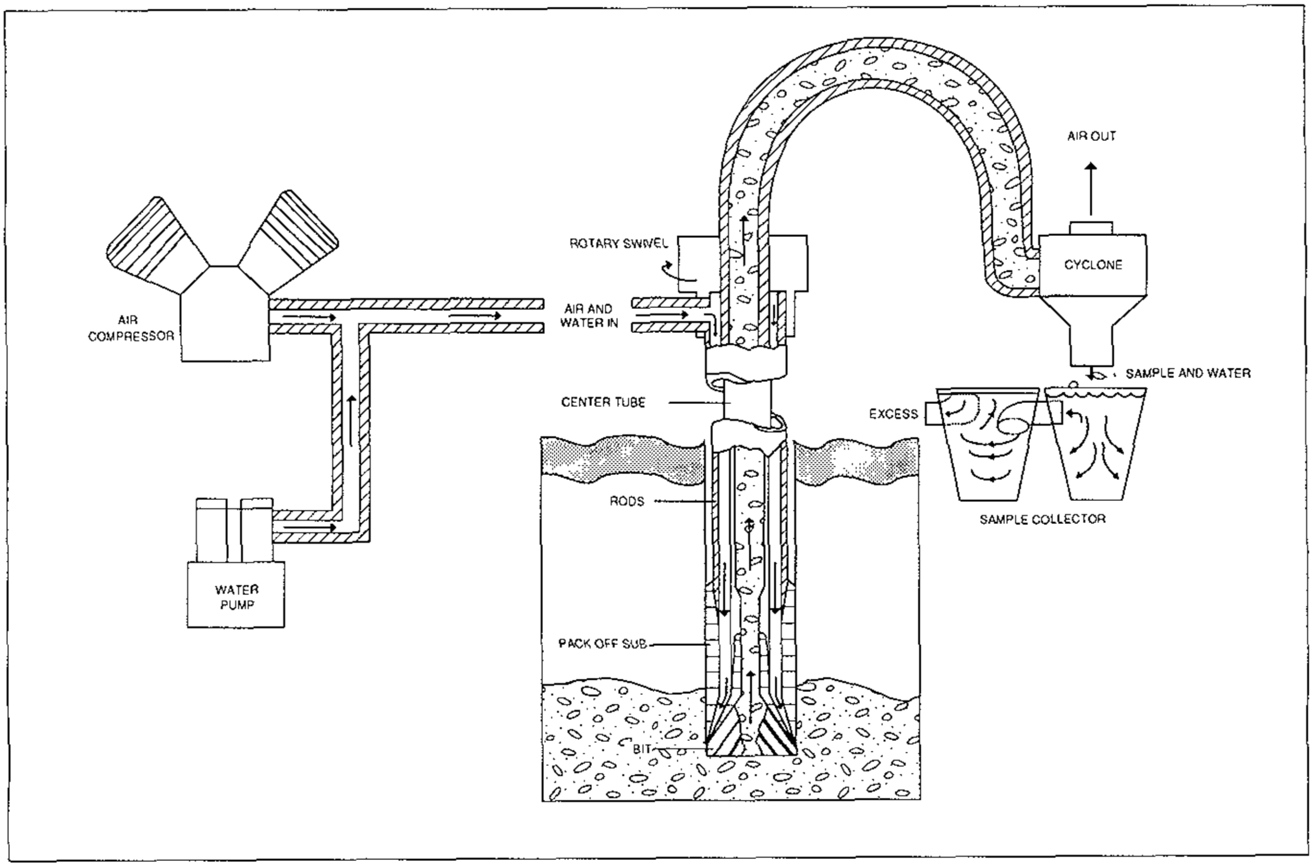

Figure 4-1. Schematic cross-section of a reverse-circulation drill; modified from Averill (1990).

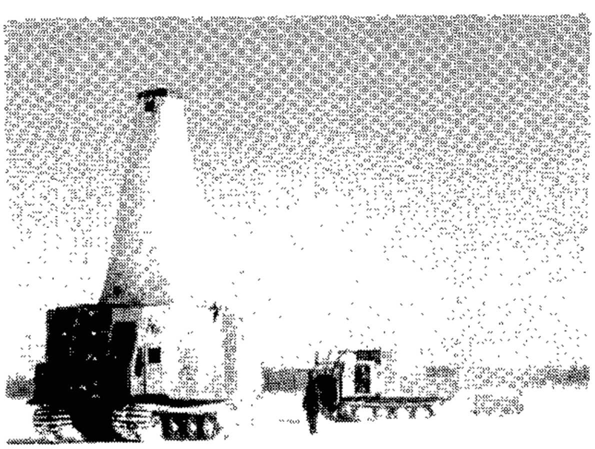

Photo 4-8. Reverse-circulation drill mounted on a Nodwell to drill through a frozen lake surface in Québec (GSC-1993-267-C).

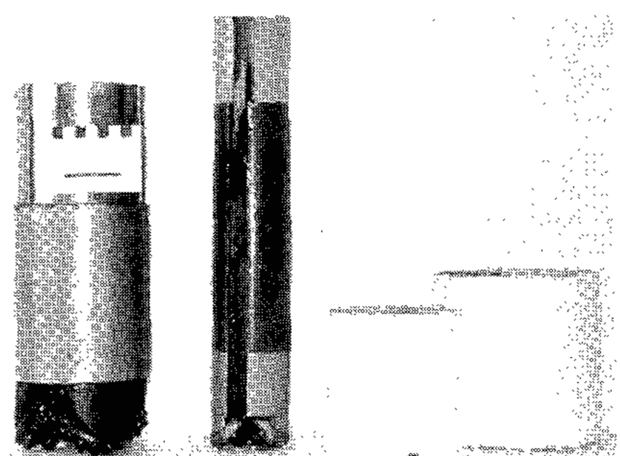

Photo 4-9. From left to right: (1) 4 7/8 tricone bit, (2) tricone bit specially designed for overburden drilling, (3) rotasonic coring bit and (4) rotasonic casing bit (GSC-1993-267-E).

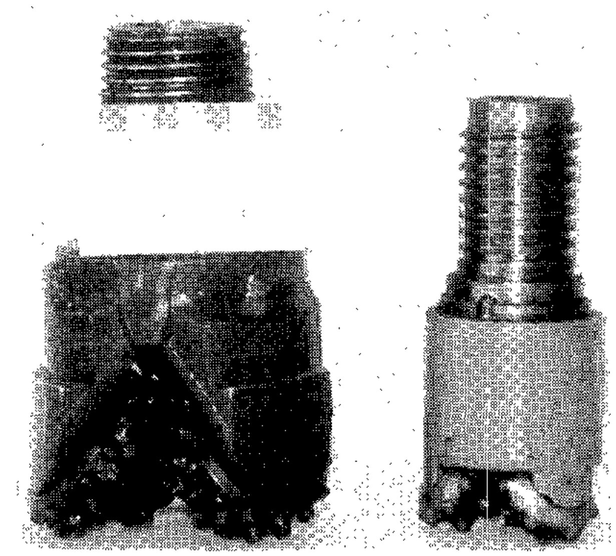

Photo 4-10. Closer view at two kinds of tricone bits. Left: 4 7/8 tricone bit; right: tricone bit with ports designed so that the compressed water-air mixture goes directly into the bit (GSC-1993-267-G).

Photo 4-11. Cyclone used to decrease the velocity of the slurry returned from the reverse-circulation drill. Notice the sieve placed underneath the cyclone (GSC-1993-267-H).

millimetre (-65+100 mesh), 0.36 millimetre (-35+48 mesh), 0.72 millimetre (-20+28 mesh) and 1.44 millimetre (-10+14 mesh) were mixed with gravel, frozen, then inserted into four holes previously drilled. Gravel was dumped and compacted into the hole prior to re-drilling. Presence of radioactive gold particles was determined with a scintillometer. Recovery among the four holes varied between 2 and 98%. Determining gold recovery by this method was greatly hampered by the caving of open holes, which interfered with the placement of the test samples. Some gold particles were lost by spillage and blow-by around the collar of the hole or were recovered from the hose fittings and sampling cyclone. These results indicate that some gold grains may be lost during drilling. However, more research has to be done to improve the methodology used to evaluate gold grain recovery with a drill. Only then will it be possible to evaluate the amount of gold grain loss.

Recent figures for the cost of reverse-circulation drilling have been published by Averill (1990). Drilling costs for a project having a hole spacing of 300 to 400 metres are $220 to $240 per hour plus mobilization or $45 to $60 per metre.

ROTASONIC DRILLING

The rotasonic drilling method (Figure 4-2) uses a combination of high frequency (averaging 5000 rpm) resonant vibration and rotation to recover continuous large-diameter (9 cm) cores of unconsolidated surficial sediments (Smith and Rainbird, 1987). No drilling fluids are needed for coring overburden, except when large boulders or bedrock are encountered. Sediment is cored with tungsten carbide fronted bits into 14.8 centimetre O.D. core barrels. Casing is flushed down to the level of the core barrel to prevent collapse of the borehole walls. After the core barrel is pulled to the surface, cores are retrieved in plastic sleeves 1.5 metres in length (Photo 4-12). These steps are repeated until the desired depth is reached. To store cores, wooden boxes should be constructed in advance. They can be made of 3/4 or 5/8 inch thick plywood or spruce lumber. Averill *et al.* (1986) used 1 x 6 inch spruce lumber to make boxes with inside dimensions of 12.1 x 14.0 cm. Although the drill is not meant for bedrock drilling, bedrock cores can be recovered. Averill *et al.* (1986) discuss in more detail operational procedures to achieve the best production rate and sample recovery in different sediment types with a rotasonic drill.

TABLE 4-3
METAL CONCENTRATIONS IN TWO GREASES

Brand Name	Cu	Pb	Zn	Mo	Ni
Esso Unitol	ND	18	3740	2	7
Shell Extrem	4	193	6	31	0

Concentrations in ppm (Averill et al., 1986)

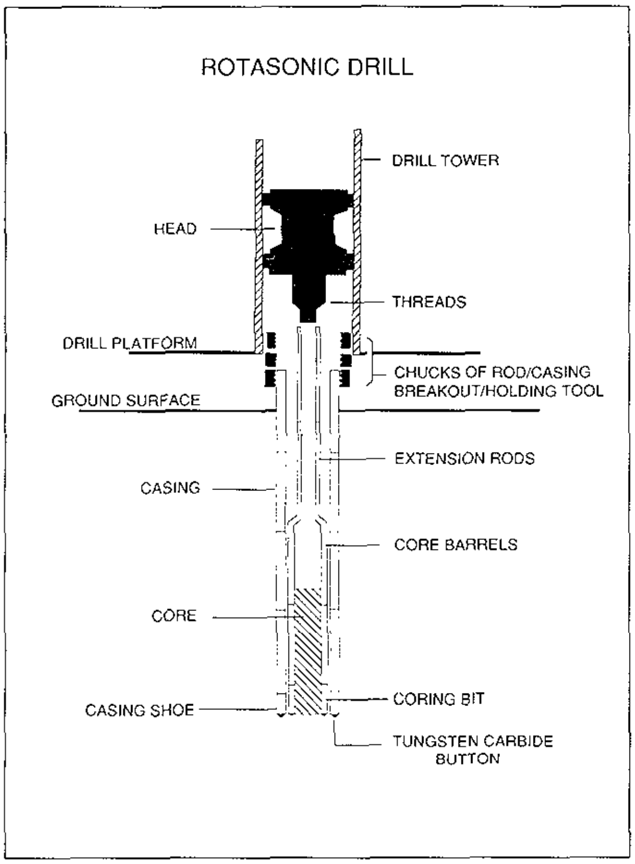

Figure 4-2. Schematic cross-section of a rotasonic drill; modified from McClenaghan (1991).

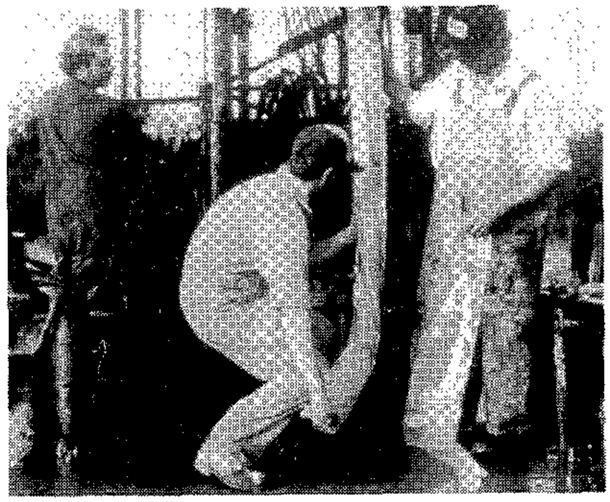

Photo 4-12. With the rotasonic drill, the core barrel is pulled to the surface and cores are retrieved in plastic sleeves in segments 1.5 metres long (GSC-1993-277-C).

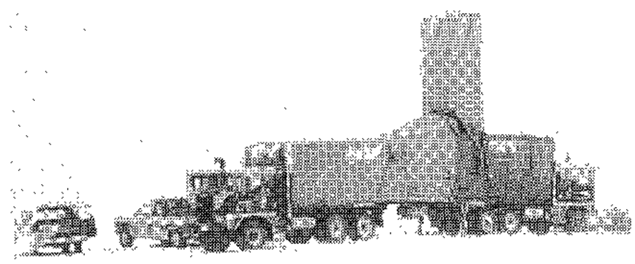

Photo 4-13. Rotasonic drilling set-up with two trucks back to back (GSC-1993-281-A).

The drill can be mounted on a multi-wheeled vehicle (truck), skid, Nodwell tracked vehicle or barge so that it can be used in different terrains. If the drill is mounted on skids, a skidder or bulldozer can be used to move the drill. As illustrated in Photo 4-13, the drilling set-up with trucks involves two vehicles: one contains the rig and the other the rods and casing. Drilling on a lake in the winter may require the build-up of an ice-bridge and platform.

Length distortion in cores may take place when recovering core from the barrel, which can produce a core up to 50% longer than the interval drilled. Hence the on-site geologist must observe the actual depth at which the core was obtained. During drilling, the coring bit which displaces sediments and the high-frequency vibrations may induce soft-sediment deformation. However, Smith and Rainbird (1987) used seven criteria to differentiate secondary deformations (drill-induced) from deformations of primary (synsedimentary) origin.

A significant advantage of rotasonic drills is the ability to recover continuous cores of sediments which greatly facilitate the interpretation of sediment stratigraphy and glacial history. On several occasions, this drill type has been selected to establish stratigraphy and reconstruct ice-flow patterns in areas where natural sediment exposures are rare or absent (*e.g.* Bird and Coker, 1987; DiLabio *et al.*, 1988; Lamothe, 1989; Shilts and Smith, 1986, 1988). The rotasonic drill is an important asset to an exploration program where ice-flow patterns are not known or known to be complex, and the surficial sediment stratigraphy is poorly understood.

On an hourly basis, rotasonic and reverse-circulation drilling are approximately equal. However, the productivity is not as high for the rotasonic drill as it is necessary to pull the core and re-enter the hole at 1.5-metre intervals. Consequently, rotasonic drilling costs are higher (Table 4-1; Averill, 1990).

CONCLUSIONS

Different methods are available to collect samples of unconsolidated sediments for drift prospecting. Hand excavation can be useful at the reconnaissance level of exploration or for detailed sampling in areas of thin drift (<3 m) but limits sampling to a maximum depth of about 1 metre. Trenching with the use of digging devices such as a backhoe can be very efficient in areas where surficial sediments do not exceed 5 metres. Boulders can hamper the use of portable drills for till sampling. However, small drills can be useful in areas where till is not bouldery, where environmental damage must be limited or where till has to be sampled underneath a veneer of sand. At a more advanced stage of exploration, when an anomaly in surficial sediments has been defined, overburden drilling could be the appropriate choice in thickly drift-covered areas. Two types of drills are most commonly used and have been successful in recovering large samples of surficial sediments: reverse-circulation and rotasonic drills. The reverse-circulation drill returns a sample slurry (sediment and bedrock) to the surface which can be logged by experienced Quaternary geologists. The rotasonic drill recovers a continuous core of the overburden, which facilitates the interpretation of the sediment stratigraphy, and is also capable of coring bedrock at the bottom of a hole.

ACKNOWLEDGMENTS

S.A. Averill of Overburden Drilling Management, Nepean, Ontario made major unpublished contributions to the content of this paper. Some of the information presented here was obtained from discussions with the following contractors: J. F. Archibald (Sonic Soil Sampling Inc., Toronto), W. Creighton (Creighton Rock Drill Ltd.), Grenville Whyte (Heath and Sherwood). B. McClenaghan, W.B. Coker, and J.J. Veillette of the GSC provided data about some of the drilling methods. L.H. Thorleifson improved the first version of the manuscript. K. Montour digitized Figures 4-1 and 4-2. All these contributions are gratefully acknowledged.

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QUATERNARY STRATIGRAPHY AND TILL GEOCHEMISTRY IN THE TINTINA TRENCH, NEAR FARO AND ROSS RIVER, YUKON TERRITORY

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INTRODUCTION

The discovery of a Tertiary epithermal gold-silver prospect in the Tintina Trench, Yukon Territory, indicates a potential for similar mineralization elsewhere along this structurally controlled depression (*e.g.* Duke, 1986; Duke and Godwin, 1986; Jackson *et al.*, 1986). Circumstantial evidence links the occurrence of placer gold, ice-flow directions and Tertiary volcanic rocks along the Tintina Trench (Jackson *et al.*, 1986). This relationship could not be tested by conventional exploration techniques (*e.g.* bedrock mapping, bedrock geochemistry, geophysics) because of the locally thick and extensive cover of glacial drift. For that reason, a drift prospecting study was initiated. The study, conducted during the summer of 1987, consisted of: a detailed Quaternary geology study including stratigraphy, identification of ice flow and the glacial dispersal of rock fragments, and interpretation of till geochemistry. The content of this paper has been previously published in a less extensive version by Plouffe and Jackson (1992).

SETTING

STUDY AREA

The study area (Figure 5-1) is centred on the Tintina Trench, extending from Wolverine and Finlayson lakes to southeast of Faro. It includes parts of the Quiet Lake, Finlayson Lake and Tay River NTS map areas (105 F, 105 G and 105 K, respectively). Two major roads cross the area: the Robert Campbell Highway, along which most of the till sampling has been done, and the Canol Road. The Tintina Trench is bounded by the Pelly Mountains to the southwest and the Pelly and Macmillan plateaus to the northeast. Differences in elevation between the Tintina Trench and the surrounding terrain are significant. Elevations in the trench range from 760 to 910 metres above sea level with a few areas reaching 1070 metres above sea level The Pelly Mountains range in elevation from 1220 to 1830 metres, with the highest peak reaching 2353 metres above sea level in the Wolverine Lake area. Plateau surfaces vary in elevation from 910 to 1370 metres.

BEDROCK GEOLOGY

The autochthonous rocks of the study area consist of a sequence of unmetamorphosed sedimentary and volcanic rocks deposited along the western margin of the North American shelf (Figure 5-2). They vary in age from late Precambrian to Triassic. In the collision of an island arc terrane with the continent, allochthonous rocks were superposed on the autochthonous assemblage. These allochthons are subdivided into two assemblages: the Nisutlin and Anvil allochthons (Tempelman-Kluit, 1977; 1979). Intrusion of post-tectonic granites in mid-Cretaceous time was related to heating and thickening of the continental crust during the collision (Gordey, 1988). The only known extrusive equivalents to these granitic rocks in the Cordillera are the South Fork volcanics northeast of the study area.

Between Late Cretaceous and mid-Eocene time, 450 kilometres of dextral slip occurred along the Tintina fault zone (Tempelman-Kluit, 1979). Recent work by Jackson *et al.* (1986) and Pride (1988) indicates the presence of a Paleogene bimodal volcanic province which consists of an assemblage of rhyolite and basalt interbedded with coarse sedimentary rocks. This province is thought to be related to crustal extension and transcurrent slip along the Tintina fault (Jackson *et al.*, 1986).

ECONOMIC GEOLOGY

Several bedrock mineral occurrences and targets, and placer gold deposits, have been found in the study area as a result of exploration work conducted by private companies and prospectors. Most of the detailed exploration has occurred near the Grew Creek gold-silver prospect (Figure 5-3). Rocks preserved in a graben at Grew Creek consist of felsic volcanic and volcaniclastic units overlain by interbedded coarse clastic sediments, basaltic flows and basaltic volcaniclastic beds (Duke, 1986; Duke and Godwin, 1986). At Grew Creek, two zones of mineralization, the Main and Tarn zones, are characterized by intense silicic and argillic hydrothermal alteration. High-grade gold and silver mineralization occurs in chalcedonic quartz and potassium feldspar bearing veins formed during volcanism (Duke and Godwin, 1986). Both gold and silver are enriched in samples from boreholes, although mineralized outcrops are characterized only by high gold levels (T. Christie, oral presentation, Geoscience Forum, Whitehorse, Yukon, 1988).

PREVIOUS WORK

Multiple glaciations in Yukon Territory were first proposed from studies in the Carmacks area (Bostock, 1934). Later, Bostock (1966) described two series of end moraines and glacial deposits related to four glaciations: the youngest McConnell Glaciation (Wisconsinan age); the more exten-

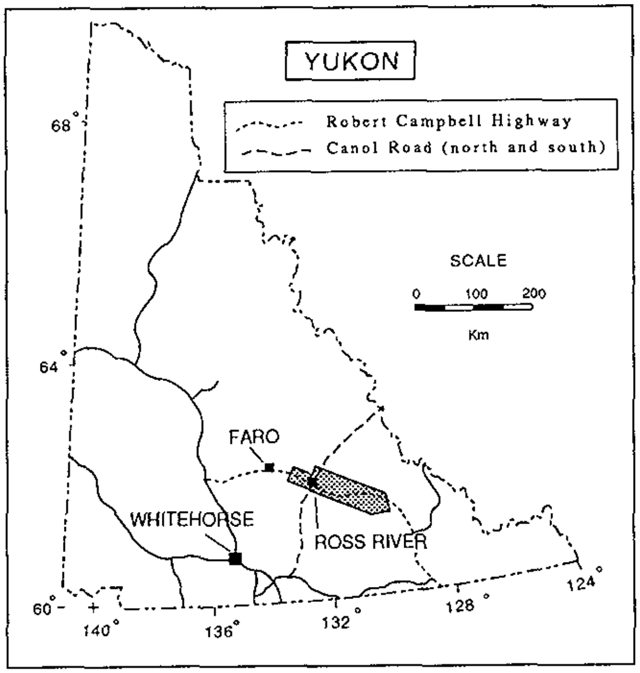


Figure 5-1. Map of Yukon Territory with study area shaded.

sive Reid Glaciation (Illinoian age; Clague *et al.*, 1992); and two pre Reid Glaciations. From interpretation of aerial photographs, and limited ground observations, Hughes *et al.* (1969) reported that the Cordilleran ice sheet flowed west to northwest over the study area during the McConnell Glaciation. Campbell (1967) gave the name "Selwyn lobe" to this sector of the Cordilleran ice sheet. Hughes *et al.* (1969) suggested that "a stage of alpine glaciation preceded the McConnell advance in mountainous areas lying within the limits of the ice sheet." Duke-Rodkin *et al.* (1986) reconstructed the profile of the Selwyn lobe using the inferred McConnell age moraines and ice-marginal channels associated with nunataks in the Glenlyon and Tay River map areas (105 L and 105 K). Jackson (1989) described the paleoglaciology of the Selwyn lobe and the Quaternary stratigraphy of parts of the study area. He also mapped the regional Quaternary geology of the Pelly Mountains and Tintina Trench area (Jackson, 1986a; 1986b; 1987). Ward (1989) and Ward and Jackson (1992) reported on the Quaternary geology for an area that extends along the Pelly River in Glenlyon and Carmacks map areas.

QUATERNARY STRATIGRAPHY

The two most complete stratigraphic sections (sections 076 and 044) in the area are exposed in the Pelly and Lapie River valleys. Other sections reveal key information regard-

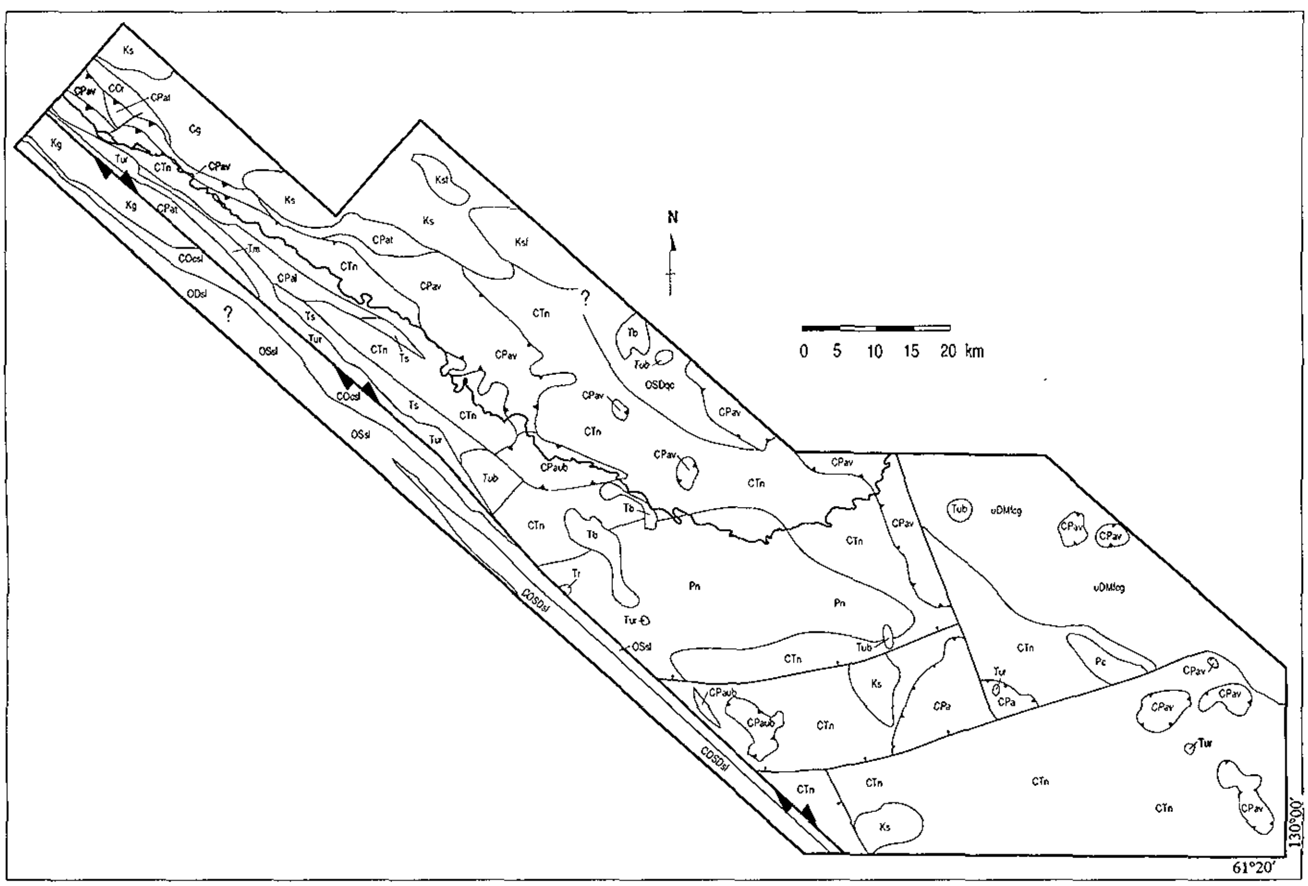


Figure 5-2. Generalized geological map of study area (modified after Tempelman-Kluit, 1977 and Gordey and Irwin, 1987).

LEGEND

NE OF TINTINA FAULT

Tertiary

T	Tr, rhyolites dated as Paleogene; Tb, basalts dated as Paleogene; Tm, mixed volcanics of known Paleogene age; Tur, undated rhyolites likely of Paleogene age; Tub, undated basalts likely of Paleogene age; Ts, sandstone, conglomerate, and shale.

Mid-Cretaceous

K	Ksf, South Fork Volcanics : crystal lithic tuff; Ks, quartz monzonite, granite and granodiorite

Allochthonous Assemblages

Pennsylvanian and Permian

CPa	Anvil Allochthonous Assemblage : Cpa, undivided; CPav, basalt, tuff, and breccia; CPat, chert, and **siliceous tuff; CPal, limestone; CPaub, dunite, peridotite, pyroxenite, and serpentinite.**

Carboniferous to Triassic

CTn	Nisutlin Allochthonous Assemblage : metaquartzite, blastomylonite, phyllite, quartzite, schist, sand conglomerate.

Autochthons

Carboniferous or Permian

Pc	limestone

Upper Devonian and Mississippian

uDMfcg	chert pebble conglomerate

Silurian and Lower Devonian

OSDqc	calcaerous and dolomitic graphitic siltstone

Cambro-Ordovician

COr	shaly limestone to calcareous phyllite

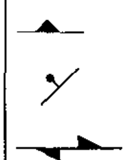
Lower Cambrian

Cg	slate and siltstone and metamorphosed equivalents near intrusions

?Cambrian?

Pn	augen gneiss

Symbols



Fault, thrust (teeth on upper plate)

Fault, steeply dipping (barb on downthrown side)

Dextral slip fault

SW OF TINTINA FAULT

Mid-Cretaceous

Kg	diorite, granodiorite, and granite

Autochthons

Ordovician to Devonian

ODsl	black siliceous and pyritic slate

? Ordovician and Silurian ?

OSsl	calcareous graphitic slate and graphitic siliceous and pyritic slate.

? Cambrian, Ordovician, Silurian, and Lower Devonian ?

COSDsl	calcareous shale, siltstone, and argillaceous limestone

?Cambrian and Ordovician ?

COcsl	calcareous siltstone, argillaceous limestone

Figue 5-2. Legend to accompany the bedrock geology map.

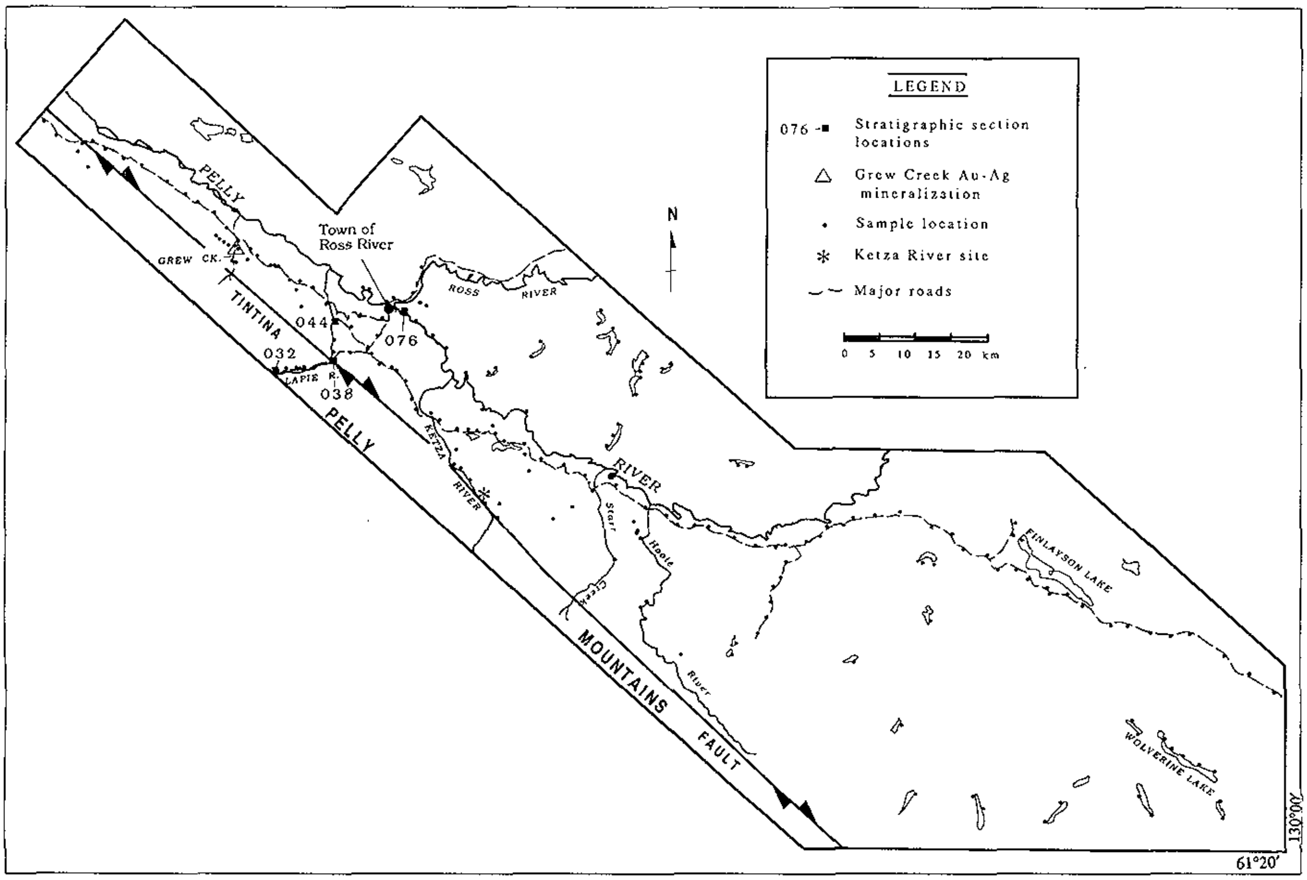


Figure 5-3. Study area with major stratigraphic sections and till sample locations indicated.

ing the Quaternary history and are also described below. More thorough descriptions of the stratigraphic units are presented in Plouffe (1989).

SECTION 076

Section 076 is exposed along the Pelly River, 3 kilometres due east of the town of Ross River (Figure 5-3) and can be reached by helicopter or by motorized canoe. It is described by Jackson (1989) as section 14686 S-1.

The lowest exposed unit is a grey, compacted diamicton, containing striated clasts, and is interpreted as pre-McConnell till (Figure 5-4). It is overlain by glaciolacustrine sediment, horizontally stratified gravel and another diamicton. The gravel sequence coarsens upward, suggesting that it was deposited in front of the advancing McConnell glacier. Several striated clasts were found at the contact between the gravel and the overlying compacted diamicton; the latter is interpreted as McConnell till. The till, in turn, is overlain essentially by a similar sequence of sediments as below: glaciolacustrine sediments and stratified gravels. The glaciolacustrine sediments are confined to the Pelly River valley, evident in river sections downstream from the town of Ross River. Correlation among exposures along the Pelly River, indicates that the uppermost stratified gravel overlying the glaciolacustrine sediments is outwash deposited in front of the retreating McConnell glacier. At the top of the section, the White River tephra (Lerbekmo *et al.*, 1975) is exposed within a well sorted fine sand and silt unit, thought to be aeolian in origin.

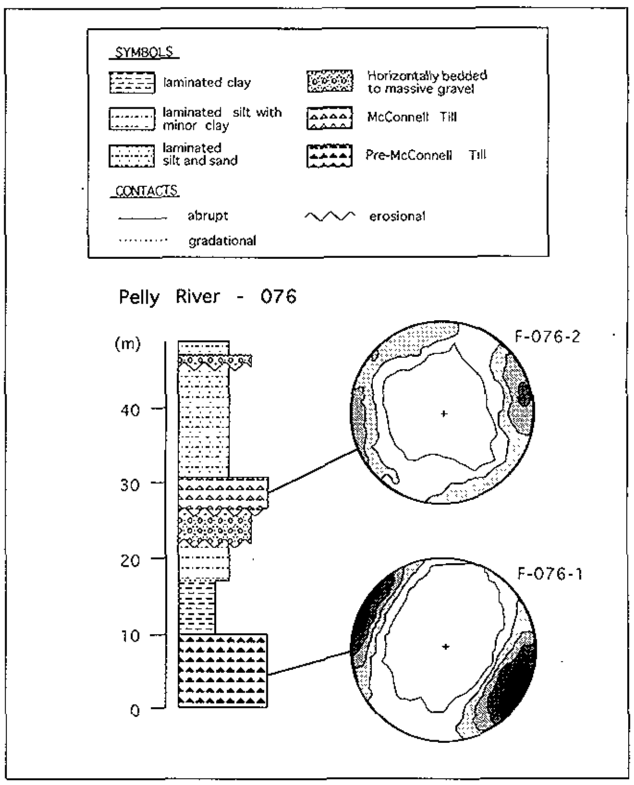


Figure 5-4. Stratigraphic column of section 076 with equal-area stereographic plots of long axes of clasts (50 measurements in each case). *See* text for description. Contours are 2, 4, 6, 8 and 10% per 1% area.

Erratics in pre-McConnell and McConnell tills include abundant metasedimentary and clastic sedimentary rocks and rare ultramafic, quartz and calcareous rocks. These rocks are probably derived from allochthons to the southeast (Tempelman-Kluit, 1977; Figure 5-2). As clast lithologies in the two tills are similar, paleo-ice-flow directions were probably toward the west to northwest in the Pelly River valley, during both pre-McConnell and McConnell glaciations.

Pebble fabrics were taken in both tills (Figure 5-4 and Table 5-1). The a-axes of clasts are primarily oriented northwest-southeast in the pre-McConnell till deposits. Pebbles in McConnell till have an east-west orientation, but with a lower eigenvalue (Table 5-1), which may result from re-orientation of clasts during deformation by an active glacier (Boulton, 1970; Åmark, 1986).

SECTION 044

Section 044 is exposed along the Lapie River, about 8 kilometres southwest of the town of Ross River (Figure 5-3) and can be reached by bush road from the Campbell Highway. It is described by Jackson (1989) as section 7686 S-2.

Stratigraphy at this section is very similar to section 076 (Figures 5-4 and 5-5). The oldest unit exposed is a poorly sorted, clast-supported bouldery gravel interpreted as alluvium. A sharp erosional contact separates the gravel from an overlying grey, compact diamicton which contains some striated boulders, interpreted as pre-McConnell till. The contact between the till and the overlying outwash gravel sequence is abrupt. The outwash deposit is characterized by numerous beds of gravel, sand and discontinuous diamicton. Diamicton beds drape underlying sediments and are thought to be gravity-flow deposits. Two depositional cycles were defined in the outwash gravel: the gravel unit fines upward in its lower part and coarsens upward in its upper part. This

TABLE 5-1

EIGENVALUES AND EIGENVECTORS OF TILL FABRICS CALCULATED WITH THE STEREONET PROGRAM

(v. 3.6 by R.W. Allmendinger), following Mark (1973) eigenvalue method

Fabric	V1	V2	V3	S1	S2	S3
F-032-1	072 01	162 18	339 72	0.802	0.147	0.051
F-038-1	057 01	147 15	323 75	0.701	0.192	0.107
F-038-2	262 01	172 22	354 68	0.714	0.164	0.123
F-038-3	307 04	217 01	116 86	0.703	0.206	0.090
F-044-1	286 03	017 11	179 79	0.544	0.390	0.066
F-044-2	112 12	017 23	227 64	0.518	0.374	0.108
F-044-3	080 16	347 11	224 70	0.667	0.222	0.110
F-044-4	098 20	188-02	282 70	0.591	0.317	0.092
F-076-1	116 06	207 13	002 75	0.686	0.268	0.047
F-076-2	090 03	181 03	315 85	0.507	0.387	0.106

Note that these values should be interpreted with care because, as presented by Woodcock (1977), bimodal and multimodal data (which is the case for the till fabrics presented here) can result in the eigenvectors falling between modes. V1, V2, and V3 represent the trend and plunge of the eigenvectors; V1 being the direction of maximum clustering, and V3 that of normal clustering. S1, S2 and S3 are the respective normalized eigenvalues.

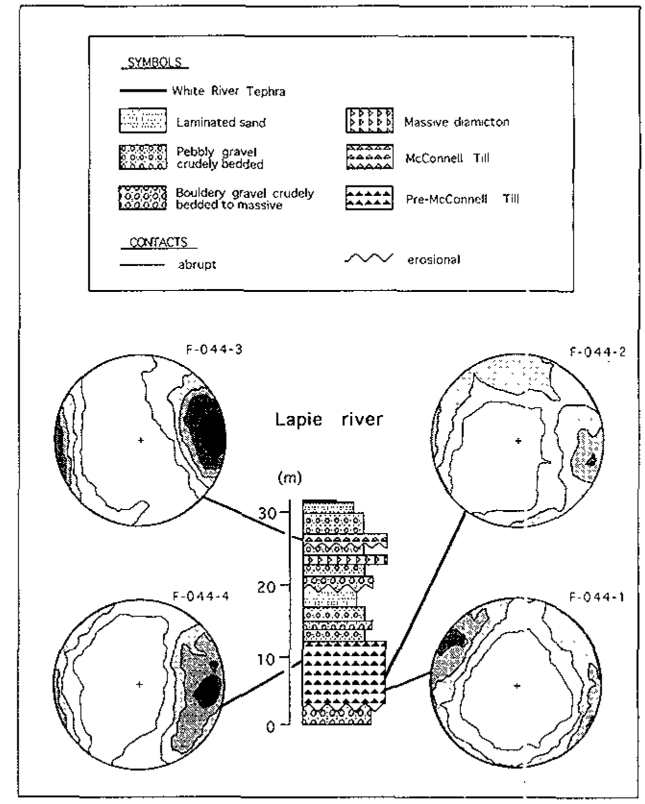


Figure 5-5. Stratigraphic column of section 044 with equal-area stereographic plots of long axes of clasts (50 measurements in each case). *See* text for description. Contours are 2, 4, 6, 8 and 10% per 1% area.

suggests that these gravels were deposited either during retreat of the pre-McConnell glacier and advance of the McConnell ice, during fluctuations of the retreating pre-McConnell ice front or during fluctuations of the advancing McConnell ice front. The gravels are sharply overlain by a diamicton, varying from 1 to 2 metres in thickness, probably the McConnell till. Finally, the section is capped by another 2 metres of outwash gravel and sand. White River tephra is exposed at the top of the section in interbedded colluvium.

The predominant lithologies in both till units are clastic sedimentary and metasedimentary rocks which are equivalent in their abundance. They indicate a provenance to the east or southeast (Tempelman-Kluit, 1977; Figure 5-2). Four till pebble fabrics were measured (Figure 5-5, Table 5-1). Pebble orientations are both parallel and transverse to the east and southeast ice-flow directions inferred from till lithologies. Fabrics transverse to ice flow can result from the reorientation of clasts in till due to deformation by the overlying active glacier (Boulton, 1970; Åmark, 1986).

SECTION 038

Section 038 is exposed along the south Canol Road near the Pelly Mountains (Figure 5-3). The lowermost unit is a grey, compacted diamicton, 18 metres thick, with abundant striated clasts, which is interpreted as McConnell till. It is overlain by 25 metres of gravels (Figure 5-6) which displays abrupt contacts, marked grain-size differences between

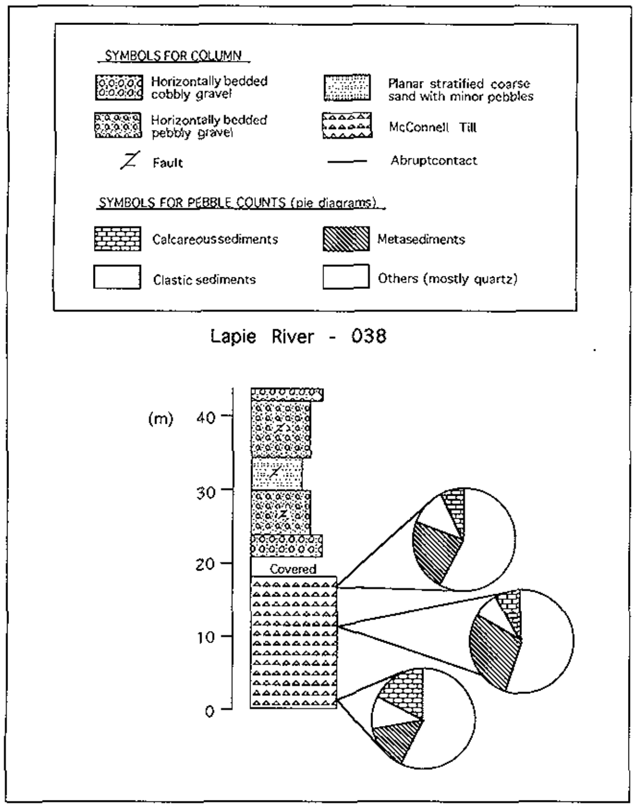


Figure 5-6. Composite stratigraphic column of section 038 with pie diagrams representing percentages of each lithology at three levels in till.

beds, and abundant faulting, all of which demonstrate that the gravel was probably deposited in contact with ice.

Till pebble samples were collected and lithologies identified at three levels (Figure 5-6). Lithologies are primarily clastic sedimentary rocks, with variable proportions of calcareous and metasedimentary clasts. The lowest part of the till is rich in calcareous sedimentary rocks and lean in metasedimentary rocks compared to the upper portion. Vertical lithologic changes could result from: local lithologies near the base of the till *versus* far-traveled lithologies in the upper part, or an earlier ice flow out of the Lapie River valley, at the onset of McConnell glaciation, which contributed abundant calcareous sedimentary rocks (*see* Figure 5-2).

Till pebble fabrics were measured at three sites, where pebble lithology samples were collected (Figure 5-7 and Table 5-1). The fabrics indicate an initial ice flow out of the Lapie River valley followed by flow parallel to the Tintina Trench. This supports the second point above. However, the possibility remains that the a-axis orientations in the lower fabrics are perpendicular to ice flow, whereas the a-axis trends in the upper fabric are parallel to ice-flow direction.

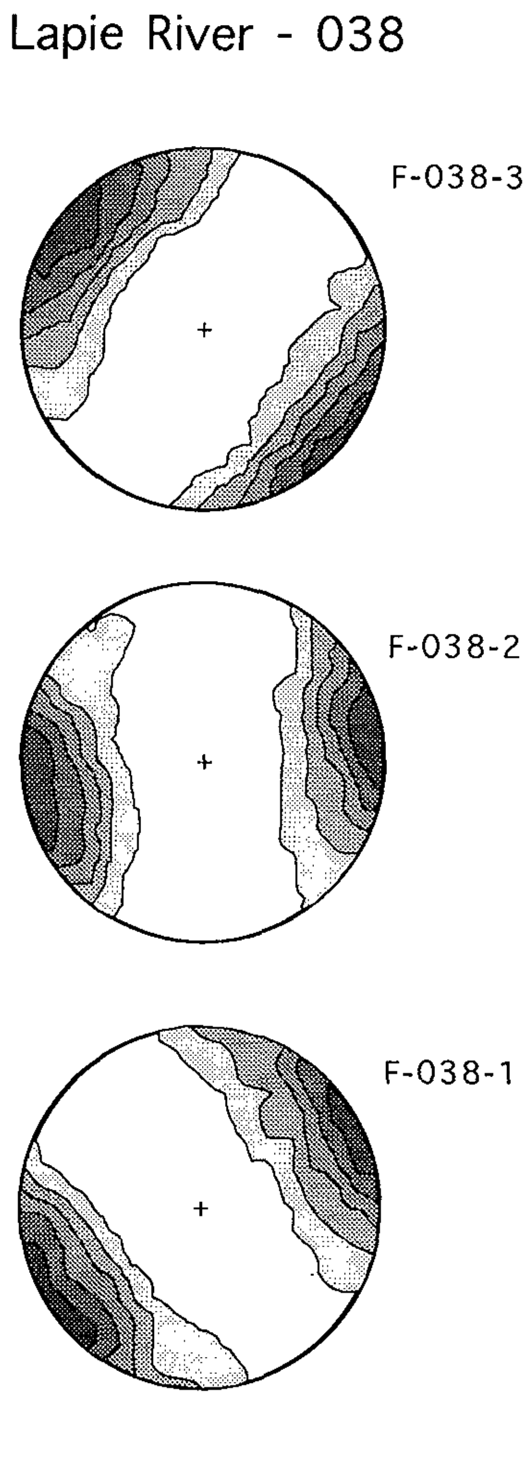


Figure 5-7. Equal-area stereographic plots of long axes of clasts at section 038 (50 measurements in each case). Fabric locations are the same as pebble counts (*see* Figure 5-6). Contours are 2, 4, 6, 8 and 10% per 1% area.

SECTION 032

Section 032 is located along the south Canol Road in the Pelly Mountains within the Lapie River valley (Figures

5-3 and 5-8). At the base of the section, 4 metres of grey, compacted diamicton is interpreted as McConnell till. Till fabric analysis reveals that clasts have a preferred orientation parallel to the valley (Figure 5-8 and Table 5-1). Cobbles of South Fork volcanics found within the till are derived either from bedrock on the Macmillan Plateau (Gordey, 1988) or from unconsolidated sediments in the Tintina Trench (Plouffe, 1989). The till is overlain by stratified sand and gravel. In one well sorted sand bed, planar cross-stratified laminations indicate a paleocurrent towards the west-southwest. Pebbles of Tertiary rhyolite with a provenance to the northeast in the Tintina Trench (Figure 5-2) occur in the gravel. The gravel is overlain by silt and clay characterized by rare and discontinuous primary laminations.

Based upon their stratigraphic position beneath glaciolacustrine sediments, the stratified gravels are interpreted as a subaqueous outwash fan deposited in a glacial lake dammed by glacier ice in the Tintina Trench. The water level elevation of this glacial lake was probably controlled by the ice dam and the water drainage divide between Lapie and Ross rivers, higher up in the Pelly Mountains at about 1080 metres elevation; gravels at Section 032 are at about 945 metres above sea level.

QUATERNARY HISTORY

The only evidence of conditions prior to the pre-McConnell glacial event comes from the lowest gravels exposed at section 044, which indicate a period of fluvial aggradation. Evidence from two exposures of pre-McConnell till indicates that ice flowed westward to northwestward during pre-McConnell glaciation. Most pre-McConnell drift was eroded during the subsequent McConnell glaciation. During the pre-McConnell ice retreat, a glacial lake formed in the Pelly River valley as indicated by laminated silt and clay in section 076 (Figure 5-4). At this time, tributary valleys of the Pelly River were characterized by glaciofluvial aggradation (Jackson, 1989). As part of the paraglacial processes (Jackson *et al.*, 1982), major streams such as the Pelly River evolved from braided to meandering as the sediment load decreased (Jackson, 1989).

In the absence of dateable materials, the time elapsed between pre-McConnell and McConnell glaciations remains unknown. Jackson and Harington (1991) report a Middle Wisconsinan assemblage of large and small mammals underneath McConnell till at the Ketza River site (Figure 5-3). However, no correlation between the Ketza River site and sections 044 and 076 (Figures 5-4 and 5-5) has been attempted because of the lack of stratigraphic information. Consequently, McConnell and pre-McConnell glaciations (as termed in this paper) may possibly be two ice advances which occurred during the same glaciation (*sensu stricto*).

At section 038, a valley glacier apparently flowed northward out of the Lapie River valley at the onset of McConnell glaciation. At the McConnell maximum, ice flow in the Selwyn lobe was west to northwest. As McConnell glacier ice retreated, an ice tongue blocked the Lapie River valley, damming drainage and creating a glacial lake at about 1080 metres elevation, as estimated from the highest occurrence of glaciolacustrine sediments (Jackson, 1989) and the lowest possible outlet for the lake. As for pre-McConnell glaciation, during the retreat of McConnell glacier, a glacial lake inundated the Pelly River valley (Jackson, 1989).

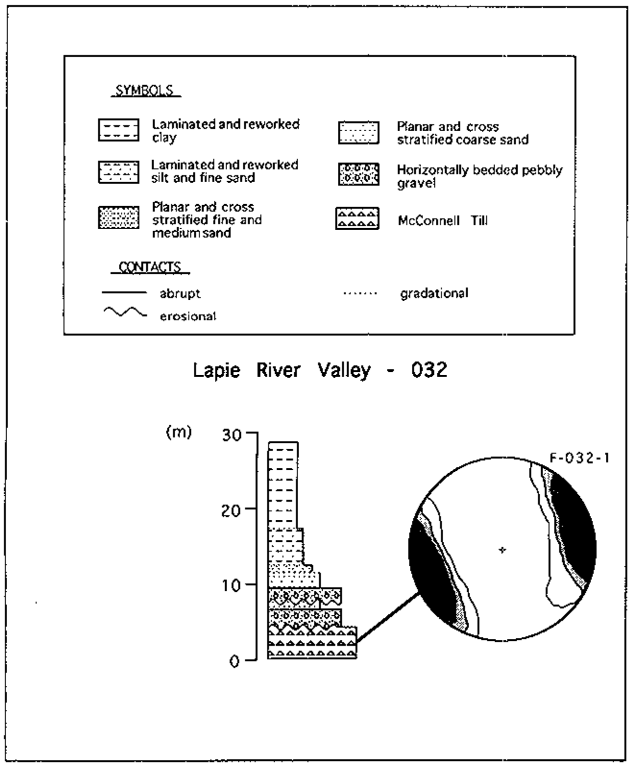


Figure 5-8. Stratigraphic column of section 032 with equal-area stereographic plot of long axes of clasts (30 measurements). Contours are 2, 4, 6, 8, 10, 12 and 14% per 1% area.

TILL GEOCHEMISTRY SAMPLING AND ANALYSIS

Two hundred and four till samples were collected for geochemical analyses (Figure 5-3). Samples were collected from river bank sections, road cuts, old trenches and hand dug pits. Care was taken to collect samples below the postglacial solum. In areas of easy access, such as along the Campbell Highway, the distance between till samples averages 2 kilometres. Elsewhere, because of limited accessibility with a floatplane and helicopter, a much greater distance separates each sample.

LABORATORY PROCEDURES

Till samples were sieved to separate the silt and clay size fraction (<63µm). The clay fraction (<2µm) was separated by centrifuge, following procedures developed by the Geological Survey of Canada. Determination of the silt/clay ratio was completed by pipette analysis (Folk, 1968). Samples were wet sieved in order to separate the 125 to 250-micron size fraction. Heavy minerals were then separated from this fraction with a shaking table and methylene iodide (s.g.

3.3) by Overburden Drilling Management Ltd., Nepean, Ontario.

Geochemical analyses on the clay, and silt and clay size fractions were performed by Acme Analytical Laboratories Ltd., Vancouver, B.C. The clay fraction was analyzed for silver, arsenic and antimony by ICP (inductively coupled plasma) after a hot acid ($HCl-HNO_3$) leach using 0.5-gram samples; mercury was analyzed by flameless atomic absorption.

In oxidized till, the greatest concentrations of most metals occur in the clay size fraction because: phyllosilicates, which preferentially occur in the clay size fraction, have a primary metal enrichment within their structure, and metals, released by weathering of labile minerals, are scavenged by colloidal particles such as clay minerals, oxides and hydroxides (Shilts, 1984). The -63 micron fraction was analyzed for gold by atomic absorption using 10-gram samples with a detection limit of 1 ppb. That size fraction was selected because gold is preferentially enriched in the fine fractions of oxidized till (DiLabio, 1985). In unoxidized samples "gold is most abundant in grain size fractions that reflect the grain size of the glacially liberated and comminuted native gold and oxide or sulfide host minerals" (DiLabio, 1985). At Grew Creek, gold occurs in bedrock as native particles with an average diameter of 7.5 microns (J.L. Duke, personal communication, 1988). Consequently, assuming similar mineralization elsewhere in Tintina Trench, it is probable that in unoxidized till gold is concentrated in the silt and finer size fractions. Coarser size fractions include minerals such as quartz and feldspar that would 'dilute' the sample, leading to lower measured gold concentrations. Heavy minerals were analyzed for gold by neutron activation at Bondar-Clegg & Company Ltd., Ottawa, Ontario. The clay size fraction was also analyzed for base metals and heavy minerals for a series of gold pathfinders; these results are discussed by Plouffe (1989).

RESULTS AND DISCUSSION

Several methods of calculating thresholds for exploration geochemical data are presented in the literature (Rose *et al.*, 1979; Sinclair, 1974). As the threshold of a particular element in till can vary over different bedrock lithologies, and because this survey covers a variety of bedrock types, the 90th percentile was arbitrarily selected as the threshold. In the case of gold in the silt plus clay size fraction of till, the 90th percentile is equivalent to 7 ppb.

GOLD IN THE SILT PLUS CLAY SIZE FRACTION OF TILL

Textural analyses were performed on a series of samples to verify any possible relationship between the gold and silt contents (*i.e.* to determine if gold was preferentially concentrated in the silt size fraction compared to the clay size fraction). As illustrated in Figure 5-9, correlation between gold and silt-clay ratio is low. It is concluded that size distribution of the -63 micron fraction does not affect gold values, and gold must be present in the silt (<63μm - 2μm) and the clay (<2μm) size fractions, probably bound as complexes to oxides, hydroxides and/or clay minerals (Boyle, 1979; Boyle *et al.* 1975). To date, there is a lack of data to indicate if gold in the silt plus clay size fraction is detrital and/or chemically remobilized. Detailed work on gold particles recovered from this fraction (*e.g.*, fineness) could clarify whether their mode of transportation was detrital or chemical.

Forty-seven till samples were analyzed twice to estimate analytical precision. Samples were chosen at random throughout the set of 204 samples. Results obtained after the first and second analyses are depicted in Figure 5-10 (using a graphic technique modified from Shilts, 1975). Vertical shading indicates values above background (7 ppb or 90th percentile) after the first analysis; horizontal shading is above background after the second analysis. Samples anomalous in both analyses are plotted in the cross-hatched field, and background samples in the clear field. Poor correlation between first and second analyses demonstrates the low reproducibility and precision of gold analyses. The poor precision of the analytical method for the silt and clay size fraction is attributable to heterogeneous distribution of gold particles in samples, and several geochemical results close to the detection limit of 1 ppb, where precision is low (Thompson and Howarth, 1976).

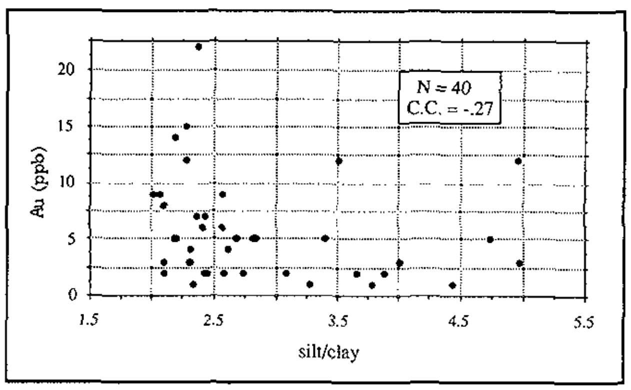


Figure 5-9. Correlation graph of gold content and silt/clay ratio of the silt plus clay size fraction of till (C.C. = correlation coefficient).

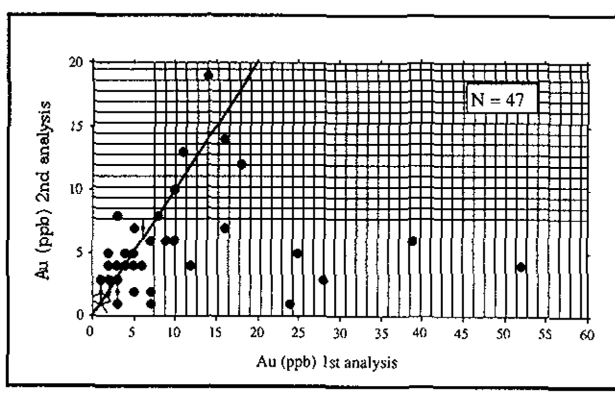


Figure 5-10. Graph showing results of duplicate analyses, using a graphic technique modified from Shilts (1975).

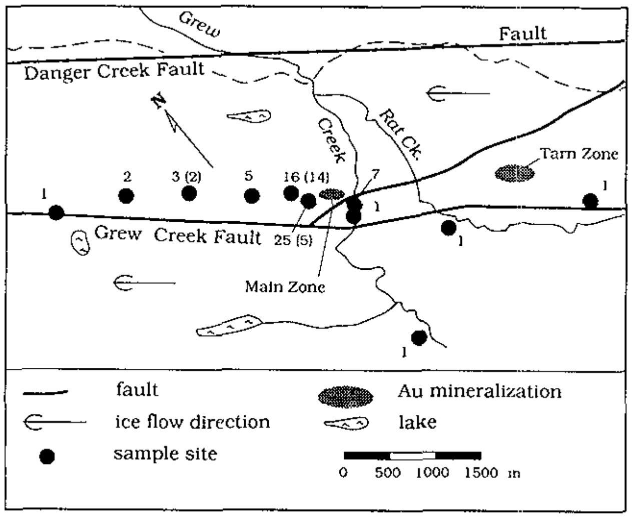


Figure 5-11. Detailed view of glacial dispersal of gold in the silt and clay size fraction of till near the Grew Creek prospect. Concentrations are in ppb, and values in parentheses represent duplicate analyses. Location of mineralized zones and faults from Duke and Godwin (1986).

TRANSPORT DISTANCE OF ANOMALOUS CONCENTRATIONS OF GOLD IN TILL

In the Grew Creek area, where two mineralized zones are known, detailed till sampling was conducted to determine the distance of transport of anomalous concentrations of gold (Figure 5-11). Assuming that gold is derived from the Main zone, a single sample collected 250 metres down-ice from the showing would have been recognized as anomalous (above the 90th percentile or 7 ppb). Furthermore, if the 75th percentile is declared anomalous (5 ppb), mineralization could be recognized as far as 500 metres down ice. From these data, it is concluded that prospects similar to Grew Creek might remain undetected with the sample interval of 2 kilometres employed along the Campbell Highway. Prospecting for epithermal deposits similar to Grew Creek, requires a sample interval no greater than 500 metres measured parallel to the ice-flow direction. More work will be required in order to define the width of the gold dispersal train at Grew Creek and to define a sampling interval measured perpendicular to the ice-flow direction.

GOLD GEOCHEMICAL MAP

High gold concentrations occur in the northwestern part of the study area, between Ketza River and Grew Creek (Figure 5-12). The Grew Creek gold-silver deposit is reflected in this size fraction by a series of anomalies directly

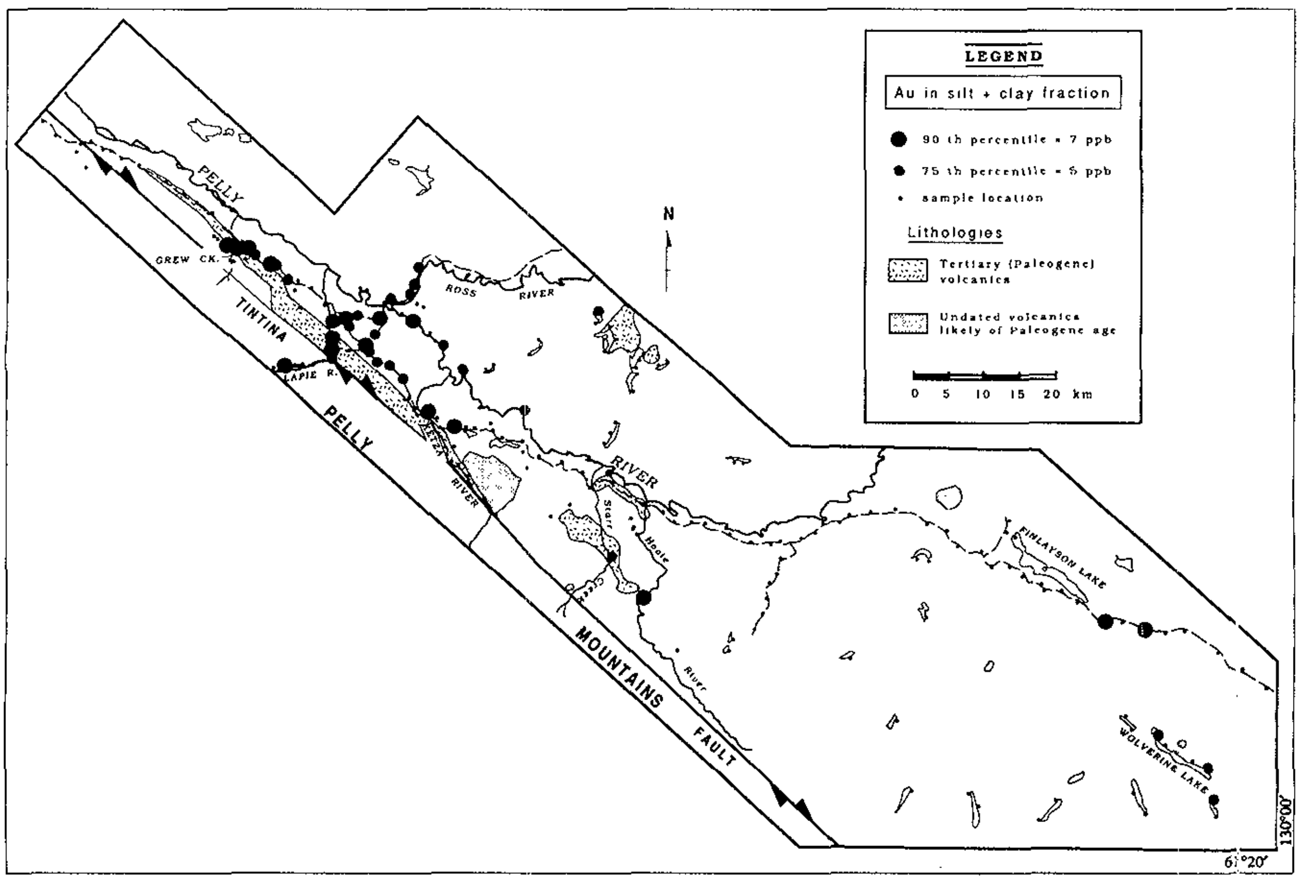


Figure 5-12. Gold abundance in silt and clay size fraction of till.

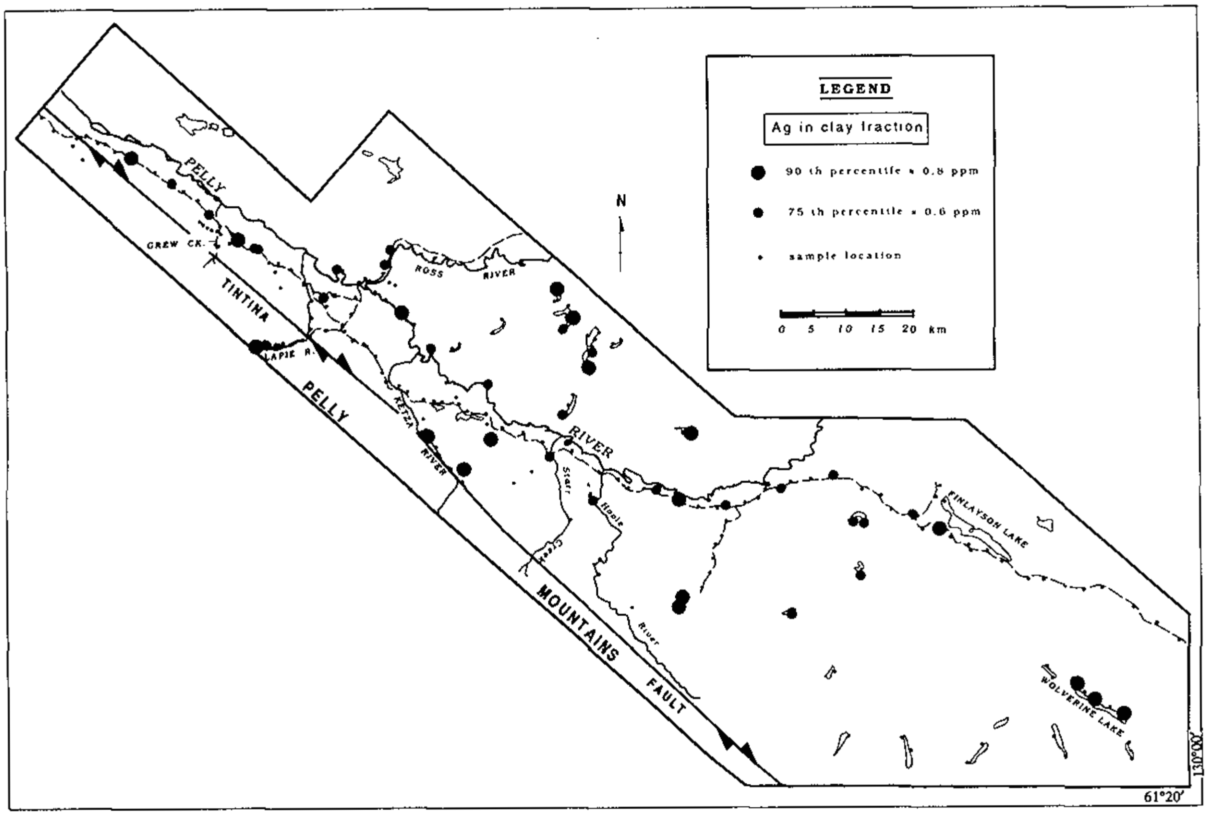


Figure 5-13. Silver abundance in the clay size fraction of till.

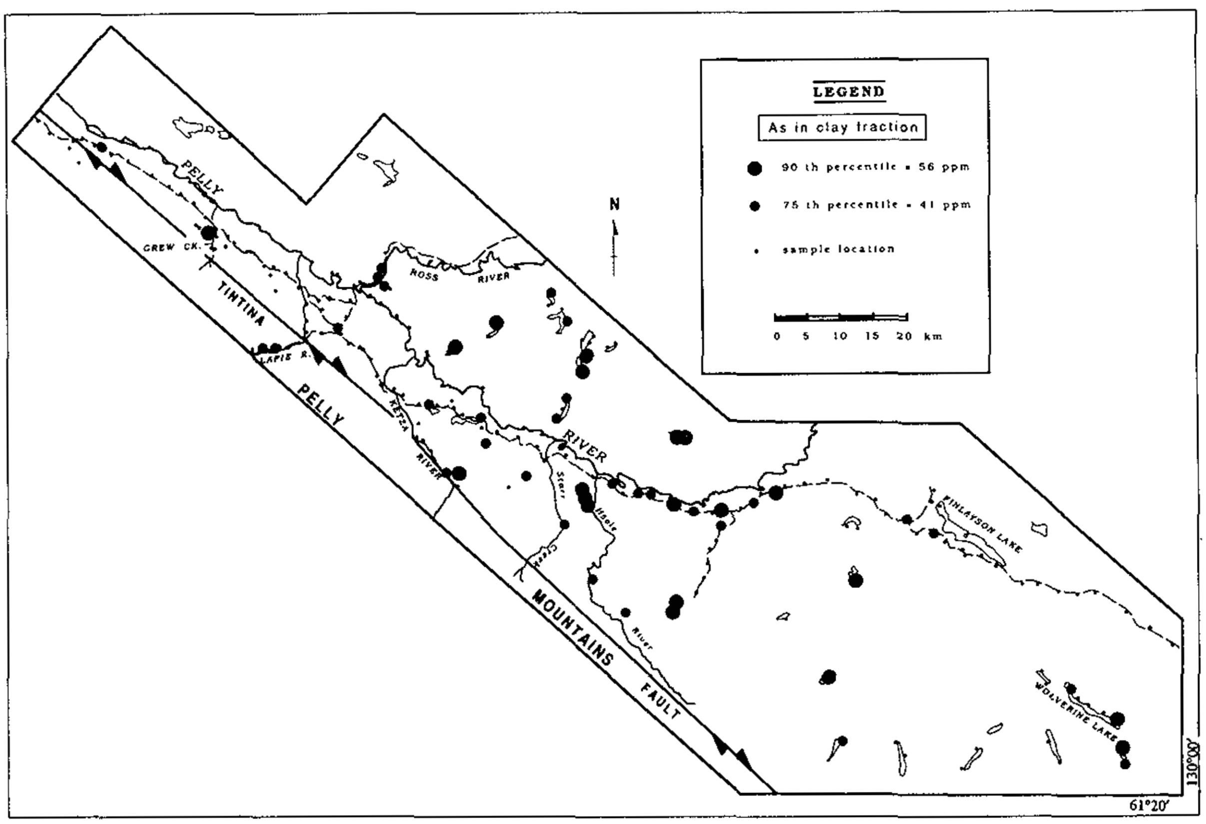


Figure 5-14. Arsenic abundance in the clay size fraction of till.

over and to the northwest of the Main zone (Figure 5-11). Anomalies are also associated with gold occurrences reported by Kindle (1946; p.24) along the Lapie River. High gold concentrations are associated with Tertiary felsic and intermediate volcanic bedrock in the Tintina fault zone (Tempelman-Kluit, 1977), indicating that bedrock may contain gold mineralization similar to Grew Creek. Follow-up work on anomalies near the Lapie River valley should be undertaken with special care because of complex ice-flow patterns.

TABLE 5-2
CORRELATION COEFFICIENTS OF GOLD WITH ARSENIC, ANTIMONY, MERCURY AND SILVER

Correlation coefficients

	Au	Ag	As	Sb	Hg
Au	1				
Ag	-.04	1			
As	-.071	.283	1		
Sb	-.105	.2	.357	1	
Hg	.14	.445	.295	.232	1

Jackson *et al.* (1986) suggested that Paleogene volcanic rocks are a source of placer gold. That is consistent with values above the 75th percentile overlying and to the northwest of some of these volcanic bodies (Ketza River, Starr Creek and northeast of Ross River; Figures 5-2 and 5-12). To verify this possible relationship, additional till sampling is needed closer to these volcanic bodies, as the transport distance of anomalous gold concentrations in till was found to be fairly short, that is, in the order of 250 to 500 metres. Follow-up on any of these anomalies should be undertaken with special care and as a first step, an attempt should be made to reproduce the results presented in this study.

GOLD PATHFINDERS

Samples were analyzed for silver, arsenic, mercury and antimony to determine if these elements could be used as gold pathfinders. Correlation coefficients calculated for these elements and gold are all low and are depicted in Table 5-2. Also, a comparison of geochemical maps for these elements, together with gold (Figures 5-12, 13, 14, 15 and 16), demonstrates that only a few gold anomalies are associated with high concentrations of these traditional pathfinder elements. This poor correlation reflects the bedrock geochemistry of Grew Creek where, at shallow depths (outcrop level), gold mineralization is not associated with high arsenic, silver, mercury or antimony concentrations (T. Christie, oral presentation, Geoscience Forum, Whitehorse, Yukon, 1988). Consequently, these elements have a limited

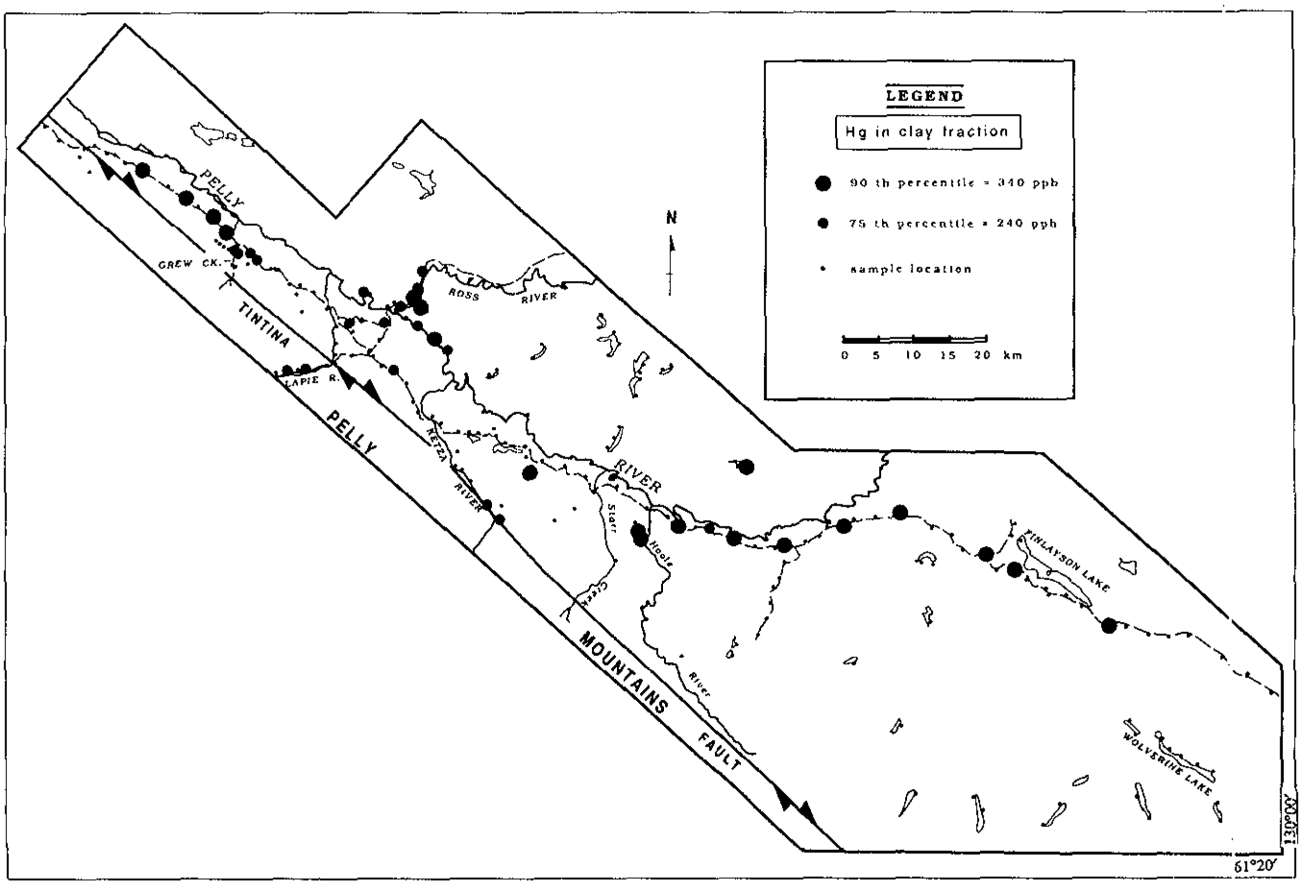


Figure 5-15. Mercury abundance in the clay size fraction of till.

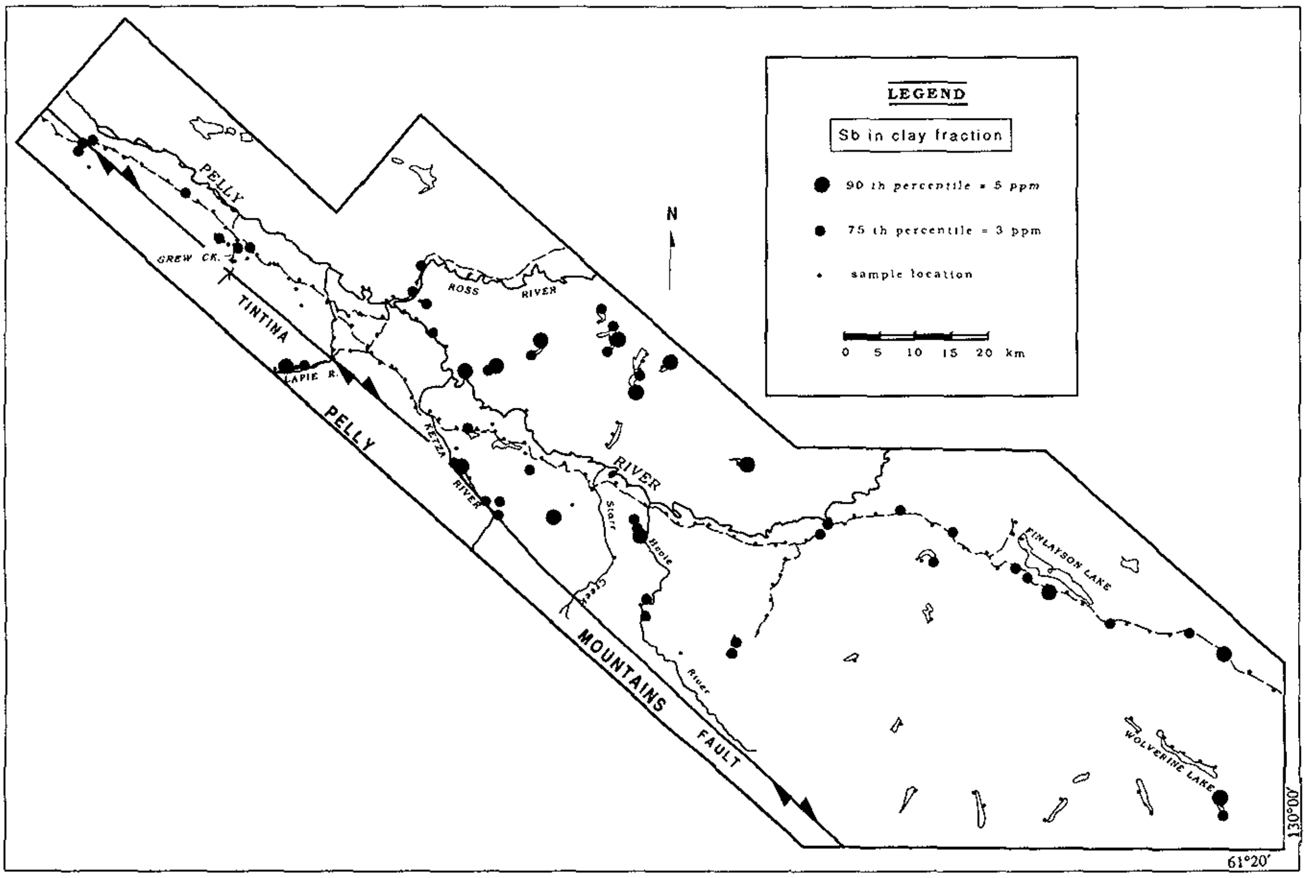


Figure 5-16. Antimony abundance in the clay size fraction of till.

application as drift prospecting pathfinder elements for epithermal gold deposits in the Tintina Trench.

USE OF HEAVY MINERALS FOR GOLD EXPLORATION

As part of this study, the use of heavy mineral concentrates for drift prospecting for gold was tested. Before any analyses were done on heavy minerals, site-specific limitations (Shilts, 1978) were envisaged: most of the gold at Grew Creek is attached to quartz with a minor amount bound in pyrite (Duke and Godwin, 1986; Duke, 1986); gold in quartz is not necessarily recovered in heavy mineral concentrates; and surficial samples, as collected in reconnaissance surveys, are oxidized (except where samples are collected from sections). Thus, gold in sulphides may be released and reprecipitated or fixed in finer size fractions. In both cases gold would go undetected in heavy mineral concentrates.

Heavy mineral separations, (s.g. ≥3.3) on the 125 to 250-micron size fraction, were done for samples from the northwestern region. Gold grains were not seen in heavy mineral concentrates with the aid of a binocular microscope. In a few samples down-ice from the Grew Creek prospect, the deposit is reflected in the gold content of heavy mineral concentrates of McConnell till. Likewise, heavy minerals show patterns of gold enrichment similar to those observed in the silt plus clay size fraction along the Campbell Highway, close to the Lapie River (Figures 5-12 and 5-17). Anomalous gold values (above 90th percentile) occur throughout the area (Figure 5-17); some are located close to

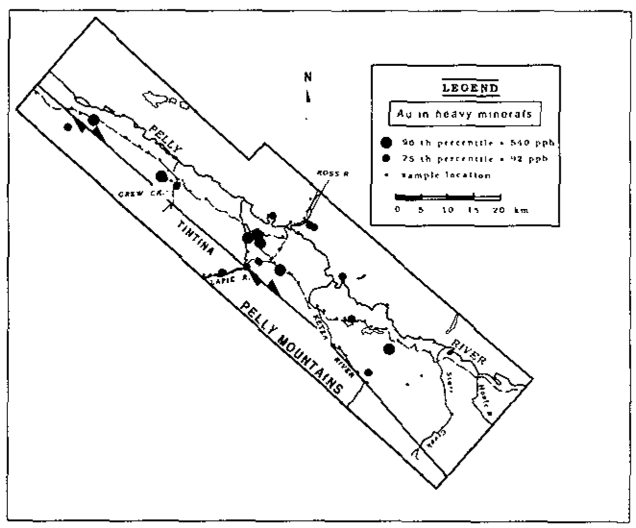


Figure 5-17. Gold abundance in heavy mineral concentrate from till in the northwest part of the study area.

documented mineral occurrences (MINFILE 105F 050, 051, 060) but others are not associated with known prospects.

Most bedrock in the study area is impoverished in heavy minerals, as is the derived till. In some samples, not enough (<5 g) heavy mineral concentrate was recovered for geochemical assays. To obtain a representative amount of heavy minerals for geochemical analysis (>5 g), much larger till samples would have to be taken (>10 kg). This can represent a practical problem where large samples have to be carried long distances.

In conclusion, heavy minerals could be used for gold exploration in the Tintina Trench at a reconnaissance level, if sample size does not represent a practical problem. In follow-up surveys, where samples are recovered from below the zone of oxidation (from sections or overburden drill cores), heavy minerals could be efficient in detecting mineralization.

CONCLUSIONS

Based upon till lithologies and till fabrics, glacier ice flowed west to northwest during the McConnell and pre-McConnell glaciations. At the onset of McConnell glaciation, a valley glacier may have flowed northeasterly, out of the Lapie River valley. At the end of both glaciations, a glacial lake invaded the Pelly River valley. Because of the lack of chronological information, the time elapsed between the two glaciations is still unknown. Consequently, McConnell and pre-McConnell glacial advances may be related to the same glaciation (*sensu stricto*).

The silt and clay size fraction of till reflects known gold mineralization at Grew Creek and does not appear to be influenced by textural parameters. On the other hand, reproducibility of gold analyses on the -63 micron size fraction is very low because gold particles are not uniformly distributed in the samples and gold concentrations in this size fraction are near the detection limit where precision is low. Poor reproducibility can be measured by duplicate analyses.

High gold values in the silt plus clay size fraction of till near Tertiary volcanic bedrock support the hypothesis that these rocks could be a source of placer gold. However, as the transport distance of gold in till is short (250 to 500 m), detailed sampling near volcanic bedrock is needed to locate mineralized sources. The use of silver, arsenic, mercury and antimony as pathfinder elements for gold exploration is not recommended because their correlation with gold is very poor in surficial samples. Heavy minerals could be used at a reconnaissance level for gold exploration in the Tintina Trench.

ACKNOWLEDGMENTS

Much of this paper was extracted from a M.Sc. thesis (Plouffe, 1989). Dr. W.W. Shilts and Dr. F.A. Michel are acknowledged for supervising the thesis and for providing useful discussions of the material presented here. I. Poliquin provided cheerful field assistance. Noranda Exploration Company, Limited financed the geochemical analyses and heavy mineral separations. Field work was funded by Indian and Northern Affairs Canada and by a grant from the Northern Research Group of the Ottawa-Carleton Geoscience Centre. R.A. Klassen greatly improved a preliminary version of this manuscript.

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GLACIAL DISPERSAL PATTERNS OF MINERALIZED BEDROCK: WITH EXAMPLES FROM THE NECHAKO PLATEAU, CENTRAL BRITISH COLUMBIA

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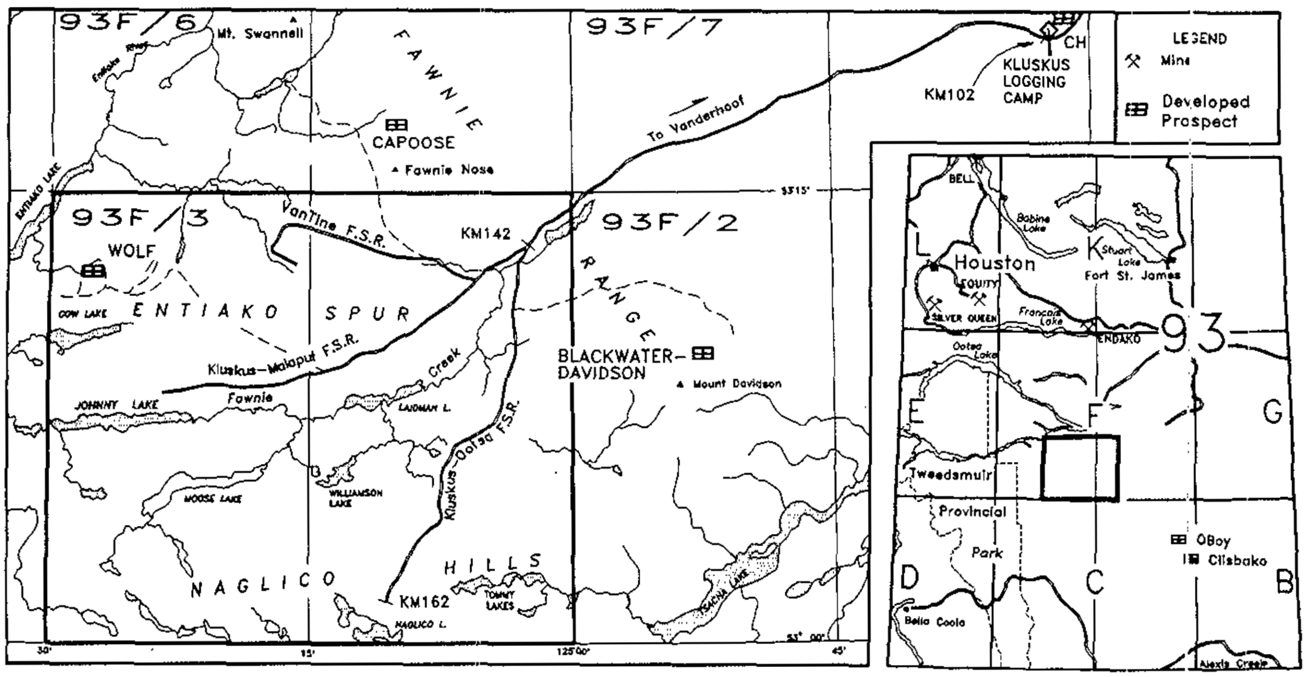
INTRODUCTION

High mineral potential in the Nechako Plateau region, in north-central British Columbia, is indicated by the occurrence of several large mineral deposits including the Equity silver-gold-copper deposit and the Endako porphyry molybdenum and Bell poryphyry copper deposits (Figure 6-1). The discovery of new mineral deposits in the region, however, has been hindered by the typically thick overburden, a poor understanding of the Quaternary history of the area and by a lack of published data describing glacial dispersal patterns in the region. In this paper, we address these problems first by discussing Quaternary geology data recently collected in the southern Nechako Plateau and, second, by an evaluation of unpublished industry data, from that area, that is relevant to drift exploration programs. Emphasis is placed on mechanical (mainly glacial) dispersal of mineralized bedrock including data on the following:

- The size, shape and concentration of soil geochemical anomalies and erratics trains.
- The influence of different surficial materials and depositional environments on mechanical dispersal.
- Stratigraphic and glaciological factors that effect erosional and depositional processes.

To address problems associated with poor bedrock exposure, typical of much of the Interior Plateau, a drift exploration program was initiated in the southern Nechako Plateau in 1993 by the British Columbia Ministry of Energy, Mines and Petroleum Resources. The program includes Quaternary stratigraphic studies, surficial geology mapping, till geochemistry surveys and detailed case studies around known mineral deposits (Giles and Kerr, 1993; Giles and Levson, 1994a, b; Levson and Giles, 1994).

The program objectives are to apply Quaternary geology and ice-flow history data to drift prospecting problems in areas where mineral exploration has been hampered by a variably thick and heterogeneous drift cover, to provide a basis for the design of till geochemical sampling programs, and to produce a series of till geochemistry and drift exploration potential maps for mineral exploration purposes. Regional (1:50 000 scale) surficial geology mapping and till sampling in the Fawnie Creek (93F/3) map area (Giles and Levson, 1994a, b; Levson and Giles, 1994) and reconnaissance stratigraphic studies elsewhere in the southern



Figue 6-1. Location map of the southern Nechako Plateau region and locations discussed in the text.

Nechako Plateau (93F/3, 6, 7, and 10) were conducted in the 1993 field season. Results of these studies, of particular relevance to this discussion, are summarized here. This work is part of a larger program in the Interior Plateau that includes bedrock mapping (Diakow and Webster, 1994; Diakow *et al.*, 1994), lake sediment geochemistry (Cook and Jackaman, 1994) and mineral deposit studies (Schroeter and Lane, 1994).

Few studies dealing with glacial dispersal processes in the southern Nechako Plateau area have been published (Kerr and Levson, 1994) but a wealth of information is contained in unpublished assessment reports housed by the B.C. Ministry of Energy, Mines and Petroleum Resources (*c.a.* Kerr, 1995, this volume). A review of these reports, filed for the southern Nechako Plateau area, was conducted to examine current methods of exploration in the region, to identify typical problems encountered by explorationists and to compile information that can be used to develop and refine drift exploration methods. The results of drift exploration programs from three selected areas are discussed here, in a Quaternary geology context, as are the implications of these studies for property and regional-scale exploration activities.

The Nechako Plateau is located in the northern part of the Interior Plateau physiographic region (Holland, 1976). The southern part of the plateau, south of Highway 16, is discussed here (Figure 6-1) and includes the Nechako Reservoir area south to the Fawnie Mountains. The region is characterized by gently rolling topography; mountainous areas occur mainly in the south and seldom reach elevations above 2000 metres. Local relief in the northern part of the study region, in the Nechako Reservoir area, is a few tens to hundreds of metres and, even in the more mountainous regions to the south, relief is generally less than 1000 metres.

BASAL TILLS AS A GEOCHEMICAL SAMPLING MEDIUM

Fundamental to the success of any overburden geochemical sampling program is the selection of a sampling medium suited to the objectives of the survey (Shilts, 1976; Gleeson *et al.*, 1989; DiLabio, 1990). In reconnaissance-scale surveys (~1 sample/100 km^2) in relatively unexplored areas, for example, heavy mineral samples of eskers or other glaciofluvial concentrates may be more effective than till samples (Saarnisto, 1990). In contrast, colluvial sediments may be more suited to detailed property evaluations as these deposits are typically more locally derived than tills. For exploration programs in the Nechako Plateau area, at scales intermediate between these two extremes, we recommend sampling of basal tills rather than other types of surficial materials for the following reasons:

- Basal tills are deposited in areas directly down-ice from their source and therefore mineralized materials dispersed within the tills can be more readily traced to their origin than can anomalies in other Quaternary sediment types. Processes of dispersal in supraglacial tills, glaciofluvial sands and gravels, and glaciolacustrine sediments are more complex and they are typically more distally derived than basal tills.
- As dispersal trains developed in basal tills are typically larger than those in colluvial deposits and stronger than those in glaciofluvial or supraglacial deposits, mineral anomalies in basal tills may be more readily detected in regional surveys (DiLabio, 1990).
- The dominance of one main regional ice-flow direction in the southern Nechako Plateau throughout much of the last glacial period has commonly 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.

Regardless of which sampling medium is selected, it is critical, for interpretation purposes, that detailed descriptions of the sampled deposits are obtained and that different types of materials are distinguished (Giles and Levson, 1994a, b). 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 bedrock lithology or surficial geology can therefore be minimized in favour of processes relating to mineralization. A particularly significant difference exists between till covered areas and colluvial deposits in more mountainous areas. For example, geometric means (log normal) for copper, molybdenum, zinc, lead and nickel 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.

The utility of C-horizon sampling of basal tills for outlining areas of mineralization has long been known (*e.g.* Shilts, 1973a, b) but it has been little used by exploration companies in British Columbia; A or B-horizon sampling has generally been favoured (*e.g.* Kerr, 1995, this volume). 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).

GLACIAL DISPERSAL PROCESSES

Glacial dispersal trains may be hundreds to thousands of times larger in size than their original bedrock source, providing a cost-effective target for mineral exploration programs (Shilts, 1976; DiLabio, 1990). Mineralized bedrock, eroded and transported by a glacier, may be redeposited in either the gravel fraction of a till (as erratics) or in the matrix (clay to sand fractions). Erratics trains can be delineated by boulder tracing whereas evidence for mineralization in the clay to sand fractions can only be defined by geochemical methods. Dispersal trains are commonly very thin in comparison with their length and have clear lateral and vertical contacts with the surrounding till. Progressive dilution of the mineralized material generally occurs in a down-ice direction until the train can no longer be detected. 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 relatively flat shield areas (Shilts, 1976a, b), some examples have also been described from British Columbia (*e.g.* Fox *et al.*, 1987; Kerr *et al.*, 1993; see also references in Kerr and Levson, 1995, this volume). Variations in the ice-flow direction caused by topographic irregularities or changing dynamics at the base of the ice may cause the anomaly to have 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.

IDENTIFYING BASAL TILLS

A comprehensive discussion of criteria for the recognition of different types of tills is beyond the scope of this paper. However, it is important to emphasize that glacial sediments can be eroded, transported and deposited by a wide variety of mechanisms, all of which may produce tills of distinctly different character. 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, often (but inappropriately) referred to as ablation tills, are usually deposited as debris flows and are comprised of relatively far-travelled 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). 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. This is not to say, however, that geomorphic data alone are diagnostic. 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-travelled, supraglacial, flow tills. 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).

QUATERNARY GEOLOGY OF THE SOUTHERN NECHAKO PLATEAU

SURFICIAL DEPOSITS

Regional surficial geology mapping in the southern Nechako Plateau was conducted by Tipper (1971) and Howes (1977). More detailed mapping, for mineral exploration purposes, has been recently conducted by Giles and Kerr (1993), Proudfoot (1993), Ryder (1993) and Levson and Giles (1994). Unconsolidated deposits in the region are generally a few to several metres thick but may attain a thickness of 200 metres or more in some large valleys. An extensive cover of till blankets most of the plateau with drumlins and other streamlined glacial landforms covering approximately half of the region. Till thickness varies from a few to tens of metres in low-lying areas to less than 2 metres in upland regions and along steep slopes. The thickest sequences tend to be in valleys oriented perpendicular to the regional ice-flow direction. Two distinct facies of morainal sediments (Photo 6-1) are recognized on the southern Nechako Plateau: a massive, compact, matrix-supported, fine-grained diamicton (poorly sorted deposit consisting of mud, sand and gravel) and a loose, massive to stratified, sandy diamicton. The first is interpreted to be lodgement and basal melt-out till and the latter to be debris-flow deposits. Basal tills seldom occur at the surface, usually being overlain by glacigenic debris-flow deposits and, on slopes, by resedimented diamictons of colluvial origin.

Deposits interpreted as basal tills commonly exhibit a moderate to strong platy fissility and vertical jointing, both with iron oxide staining. Subhorizontal slickenside 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 small pebbles to large boulders. Total

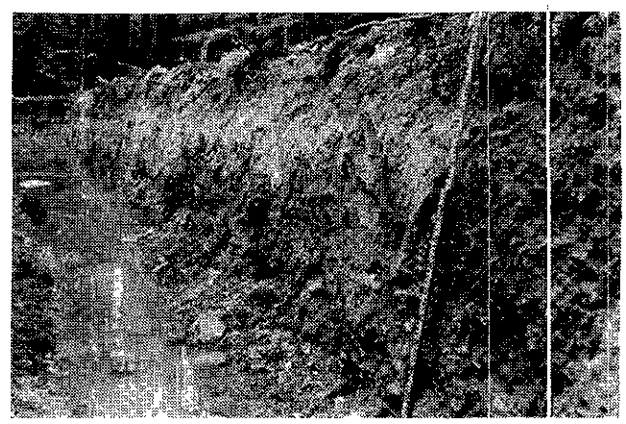


Photo 6-1. Massive, compact, matrix-supported, fine-grained diamicton (basal till) overlain by loose, massive to stratified, sandy diamicton (debris-flow deposits) at the Wolf deposit.

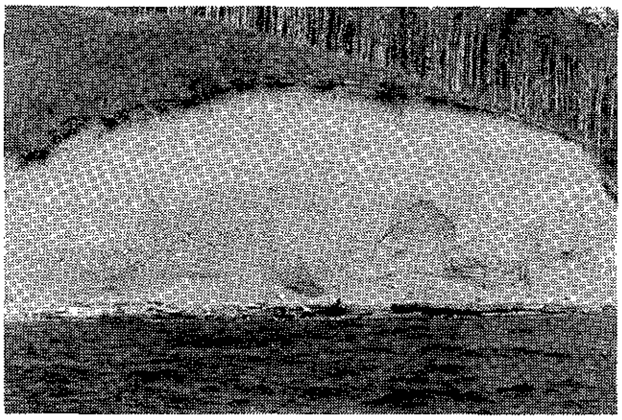


Photo 6-2. Basal till unconformably overlying glaciofluvial gravels and sands in a typical Quaternary section on the Nechako Reservoir. The exposure is 6.5 metres high.

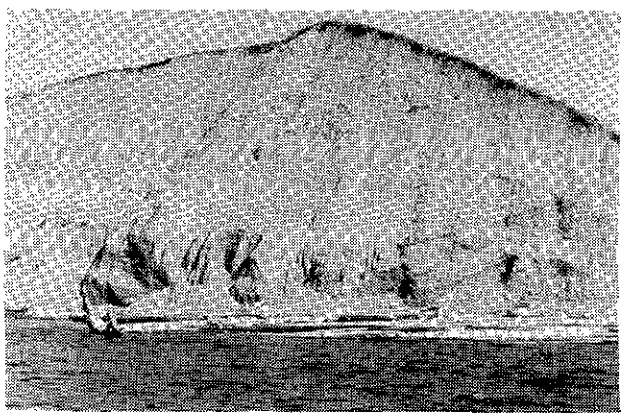


Photo 6-3. Glaciofluvial gravels and sands on the Nechako Reservoir exhibiting large-scale planar crossbedding. The exposure is 12 metres high.

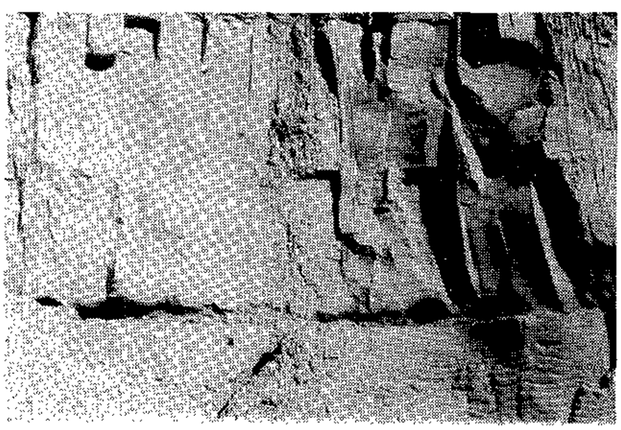


Photo 6-4. Climbing-ripple bedding in well sorted, glaciolacustrine silts and fine sands approximately 50 kilometres north of the Nechako Reservoir. The exposure is 1 metre high.

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 (Photo 6-2). All of these characteristics are consistent with a basal melt-out or lodgement till origin (Levson and Rutter, 1988). The presence of injection structures and sheared, folded and faulted bedrock slabs within these deposits indicates the local development of deformation tills.

Diamictons of inferred debris-flow origin are loose to weakly compacted and are either massive or interbedded with stratified silt, sand or gravel. These diamictons typically contain 20 to 50% gravel, but locally may have up to 70% clasts. Subangular to subrounded clasts are most common, but in some exposures angular fragments dominate. Up to 10% of the clasts may be striated. 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 commonly less than a metre wide. These deposits are interpreted as glacigenic debris-flows and resedimented glacial deposits and they commonly are in gradational contact with underlying basal tills.

Colluvial deposits, comprised mainly of local bedrock fragments, occur as thin veneers on steep slopes throughout the area. They grade downhill into a thicker cover of colluvial diamicton derived from both local bedrock and till. Colluvial diamictons are differentiated from till by their loose, unconsolidated character, the presence of coarse, angular clasts of local bedrock, crude stratification and lenses of sorted sand and gravel.

In most valleys, morainal sediments are largely buried by glaciofluvial outwash, glaciolacustrine sediments or fluvial deposits. Glaciofluvial sediments occur as eskers, kames, terraces, fans and outwash plains in valley bottoms and along valley flanks. They consist mainly of poorly to well sorted, stratified, rounded to well rounded, pebble to cobble gravels with interbedded sands (Photo 6-3). Glaciofluvial sand and gravel sequences up to tens of metres thick occur in large valleys whereas in other areas they occur mainly as veneers, up to a few metres thick, over till. Ice-marginal meltwater channels, formed during ice retreat or stagnation, are commonly associated with these glaciofluvial deposits. Large esker and kame complexes are also locally common. Postglacial, fluvial sediments consist mainly of meandering stream deposits, often with gravel channels. Floodplains are dominated by fine sands, silts and organics. Postglacial alluvial fans are generally not a prominent feature of the region except in the more mountainous areas in the south (Giles and Levson, 1994a; Levson and Giles, 1994). Widespread glaciolacustrine clays, up to 30 metres thick, deposited in a series of ice-dammed lakes are especially common in the northern parts of the region. They typically consist of horizontally stratified, well sorted, fine sands, silts and clays (Photo 6-4).

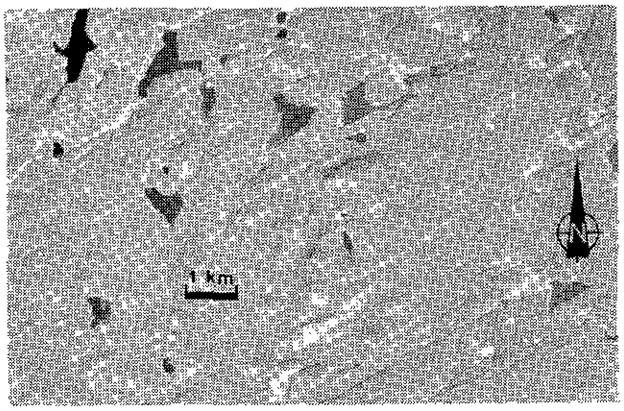


Photo 6-5. Northeast-trending, fluted and drumlinized terrain reflecting regional ice-flow direction during the last glaciation in the Arrow Lake area (White claim group) (Government of British Columbia air photo 88074-063).

ICE-FLOW HISTORY

The Nechako Plateau has a complex history of ice flow due to multiple ice sources and varied topography (Tipper, 1971) but in comparison with more mountainous parts of British Columbia the ice-flow history of the plateau is relatively simple. During the last or Late Wisconsinan glaciation ice moved north, northeast and east onto the Nechako Plateau from the Coast Mountains. Coast Mountain ice extended as far east as the Fraser River before coalescing with Cariboo Mountain ice flowing to the west and northwest. The direction of regional ice flow during the last glaciation is reflected in the geomorphology of many regions by extensive areas of unidirectional, fluted and drumlinized terrain (Photo 6-5). Minor modifications in ice flow resulted from topographic control during both early and late stages of glaciation. Topographic control of ice-flow direction during early glacial phases is indicated by valley-parallel striae on bedrock surfaces that are buried by thick till sequences in the Nechako Reservoir area. At the Late Wisconsinan glacial maximum, ice covered the highest peaks in the region; ice flow appears to have been unaffected by topography, suggesting an ice thickness in excess of 1000 metres. Orientations of crag-and-tail features, drumlins, glacial flutings and bedrock striae across the region typically indicate northeasterly to easterly flow during full glacial times (Photo 6-5). Crosscutting striae along the sides of some mountains in the region indicate topographically influenced ice flow during waning stages of glaciation.

The Quaternary stratigraphy of the southern Nechako Plateau was investigated by the authors during detailed studies of the Fawnie Creek map area (93F/3) and reconnaissance stratigraphic studies of exceptional exposures along the Nechako Reservoir (93F/6, 7, and 10; Figure 6-1). Preliminary results of these studies indicate that tills deposited during the last glacial period are underlain by a thick unit of advance phase glaciofluvial deposits (Photo 6-2) and stratigraphically overlain by a complex sequence of glaciofluvial (Photo 6-3) and glaciolacustrine (Photo 6-4) deposits. The latter include both proximal glaciolacustrine deposits consisting of strongly deformed, interbedded mud, sand and gravel facies and an overlying more distal sequence of well bedded sand, silt and clay facies. The stratigraphic record of pre-Late Wisconsinan glacial events in the region was largely removed during the last glaciation.

EXAMPLES OF GLACIAL DISPERSAL TRAINS IN THE SOUTHERN NECHAKO PLATEAU

WHITE CLAIM GROUP, ARROW LAKE MINERAL SHOWING (NTS 93F/11E, 6E; LATITUDE 53°30'N, LONGITUDE 125°05'W).

The Arrow Lake mineral showing on the White claim group of Newmont Exploration of Canada Limited, was discovered in 1987 by following a train of stibnite-bearing quartz feldspar wacke/tuff erratics (Bohme, 1988). The erratics were traced up-ice (southwesterly) approximately 7 kilometres before the mineralized zone was discovered. The property is located south of the Ootsa Lake logging road, about 10 kilometres southwest of Kenny dam on the north side of the Nechako Reservoir (Figure 6-1). Almost the entire area is covered by a blanket of till with flutes and drumlinoid ridges trending north-northeast (Plate 6-5). Organic deposits and glaciofluvial sands and gravels occur in low-lying areas. Bedrock outcrops are rare. The area is underlain by Eocene felsic volcanics and minor sedimentary rocks of the Ootsa Lake Group (Tipper, 1954, 1963; Diakow and Koyanagi, 1988).

Intensely sheared, arkosic sandstone and bleached, pyritiferous and silicified rhyolite host the showing, believed to be a high-level epithermal deposit (Bohme, 1988). Stibnite occurs in chalcedonic veinlets and siliceous breccia zones. Erratic gold concentrations and variable amounts of pyrite, arsenopyrite, cinnabar and marcasite are characteristic of mineralization in the area. Elevated values of mercury (6200 - 28000 ppb), antimony (660 - 21800 ppm), arsenic (21 - 598 ppm), barium (up to 239 ppm) and minor gold (up to 86 ppb) occur in a northeast-trending zone 600 metres wide and 150 metres long. Samples were taken at depths of at least 15 centimetres (presumably of A and B soil horizons) and the -177 micron (-80 mesh) fractions were analyzed for gold and 30 additional elements. Threshold values (based on the 95th percentile) were determined to be 4 ppb gold, 0.4 ppm silver, 96 ppm arsenic, 78 ppm antimony, 146 ppm barium and 166 ppm zinc; arsenic and antimony, and barium and zinc showed strong positive correlations (Bohme, 1988).

A dispersal train, defined by the antimony content of soils, extends for at least a kilometre down-ice from the Arrow Lake showing. Contoured antimony values, from soil samples taken every 25 metres on a grid with a line spacing of 100 metres, are shown on Figure 6-2. The antimony anomaly, defined by the 10 ppm contour, is 1 kilometre long and up to 200 metres wide. The highest values (100 ppm) occur directly down-ice from the mineralized outcrop. Arsenic concentrations greater than 10 ppm correspond well with the antimony anomaly but are more erratic. Anomalous

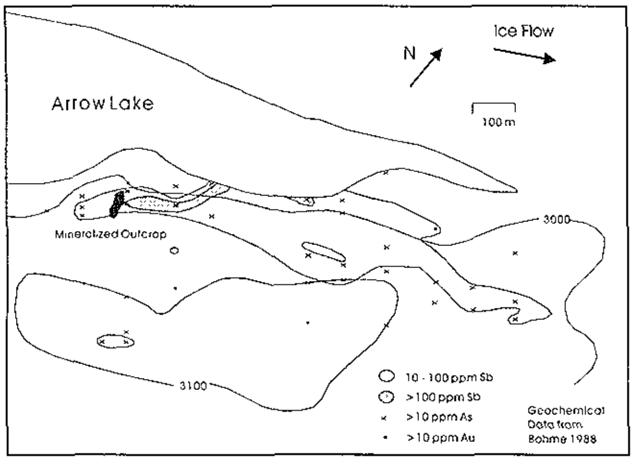


Figure 6-2. Antimony soil anomaly extending down-ice from the Arrow Lake mineral showing (White claim group). Anomalous arsenic and gold values are shown as point data. *See* Photo 6-5 for aerial photograph of area.

gold values are also erratic (Figure 6-2) and occur mainly in clay-rich tills (Bohme, 1988).

CH 10-16 MINERAL CLAIMS (NTS 93F/7E, 8W; LATITUDE 53°31'N, LONGITUDE 124°25'W)

The Placer Dome Inc. CH property is located near kilometre 100 on the Ootsa-Kluskus forestry road near the Kluskus logging camp (Figure 6-1). The area is underlain mainly by Middle Jurassic andesitic tuffs and flows of the Hazelton Group and occurs near the margin of a small granitic pluton (Tipper, 1954, 1963). Lead-zinc-silver-gold mineralization in bedrock has been exposed in shallow trenches in two areas on the property (Figure 6-3). In the northwest, massive pyrite, magnetite, sphalerite, galena and arsenopyrite, with minor chalcopyrite and quartz occur in

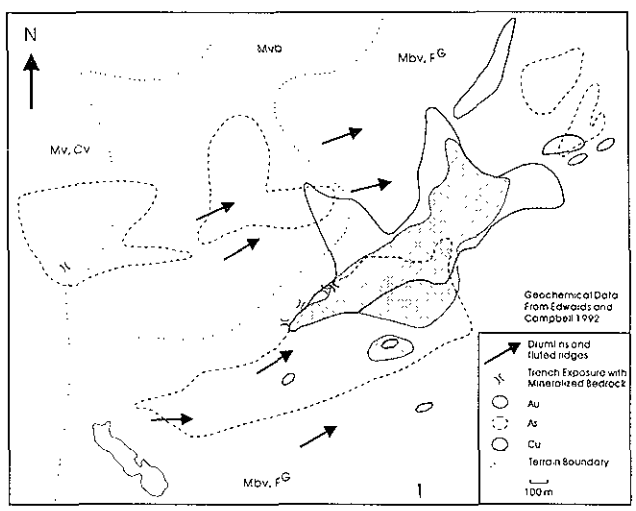


Figure 6-3. Surficial geology and distribution of gold, copper and arsenic soil anomalies on the Placer Dome Inc. CH property near Chutanli Lake (modified from Edwards and Campbell, 1992).

veins and fractures. In the centre of the property, a quartz-magnetite-pyrite-chalcopyrite stockwork in altered and silicified volcanic and intrusive rocks carries minor gold. (Edwards and Campbell, 1992). The site is blanketed by up to 20 metres of till and glaciofluvial deposits. Several, large, drumlinoid features on the property trend northeasterly, parallel to the regional ice-flow direction.

Soil samples were collected mainly from the B-horizon at depths of 10 to 100 centimetres. The -177 micron (-80 mesh) fractions of the samples were analyzed by ICP. Thresholds between background and anomalous values were interpreted from previous statistical analysis of soil geochemical data in the area (Warner and Cannon, 1990).

A well developed dispersal train in the till extends northeasterly (down-ice) from the area of copper-gold mineralization in the centre of the property (Figure 6-3). The lateral extent of glacial dispersal in the area was first realized with the discovery of ice-parallel trends in soil copper anomalies on two sampling grids separated by over 800 metres (Warner and Cannon, 1990). 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. Mineralized rock fragments (quartz stockwork with magnetite, chalcopyrite and pyrite) are common in the train and are readily recognized by malachite staining. Anomalous values of gold, silver, copper, lead and zinc in soils commonly extend up to 2 kilometres northeast of the mineralized zone. The main area of anomalous gold values (up to 1310 ppb) varies from about 0.2 to 0.5 kilometre in width and is 1.5 kilometres long (Figure 6-3). The copper anomaly (defined by values ranging from 82 to 903 ppm) is approximately coincident with the gold dispersal train (Figure 6-3) but is much larger, extending over 2 kilometres to the northeast and up to 800 metres in width. Soils in the area directly down-ice from the showing are also characterized by anomalous values of zinc (180 to 1121 ppm) and silver (0.6 to 30 ppm) and concentrations of lead up to 2320 ppm. Dispersal trains of these elements are very similar, all forming long and narrow anomalies that typically are only about 200 to 300 metres wide and 1 to 1. 5 kilometres long. Although 75% of the samples analyzed for gold and 64% for silver were below the detection limit, the ice-parallel elongation of the dispersal trains of these elements and their coincidence with the anomaly patterns of other elements suggests that they can also be useful for detecting mineralization.

Concentrations of copper on the north side of the largest soil anomaly (Figure 6-3) are highest on the northeast side of two topographic highs. Edwards and Campbell (1992) attributed the resultant northwesterly 'protrusions' in the dispersal pattern to a possible late glacial movement with a northwesterly (330°) ice-flow direction. There is no other evidence, however, for such a flow in the region and we prefer the interpretation of selective deposition of the copper-enriched till along the lee-side of topographic highs. Preferential deposition of tills in lee-side settings in both modern and ancient glacial environments has been well documented in other mountainous areas (Boulton, 1971;

Haldorsen, 1982; Levson and Rutter, 1986). Some enrichment by hydromorphic processes is also probable but coincident elevated values of other elements such as gold, lead, zinc and silver in some of the low areas northeast of topographic highs is more consistent with a lee-side origin.

Elevated arsenic values (33 to 1020 ppm) at the property occur over an area 2 kilometres long and up to 700 metres wide and form a broad, fan-shaped anomaly that extends over a kilometre up-ice from the main copper-gold deposit (Figure 6-3). Edwards and Campbell (1992) speculated that the particularly thick drift along the southwest part of the anomaly may account for the low values of other elements in this area. A similar argument was used by Warner and Cannon (1990) to explain low values of copper, gold and molybdenum in some parts of the area. The location, large size and well developed fan shape of the arsenic anomaly suggest that another mineralized bedrock source may occur near or up-ice from the southwest end of the anomaly. This is also suggested by a magnetic high that coincides with the anomaly in the vicinity of the lake (Figure 6-3) at the west side of the property (Edwards and Campbell, 1992).

A second, less well developed dispersal train is associated with the lead-zinc-silver-gold showing in the northwest part of the area (Figure 6-3). Elevated values of arsenic, lead and zinc occur over a broad zone extending northeast from the sulphide veins. Interestingly, anomalously high values of all three of these elements, as well as silver, also occur on a small hill about 1 kilometre directly northeast of the mineralized zone. The elevation of this hill at the up-ice end of the anomalous area is nearly identical to that at the showing. Only background levels of arsenic, lead, zinc and silver occur in a low area that separates the hill from the sulphide veins. This suggests that the anomaly on the hill may reflect an undiscovered area of mineralization. Alternatively, but less likely, the anomaly patterns may have resulted from ice erosion of bedrock at the showing and subsequent redeposition of the mineralized material at the same elevation on the next hill down-ice, with little deposition in the low area in between. For this to occur, glacial flow lines must have been nearly horizontal and the intervening low area may have been infilled with sediment, now eroded away, or relatively inactive ice that would have prevented deposition of any significant amount of till.

Other large glacial dispersal trains have been described in the Chutanli Lake region by Mehrtens *et al.* (1973) and Mehrtens (1975). An extensive (up to 9 km^2) B-horizon soil molybdenum anomaly, about 3 kilometres northwest of the CH property, extends for nearly 2.5 kilometres northeast of an area of mineralized bedrock containing more than 0.03% molybdenum. Much of the anomalous area occurs down-ice and up-slope of the bedrock metal source and it is therefore inferred to have formed by glacial dispersal processes. Molybdenum values range from 15 to 50 ppm over much of the anomalous area. They are relatively widely dispersed over an area up to three times the width of the 800-metre-long zone of bedrock mineralization. However, strongly anomalous molybdenum values, with a maximum anomaly contrast of 48 times threshold values, are probably of hydromorphic origin and occur in the overburden immediately down-slope from the bedrock source (Mehrtens, 1975).

The CH property provides an excellent example of glacial dispersal processes in an area of relatively thick till cover. As discussed above, dispersal trains in the area are well developed and up to 2 kilometres long and several hundred metres wide. They show a pronounced elongation parallel to the ice-flow direction and mineralized source rocks occur at or near the up-ice end of the dispersal trains. The anomalies have relatively sharp lateral boundaries and have typical cigar and fan shapes characteristic of trains formed by mechanical dispersal processes at the base of glaciers.

WOLF PROPERTY (NTS 93F/3W; LATITUDE 53°12'N, LONGITUDE 125°27'W)

The Wolf epithermal gold-silver deposit occurs near the terminus of the Kluskus-Malaput logging road about 130 kilometres southwest of Vanderhoof (Figure 6-1). Mineralization was discovered in 1982 following up results of a regional lake sediment sampling program conducted by Rio Algom Exploration Inc. The property is underlain mainly by Eocene felsic volcanic and subvolcanic intrusive rocks of the Ootsa Lake Group (Tipper, 1954, 1963; Andrew, 1988; Dawson, 1988). At the Ridge and Blackfly zones (Figure 6-4), gold-silver occur in silicified hydrothermal breccias and stratabound, pervasively silicified and brecciated rhyolite (Dawson, 1988). Metallic minerals include micron-sized electrum, silver and galena as well as minor fine-grained disseminated pyrite and rare chalcopyrite (Andrew, 1988). Typical gold grades in altered hostrocks are in the 1 to 2 grams per tonne range, but grades as high as 8.5 grams

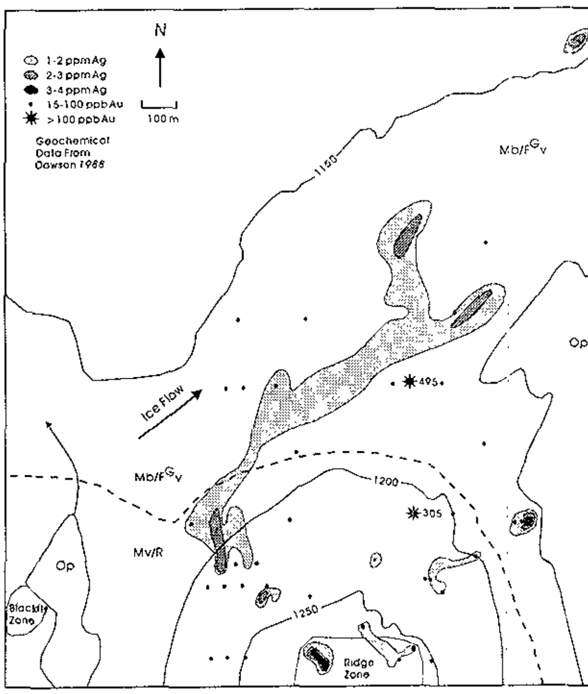


Figure 6-4. Surficial geology and silver soil anomalies at the Wolf deposit.

per tonne gold and 42.2 grams per tonne silver are reported in trenches containing silicified breccia (Dawson, 1988).

The mineralized zones occur mainly in areas of positive relief where the drift cover is relatively thin (Figure 6-4). Bedrock outcrops occur sporadically throughout the property and increase in abundance above the 1250-metre contour. Terrain maps of the region (Howes, 1976; Ryder, 1993) indicate a comparatively thick drift cover in major valleys and lowlands. Till thickness increases from generally less than a few metres around the deposit to several metres or more down ice (northeast). Morainal sediments of the last glaciation occur throughout the area and include lodgement and melt-out tills, glacially derived debris-flow sediments and minor glaciolacustrine and organic deposits.

Soil samples for geochemical analysis were collected at the site every 25 or 50 metres on east-trending lines spaced 200 metres apart. Samples, collected from the B soil horizon at depths of 15 to 45 centimetres, were analyzed by ICP for 30 elements; gold and silver data were plotted on 1:5000 scale maps (Dawson, 1988).

Anomalous gold (15 ppb) and silver (1 ppm) values generally cluster around mineralized areas. However, at the Ridge zone, high gold contents in bedrock are not well reflected in the overlying soils; for example, values of only 5 ppb occur in soils directly above bedrock containing nearly 8.8 grams per tonne gold (Dawson, 1988). This may be a reflection of the generally shallow depth of soil sampling (D. Heberlein, personal communication, 1993) or of a nonlocal origin of the overlying surficial materials. The sediments immediately overlying bedrock at the Ridge zone are mainly tills and glacially derived debris-flow deposits. Unlike colluvial sediments or residual soils, these deposits should reflect the composition of bedrock in up-ice areas and not in the immediate vicinity of the sample site. The pattern of dispersal of anomalous silver and gold in soils in the area (Figure 6-4) supports this interpretation. The main silver anomaly occurs northeast of the Blackfly zone and is separated from it by a gap of low background silver values, nearly 500 metres wide. The soil anomaly is inferred to be a glacial dispersal train extending down-ice from the mineralized zone. Although weakly developed, the anomaly is more than a kilometre long and 100 to 400 metres wide. Silver concentrations higher than 2 ppm occur as much as 2.3 kilometres directly down-ice from the deposit. Anomalous gold concentrations (defined as the mean plus 2 standard deviations) are more erratic, but generally occur in a broad zone down-ice from the deposit. One of the highest gold values in soils occurs 1.2 kilometres northeast of the Blackfly zone. Some lateral variation in the silver and gold dispersal pattern may be due to local variations in ice flow caused by the bedrock topography; bedrock striae indicate ice deflection of up to 30° around the margins of the knoll hosting the Ridge zone.

The area of low values directly down-ice from the Blackfly zone is presumably a result of dilution by till derived from unmineralized bedrock further up-ice. Thus, glacial dispersal in the area has offset the geochemical signature of the deposit nearly 500 metres to the northeast. Likewise, the highest silver values, in surface soil samples northeast of the Ridge zone, occur about 500 metres down-ice from the mineralized area. However, the accumulation of organic, lacustrine and glaciolacustrine deposits in this region has probably obscured any development of a northeasterly trending, linear soil anomaly, like the one down-ice from the Blackfly zone.

CONCLUSIONS

Glacial processes in till covered areas in the Nechako Plateau produce well developed dispersal trains, detectable by standard soil geochemical surveys. Basal tills are the preferred sampling medium for identifying glacial dispersal trains. Soil anomalies associated with glacial dispersal of mineralized bedrock are up to a few kilometres long and several hundred metres or more wide; isolated anomalies associated with the trains may cover much larger areas. They show a pronounced elongation parallel to ice-flow direction, with mineralized source rocks occurring at or near the up-ice end of the dispersal trains. The soil anomalies typically have relatively sharp lateral boundaries and typical 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, such as at the Wolf property, near-surface soil 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.

The elongate nature of soil anomalies resulting from glacial dispersion in the region is well evidenced by the Arrow Lake antimony anomaly which is approximately five times as long as it is wide (1000 metres long by 200 metres wide). Similarly, at the CH property, zinc, silver and lead geochemical anomalies are typically 200 to 300 metres wide and 1 to 1.5 kilometres long. The copper soil anomaly at the CH property is much broader (800 metres) and longer (2 kilometres). Gold, and to a lesser extent silver, anomalies tend to be erratic and more poorly developed than other element anomalies, probably due to the nugget effect.

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

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

Erratics trains in the region appear to be much longer (up to several kilometres long) and more readily detected than soil anomalies (typically 1-2 kilometres long). The Arrow Lake showing, for example, was discovered by tracing an erratics train 7 kilometres long, whereas the geochemical soil anomalies in the area are typically only 1 kilometre long. This emphasizes the importance of pebble counts and boulder prospecting surveys in drift exploration programs.

A basic understanding of ice-flow direction, glacial dispersal patterns, transportation distances, Quaternary stratigraphy and the origin of different sampling media is required for a successful drift exploration program. In addition to pedologic and site information, sedimentologic data should be collected at 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. Poor results of some traditional geochemical soil sampling programs may be due to indiscriminate sampling of different types of sediments. Interpretation of data with respect to glaciation may provide the explorationist with new avenues to explore for bedrock sources of mineralized float or geochemically anomalous surficial sediments.

ACKNOWLEDGMENTS

This paper was reviewed by S.J. Sibbick and P.F. Matysek and was improved by their comments. We would like to thank D. Heberlein and all the Metall Mining crew at the Wolf property, R. MacGillivray of Placer Dome, and K. Schiemann, T. Richards and the rest of the Cogema crew at Kenney dam for providing helpful information. We also extend thanks to S.J. Cook, L.J. Diakow, H. Jennings, B. Lane, P.F. Matysek, T.G. Schroeter, J. Riddell and I.C.L. Webster for their cooperation on this integrated program.

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ORIGIN AND STRATIGRAPHY OF PLEISTOCENE GRAVELS IN DAWSON RANGE AND SUGGESTIONS FOR FUTURE EXPLORATION OF GOLD PLACERS, SOUTHWESTERN CARMACKS MAP AREA (NTS 115I)

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INTRODUCTION

Placer gold prospecting and mining have been carried out in the Dawson Range, central Yukon since 1898 (Bostock, 1936). Prospecting and mining activity has centred in the areas of Victoria Creek, the main fork of Nansen Creek and Big Creek and its tributaries above Stoddart Creek (Figure 7-1). This area will henceforth be referred to as the Nansen - Big Creek placer district. Regional surficial geology mapping and Quaternary stratigraphic investigations of the Carmacks map area (115-I) were carried out from 1988 to 1992 as a part of Geological Survey of Canada project "Quaternary geology and terrain inventory, east-central Yukon". This paper presents observations on the origin of major gravel units within these placer districts, including stratigraphic and paleoenvironmental information, which sheds some light on the Quaternary history of the gravel deposits. Recommendations are offered for the applications of these results and interpretations to the search for new placers within this region.

SETTING

BEDROCK GEOLOGY

The Carmacks map area (115-I) includes the Yukon cataclastic and the Yukon crystalline terrains and the Whitehorse Trough (Tempelman-Kluit, 1978; Figure 7-2). The terrains are composed of Paleozoic to Jurassic sedimentary and volcanic rocks and their cataclastic equivalents which have been intruded by plutons of Triassic and Jurassic age. The Whitehorse Trough is a former back-arc basin which received volcanolithic and arkosic clastics from the Late Triassic through the Cretaceous. These terranes were sutured during episodes of continental accretion from the Middle to Late Cretaceous. Suturing was accompanied by the intrusion of biotite leucogranite, biotite hornblende granodiorite and hornblende syenite plutons. The Late Cretaceous Mount Nansen Group consists of andesite, dacite and rhyolite that were erupted in the southwestern quarter of the map area during or shortly after suturing. The extensive basalt flows and related volcanoclastic sediments of the Carmacks Group erupted contemporaneously with the Mount Nansen group over an eroded surface with local relief of up to 700 metres (Tempelman-Kluit, 1974, 1980).

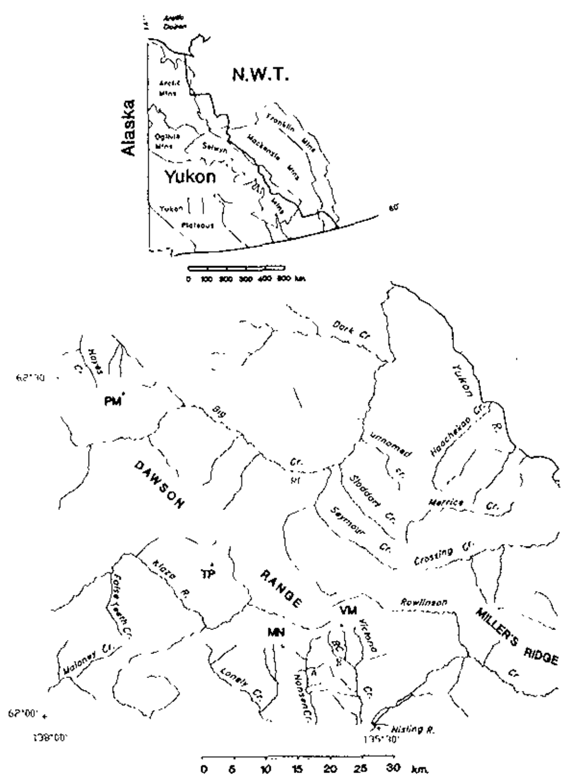

Figure 7-1. Location of the Nansen - Big Creek placer district. Large bold type: PM - Prospector Mountain, TP - Tritop Peak, MN - Mount Nansen, VM - Victoria Mountain; A - location of pre-Reid outwash and Wounded Moose soil, B - core 88 DDH 115 and pre-Reid meltwater channel.

PHYSIOGRAPHY

The Nansen - Big Creek placer district lies entirely within the Yukon plateaus (Mathews, 1986), a rolling upland with broad and accordant summits and ridges that typically lie below 1500 metres. Relief is generally in the range of 750 to 900 metres, although isolated peaks in the Dawson Range such as Tritop Peak, Victoria Mountain and Klaza Mountain rise to more than 1820 metres (Figure 7-1). Within the Carmacks map area (NTS 115/I), the Yukon plateaus show no evidence of recent glaciation, although scattered incised cirque-like valleys do occur near the summits of some of the highest peaks, such as Prospector Mountain and

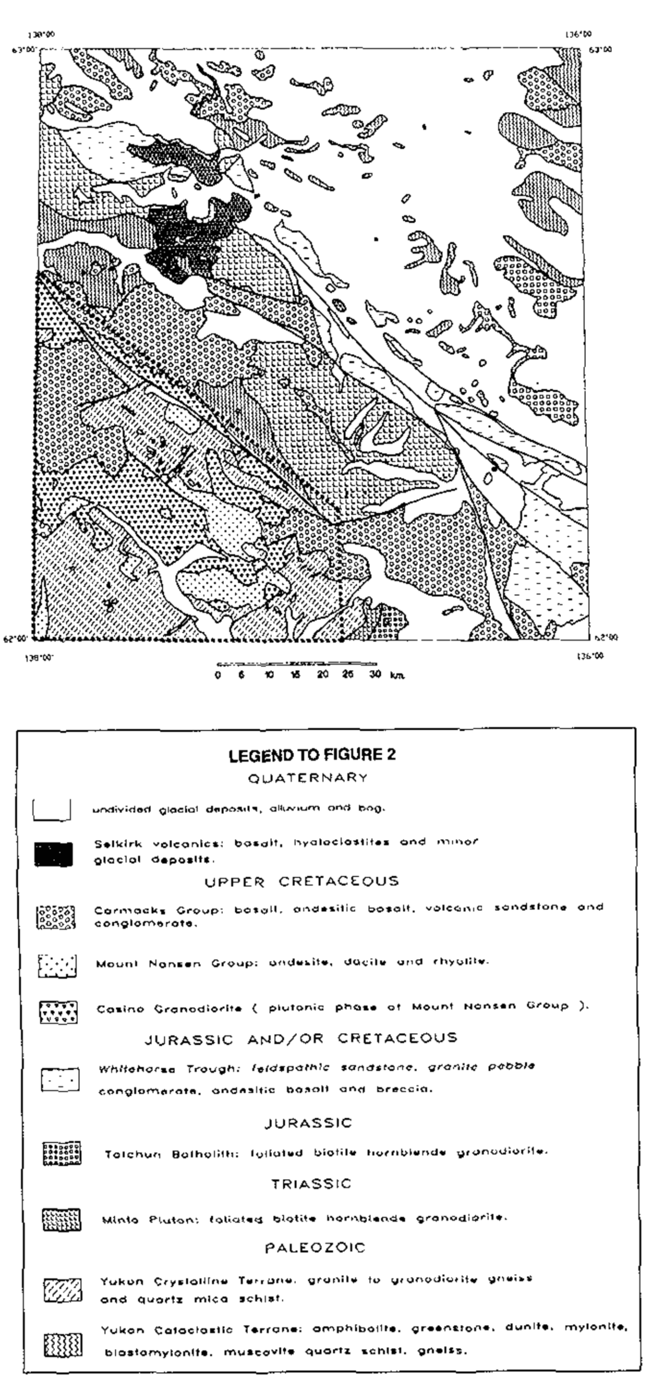

Figure 7-2. Bedrock geology generalized and modified from Templeman-Kluit (1979) using the chronologic information of Grond *et al.* (1984). The dashed line outlines the Nansen - Big Creek placer district.

and Mount Nansen. The morphology of the contemporary Yukon plateaus is inherited from a period when the region was eroded to a relative relief of less than about 550 metres. Estimates of the age of this surface have ranged from Miocene to Eocene (Bostock, 1936; Tempelman-Kluit, 1980). Drainage patterns in the Dawson Range, beyond the limit of the penultimate Reid glaciation, are primarily dendritic trellis where major faults control stream courses, or recurved trellis where trunk streams follow the curvilinear boundaries of plutonic bodies or other nonlinear discontinuities in the bedrock. Drainage is disrupted in areas of thick bog, drift and sands of inactive dunes.

The contemporary westerly flow of the Klaza River drainage network into the Nisling River (Figures 7-1 and 3) was preceded by flow to the south through the broad swampy valley presently occupied by Lonely Creek (Bostock, 1936, 1966; Hughes, 1990). The Klaza River was diverted to its present course through glacially induced stream diversion and capture in the early Pleistocene (Bostock, 1966).

QUATERNARY CONTEXT

A chronology of four glaciations of the Carmacks map area and adjacent areas of central and southern Yukon was constructed by Bostock (1966) based on morphostratigraphic, stratigraphic and geomorphic evidence. These were named Nansen (oldest), Klaza, Reid and McConnell (youngest). Although till, outwash gravels and erratics and ice-marginal features up to 1250 metres elevation associated with the two oldest glaciations were recognized by the present author and previous workers (Cairnes, 1915; Bostock, 1936) within the Nansen-Victoria and Big Creek placer districts, deposits of these glaciations have been largely removed by erosion or buried by colluvium. Consequently, discrimination between the two glacial deposits is not usually possible. The informal name "pre-Reid glaciations" is therefore used in reference to both glaciations.

Deposits of the two glaciations can be discriminated in the area of Fort Selkirk, 80 kilometres north of the Nansen - Big Creek placer district. There, basalts were erupted during the younger pre-Reid glaciation (Jackson *et al.*, 1991). Five K-Ar ages have been determined on these magnetically reversed basalts: 1.08± 0.05 Ma (Naeser *et al.*, 1982) 1.35± 0.08 Ma, 1.35± 0.11 Ma, 1.47± 0.11 Ma (Westgate, 1989) and 1.28± 0.03 Ma (GSC K-Ar 4168). The radiometric ages and reversed paleofields of the basalts are consistent with the time spans of reversed geomagnetism established in the geomagnetic polarity time scale (Mankinen and Dalrymple, 1979; Shackleton *et al.*, 1990).

The penultimate Reid glaciation is thought to have occurred between about 80 and 130 Ka B.P (Jackson *et al.*, 1991). During this event, the Cordilleran ice sheet pressed against the western and southern margins of the Dawson Range. Meltwaters spilled into the Big Creek and Nisling River basins across divides as high as 1000 metres on the west margin and south-flowing streams were dammed at elevations up to 1000 metres along the south.

The McConnell glaciation occurred between *ca.* 25 and 12 ka B.P. (Jackson *et al.*, 1991). The Cordilleran ice sheet also pressed against the Dawson Range but its upper limit was about 300 metres below that of the Reid-age glacier. Meltwaters crossed the Dawson Range only between Crossing Creek and Nisling River (Figure 7-1).

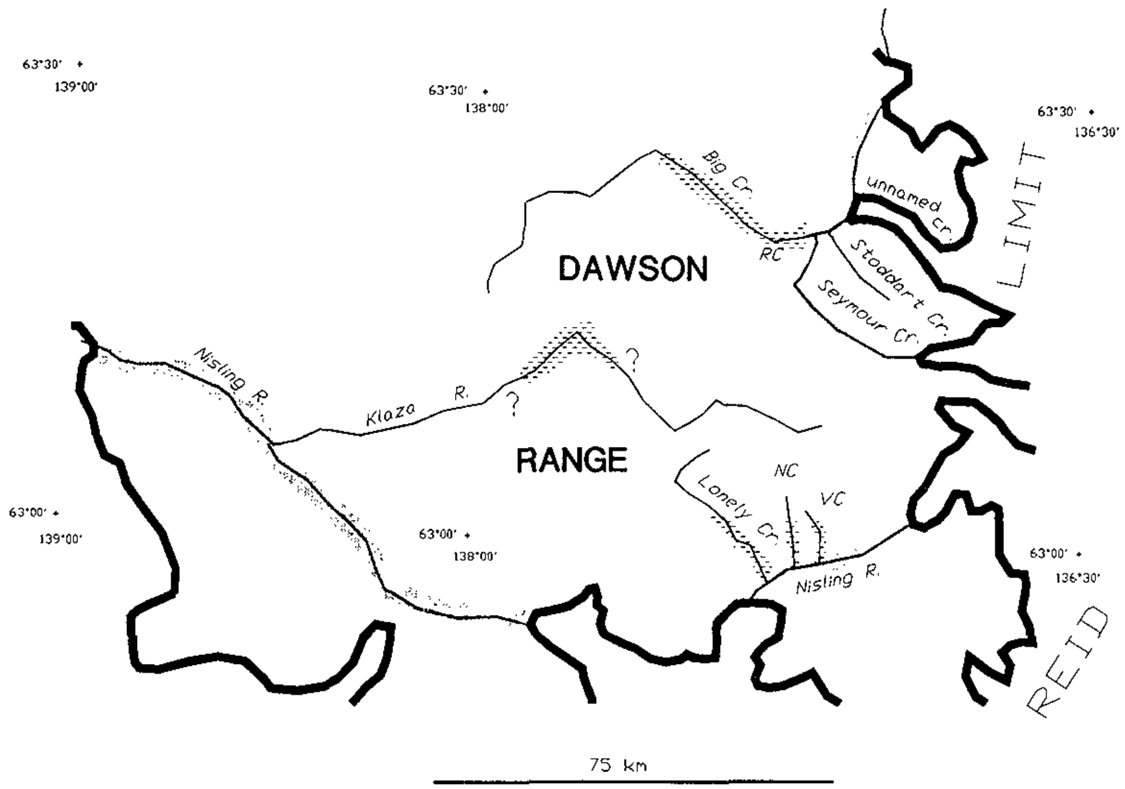

Figure 7-3. Limits of the Cordilleran ice sheet during the Reid glaciation in the area of the Dawson Range generalized from Hughes *et al.* (1969) and Hughes (1990). The stipple patterns indicate areas where stream aggradation occurred during the Reid glaciation. The dash pattern indicates aggradation along streams draining unglaciated basins.

LATE TERTIARY AND QUATERNARY WEATHERING HISTORY OF UNGLACIATED AREAS OF YUKON

Analysis of fossil soils and fossil pollen from associated sediments indicates that Yukon enjoyed a much milder climate until the onset of glaciation in the early Pleistocene (Tarnocai and Valentine, 1989; Tarnocai and Schweger, 1991). Vegetation and soils that existed in the Old Crow area (contemporary mean annual temperature and precipitation -10.1°C and 214 mm respectively) at that time, are presently found no farther north than central British Columbia (contemporary mean annual temperature and precipitation 4°C and 550 mm respectively; Drumke, 1964; Atmospheric Environment Service, 1982a and b; Tarnocai and Schweger, 1991). It is reasonable to believe that the paleoclimate of the Old Crow area, 6° of latitude south of the Dawson Range, contrasted equally as dramatically with the present climate. Such a climate, persisting over hundreds of thousands or millions of years almost certainly resulted in a deeply weathered sediment mantle over the Dawson Range. The well known White Channel gravel in the Klondike district (McConnell, 1905) was deposited during this period. The quartzose composition of this unit, from which its colour and name derive, reflect a climate warm, wet enough for chemical weathering to eliminate less chemically resistant lithologies (Boyle, 1979, p. 356).

Following the pre-Reid glaciations, the climate returned to warmer and wetter conditions at least once. The Wounded Moose paleosol is commonly found developed in pre-Reid outwash in central Yukon (Smith *et al.*, 1986; Tarnocai and Schweger, 1991). It formed under a climate with a mean annual temperature of 7°C or greater and mean annual precipitation of more than 500 millimetres. A Wounded Moose paleosol, developed in pre-Reid gravels overlying till, was exposed beneath colluvial overburden along the valley side above Discovery Creek during exploratory trenching in 1989 (UTM 386000 6884000; A in Figure 7-1) and has been observed elsewhere within the Nansen Creek basin (W. Lebarge, personal communication, 1992).

The temperate period during which the thick (1 m) and deep red Wounded Moose paleosol developed was of unknown duration. Between the time of paleosol development and the onset of the Reid glaciation (*ca.* 1.2 Ma B.P. and *ca.* 80-130 ka B.P.), the climate probably alternated between glacial climates and one similar to the contemporary interglacial climate. Climatic conditions during at least some of these glaciations were as severe as any contemporary climates. Wounded Moose soil and the pre-Reid outwash gravels are commonly cut by periglacial features such as sand wedges which are presently forming in unglacierized areas of Antarctica (Péwé, 1959).

The exposure of Wounded Moose soil examined in the Discovery Creek basin is cut by well formed sand wedges. Evidence for climatic conditions during at least one interglacial period comes from core 88 DDH 115 recovered by Archer-Cathro and Associates Ltd. (1981) above Pony Creek in the Victoria Creek basin in 1988 (UTM 382300 6956000; B in Figure 7-1). It intersected a pre-Reid meltwater channel filled with 21 metres of sediment. Three zones indicative of soil-forming activity were noted in the lower 15 metres of fill recovered in the core. Based on the intensity of weathering, the lowest soil was interpreted as being correlative to the Wounded Moose soil. Pollens recovered from fine sediment associated with less well developed soils were indicative of climates similar to or more severe than today's. These pedologic layers are separated by coarse and angular stony diamictons, probably colluvium, developed through gelifluction when the margins of the meltwater channel were devoid of vegetation and edaphically unstable.

MAJOR GRAVEL UNITS OF THE NANSEN - BIG CREEKS PLACER DISTRICTS

PRE-REID GLACIATION OUTWASH

The oldest gravels in the Nansen-Victoria and Big Creek placer districts are outwash deposited during the waning stages of the last pre-Reid glaciation. One exposure of this gravel, previously mentioned in conjunction with the discussion on the Wounded Moose soil, has been noted on the valley side aproximately 45 metres above the floor of Discovery Creek (A in Figure 7-1) and elsewhere in the Nansen Creek basin (W. Lebarge, personal communication, 1992). Gravels are discontinuously present along the north side of the Big Creek valley up to the divide with Bow Creek where former pre-Reid meltwater channels are apparent at approximately 1100 metres elevation. With few exceptions, these gravels and pre-Reid tills in the upper Nansen Creek and Klaza River basins only contain lithologies known to occur in Dawson Range and thus indicate that the glacial ice present in the upper parts of the Nansen Creek, Big Creek and Klaza River basins originated from ice centres within Dawson Range.

REID OUTWASH AND REID-AGE GRAVELS GRADED TO GLACIAL IMPONDMENT

During the Reid glaciation, the Cordilleran ice sheet advanced into the ice-free Dawson Range from the west and south. This effected fluvial sedimentation in the Dawson Range through climatic change, input of outwash and base level changes.

CLIMATIC CHANGE

The glacial climate largely denuded the uplands of vegetation. Tree line was depressed more than 850 metres in the central Yukon during the McConnell glaciation and the mean July temperature is estimated to have been less than 5°C, hence colder than the present (Matthews *et al.*, 1990). Because the Reid glaciation was more severe than the McConnell, the effects of the former glaciation on the vegetative cover were even more pronounced. The resulting denudation made whatever weathered overburden, formerly stabilized by vegetation, available for erosion and transport, as well as sediment created by the intense physical weathering environment active during glaciation. This probably increased erosion rates and delivery of sediment to adjacent lowlands.

OUTWASH INPUT

Meltwaters from the ice sheet spilled across passes between Crossing and Seymour creeks and down the unnamed creek which shares its divide with Merris and Hoochekoo creeks (Bostock, 1936) in the Big Creek basin and between Rowlinson Creek and upper reaches of the Nisling River (Figure 7-3) farther south. These meltwaters carried outwash gravels down Seymour and Big creeks and Nisling River.

BASE LEVEL CHANGES

Ice sheet encroachment into the Dawson Range raised base levels of streams flowing out of the range by impondment and diversion along ice margins. As much as 20 metres of aggradation occurred along streams draining unglaciated basins such as Nansen Creek, Victoria Creek, Lonely Creek and Klaza River. Basins that were dammed and also received outwash locally accumulated exceptionally thick deposits of gravel. A tongue of the Cordilleran ice sheet pressed up Big Creek below the confluence of Big Creek and Seymour Creek to no less than 610 metres elevation, raising the base level approximately 150 metres. Glacial ice apparently crossed the low (945 m) divide between Merrice and Hoochekoo creeks and the unnamed creek that joins Big Creek 5 kilometres below Stoddart Creek (unnamed creek in Figures 7-1 and 3). This glacial ice or resultant outwash sediment blocked Big Creek. These events resulted in 183 metres of gravel being deposited in the area of the confluences of Seymour and Stoddart creeks with Big Creek, where terraces underlain by unweathered gravels at approximately 823 metres are also present on ridge highs (area of UTM 382300 6913400).

Tributaries to Big Creek above the Seymour Creek confluence would have had to aggrade in response to this significant activity downstream. For example, the approximately 12 metres of gravel and muck overlying a highly productive gold placer at Revenue Creek may have been deposited at this time. Radiocarbon ages of more than 40 000 years B.P. (GSC 4935) and more than 38 000 years B.P. (GSC 4963) have been determined on wood from the top of the fill. Although these ages do not demonstrate clear linkage to aggradation during the Reid glaciation, they at least demonstrate formation predating the McConnell glaciation.

Lithology and physical appearance allow easy discrimination between Reid outwash gravels and gravels deposited by streams that drained glacier-free basins during the Reid glaciation. Outwash contains a significant content of lithologies external to the basin, whereas Reid age non-outwash gravels have lithologies only occurring upstream. The most striking difference is in the physical appearance of the two types of gravel. Outwash gravel typically is coarse, with subangular to subrounded clasts which characteristically occur in planar stratified to massive facies for many kilometres beyond the glacial margin. The non-outwash gravels are often angular to subangular, containing wind-sculptured clasts (ventifacts) and ice-wedge pseudomorphs. The non-outwash sediments display marked textural changes vertically, between angular gravel and coarse sand as well as laterally with texture fining markedly downstream.

The differences in physical appearance relate to depositional history. The alternation of coarse frost-shattered and ventifacted gravels and coarse sand in non-outwash probably reflects episodic fluvial events during which coarse sediments were washed out of uplands into fans and braided stream environments. The periglacial climate and catabatic winds promoted frost shattering and ventifaction of clasts before they were buried by shifting channels or flood events. In contrast, deposition and aggradation of outwash plains was rapid and periglacial modification of clasts relatively rare.

McCONNELL GLACIATION GRAVELS

Meltwaters from the Cordilleran ice sheet had minimal effect on the placer-bearing basins of southwestern Carmacks map sheet during the McConnell glaciation. Meltwaters only crossed the Dawson Range between Rowlinson Creek and Nisling River. This served to truncate and incise Reid-age non-outwash gravels at the confluences of Victoria and Nansen creeks with the Nisling River. Glacial ice did not extend far enough down the Yukon River to block the mouth of Big Creek. Consequently, base level was not affected significantly in that basin.

Probably the most significant effect of McConnell glaciation was simply denudation of the Dawson Range by the onslaught of a glacial climate. This probably resulted in increased rates of erosion and sedimentation. In addition, loess and sand driven by catabatic winds were deposited in fens and bogs thereby forming muck deposits in valley and gulch bottoms.

OBSERVATIONS ON ORIGIN OF GOLD PLACERS

Bostock (1936) noted a close association between placer and lode gold and felsic intrusives in the Nansen Creek and Mount Freegold areas. Subsequent investigations have corroborated his original observations. In Figure 7-4, existing placer operations are overlaid upon bedrock geology generalized from Tempelman-Kluit (1978). All existing placer operations either overlie or are topographically down-slope from Cretaceous granites and granodiorites or their volcanic or subvolcanic equivalents (Mount Nansen Group). Placer gold in these districts originated either within these intrusive rocks or in mineralized zones where the intrusive rocks contact country rock. All of the placers in these districts have formed between the end of the pre-Reid glaciations and the Reid glaciation. If Tertiary weathering produced placers similar to the White Channel gravel within the Dawson Range, they would have been incorporated into pre-Reid glacial deposits.

Placers in the Nansen - Big Creek district are usually found resting on deeply weathered bedrock (*e.g.* Revenue Creek) or on cohesive bouldery clay-rich diamicton (*e.g.* W.D.P. Placers in upper Klaza River basin). The bouldery clay-rich diamictons are interpreted to be till or reworked till because of the presence of bullet and flatiron-shaped striated boulders which are indicative of glacial action. It may be concluded, based on the position of the placers, that following the pre-Reid glaciations, streams in the Dawson Range degraded their beds to bedrock or to clay-rich erosionally resistant glaciogenic diamicton. It was during this period of fluvial degradation that the placers were formed. Erosion through unknown but significant thicknesses of glacial sediments probably concentrated the gold. Gold was also contributed by direct erosion of bedrock or erosion of the colluvial mantle.

Placers along second and third order streams were eventually buried by Reid-age outwash and related aggradation. "Gulch" placers on higher and steeper first order streams were buried by angular, poorly sorted gravels (often with ventifacted clasts) delivered to the channel by creep of the colluvial mantle and progradation of small steep alluvial fans. This aggradation cannot be linked to any specific glaciation or interglaciation at present. Placers along Back Creek on the west side of the Victoria Creek basin (Figure 7-1) are capped by such coarse angular gravels.

SUGGESTIONS FOR FUTURE PROSPECTING

Five recommendations are made with respect to future placer prospecting in the Dawson Range:

1. *The factors that led to the deposition of gold placers in* the Nansen - Big Creek placer district should also have been coincident elsewhere in the Dawson Range. Areas suggested for particular attention include drainage basins within or partly within the outcrop area of the Late Cretaceous granitics and Mount Nansen Group (Figure 7-4).
2. Undiscovered placers that may exist on some of the larger streams such as Big Creek and Lonely Creek are probably buried under a considerable depth of valley fill due to extensive aggradation during the Reid glaciation. Smaller, steep, first order tributaries in the upper parts of basins have the least overburden and are probably the most economically viable prospects.
3. Exploration should be concentrated beyond the limit of the Reid glaciation, because elsewhere glacial ice would have removed preexisting placers.
4. Existing geological maps and the outcrop pattern shown in Figure 7-4 should only be regarded as guides because outcrops are sparse and colluvial mantles are thick in the Dawson Range. Clasts of granitics or Mount Nansen Group lithologies present in stream gravels or in colluvium (exclusive of areas that received Reid outwash), indicate that these potential gold source rocks are present within the basin whether or not they have been mapped, and should be regarded as indicators of gold potential.

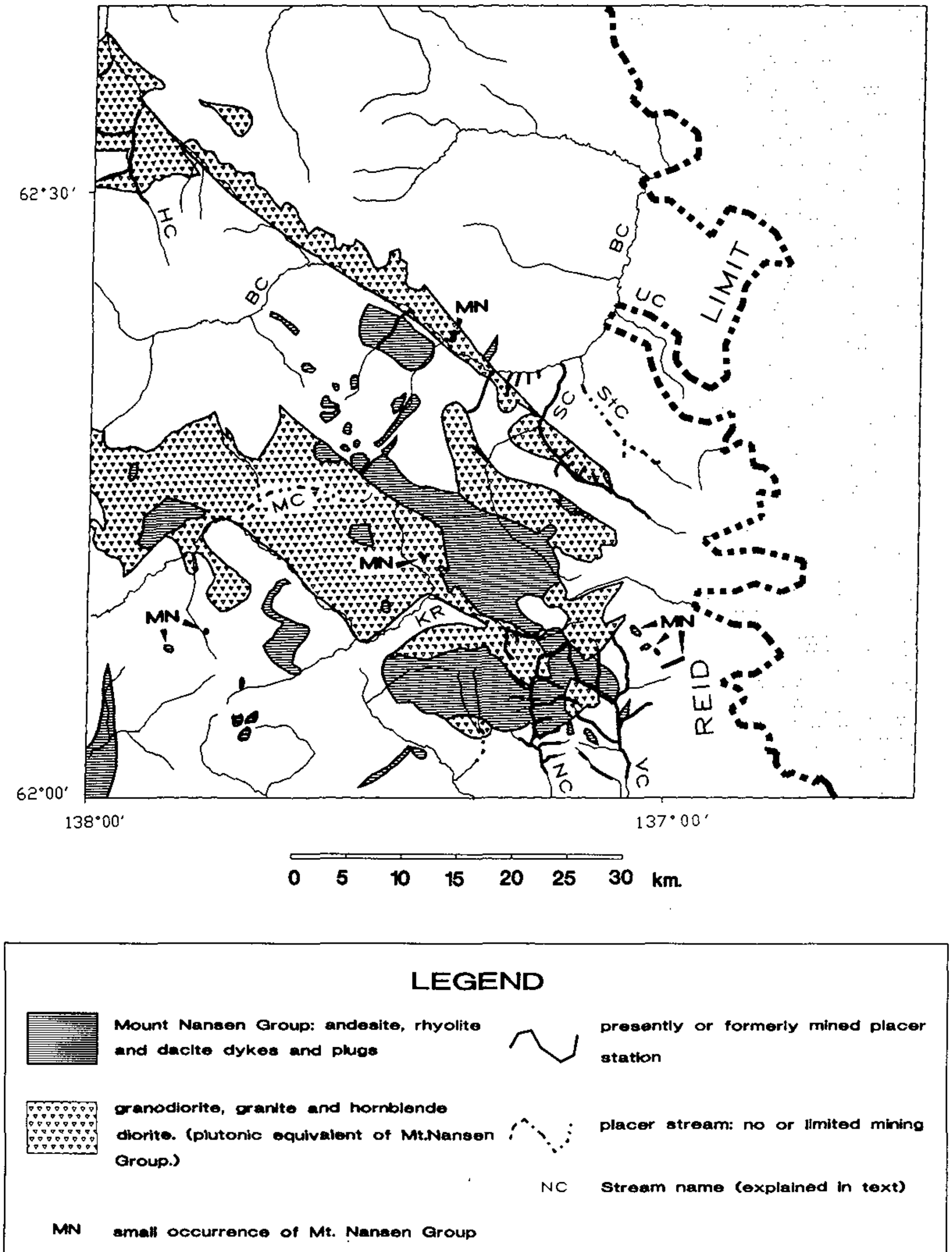

Figure 7-4. Superposition of present and past placer mines and distribution of Late Cretaceous granitics and Mount Nansen Group from Templeman-Kluit (1979). HC - Hayes Creek, BC - Big Creek, SC - Seymour Creek, StC - Stoddart Creek, KR - Klaza River, MC - Magpie Creek, NC - Nansen Creek, VC - Victoria Creek, UN - unnamed creek.

5. Pre-Reid outwash may locally contain low-grade placers. Glacial erosion acted upon a weathered bedrock mantle relict from Tertiary climates. This mantle was probably locally enriched in gold which may have been further concentrated by glaciofluvial sorting.

ACKNOWLEDGMENTS

The author thanks the many placer miners of the Nansen - Big Creek placer district for access to their claims and hospitality. Particular thanks go to Wayne and Pat Perry, Jack Coglin, Frank Cochrane, Aurchem Exploration, John Gow and Torfin Djuckenstein. The author benefitted from joint fieldwork and discussions with Steve Morison and Bill Lebarge of Indian Affairs and Northern Development Canada and Charles Tarnocai of Agriculture Canada. Paleoecological information was supplied by Bob Mott of the Paleoecology Section of Terrain Sciences Division, Geological Survey of Canada. This paper benefitted from a constructive review by Brent Ward and his comments are gratefully acknowledged.

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TERRAIN ANALYSIS AND THE SEARCH FOR GOLD, COTTONWOOD MAP SHEET (NTS 83G/1E)

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INTRODUCTION

The occurrence of an unusual series of placer gold deposits on Mary and Norton creeks 45 kilometres east of Quesnel, British Columbia, and the production of nugget gold from these deposits, stimulated an extensive search for the source of the gold in the east half of the Cottonwood map area (NTS 83G/1E; Figure 8-1). Studies and exploration extended from 1982 to 1988 and involved bedrock geology mapping, terrain analysis and air photo interpretation, pebble studies of all surficial deposits, paleocurrent indicators, and a paleogeographic analysis. This culminated in an extensive overburden and bedrock drilling program based on a variety of geophysical surveys. This report provides a summary of activities covering this project.

PHYSIOGRAPHY

The Cottonwood area straddles the Fraser Plateau on the east and the Fraser Basin on the west, two major physiographic regions of the Interior Plateau system of British Columbia (Holland, 1964). Elevations range from 800 metres on the Cottonwood River in the west to over 1600 metres in the upland to the east. Drainage is provided by the Cottonwood and Swift rivers and Lightning Creek, which then enter the Fraser River. Main tributaries of the Cottonwood include Umiti Creek (formerly known as Deep Creek), John Boyd Creek, Alice Creek, Mary Creek, Norton Creek and Barry Creek. Lakes are rare in the area but include the southern tip of Ahbau Lake and several smaller lakes such as Hyde Lake. All streams are underfit relative to the valleys in which they flow, a result of extensive glacial and preglacial erosion and deposition cycles that have affected the area. There is a dominant north to northwesterly trend to most of the minor valleys in the area, whereas major valleys trend westerly.

PHYSIOGRAPHIC DIVISIONS

Other distinctive landforms are easily recognized in the area, as shown on the physiographic map (Figure 8-2). These consist of lowlands adjacent to the main streams; extensive plains that border lowlands; linear, rounded north-trending ridges that are rock cored; and planar west-sloping benches that are also rock cored.

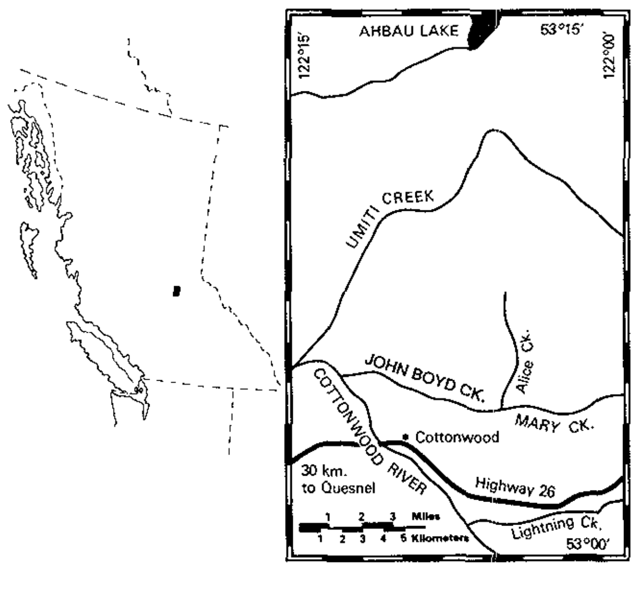


Figure 8-1. Location of map area.

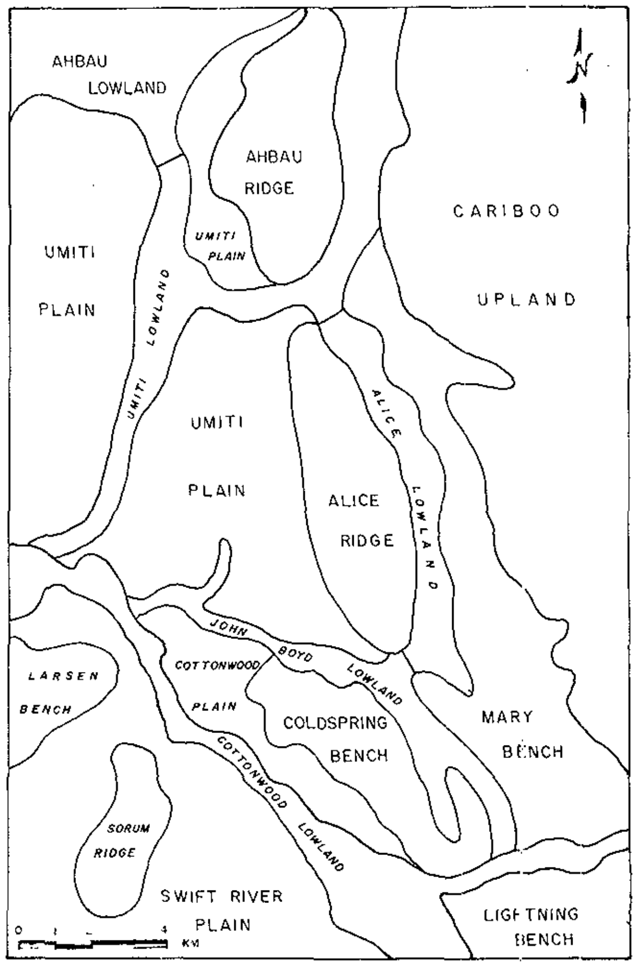
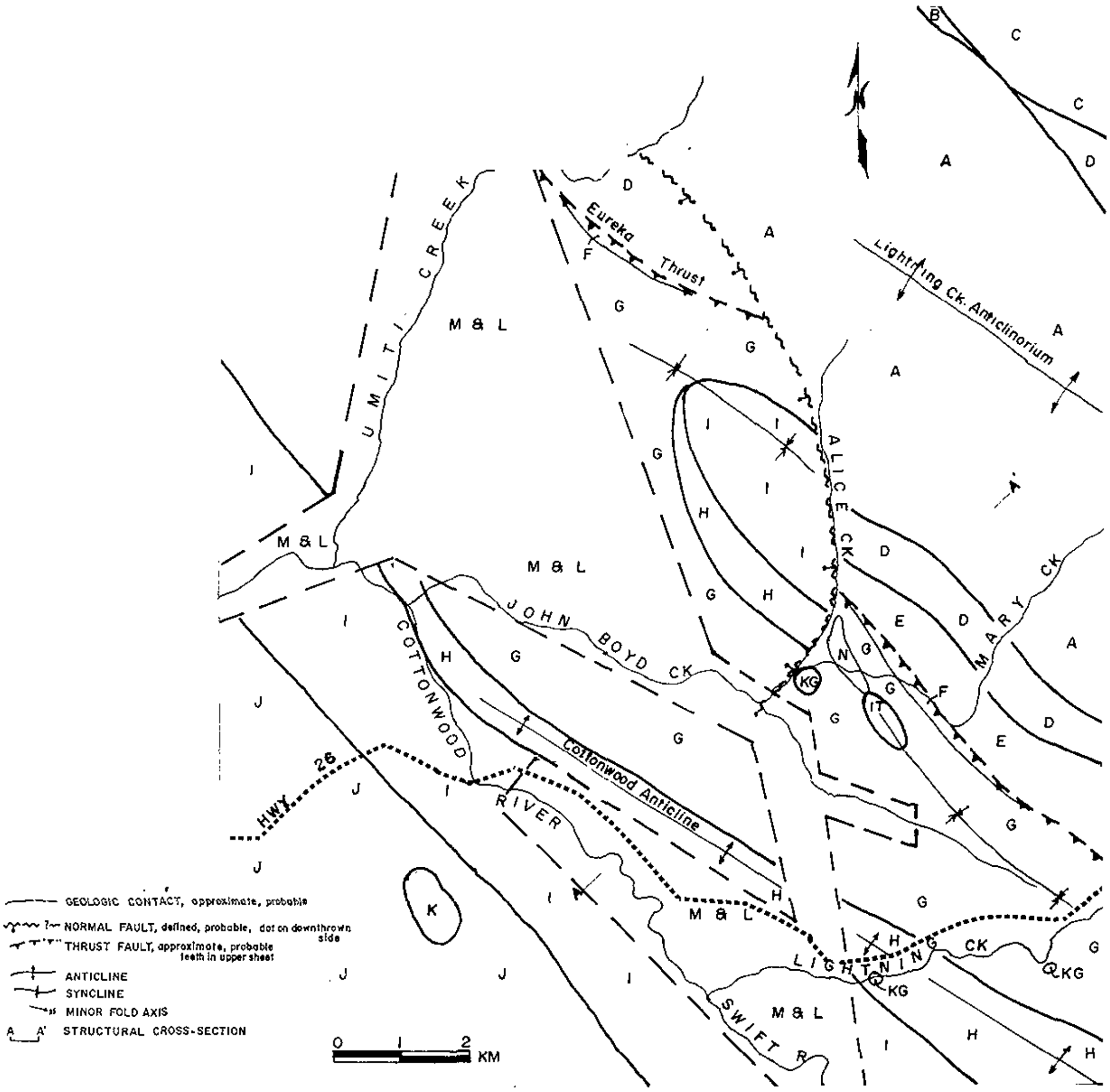


Figure 8-2. Physiographic map.



TERTIARY

?Pliocene

- N Diamicton, pale yellow to orange stony clay, Norton and Mary creeks; mined out, previous nugget gold producer (1972-1985).

Miocene

- M Fraser Bend Formation, light to medium gray platy siltstone, mudstone, laminated and banded; horizontal to very slightly inclined.

Oligocene

- L Australian Creek Formation, mudstone, cemented gravel, lignite seams; folded and faulted.

CRETACEOUS

- KG Gabbro, fine to medium grained, olive green to dark grey, euhedral pyrite, minor chalcopyrite, quartz veins; dikes and small stocks.
- K Syenite, fine to coarse crystalline. Minor chalcopyrite, galena, chalcocite.

MISSISSIPPIAN, PENNSYLVANIAN, PERMIAN

- F Antler Formation; basalt, serpentinite, quartz talc schist, horse and tail structure, highly sheared; outcrop in Mary Creek.
- E Ramos Creek Formation; psammite, gritty sandstone, micaceous quartzite, silver phyllite, argillite, siltstone.

DEVONIAN, MISSISSIPPIAN

- D Siltstone, phyllite, feldspathic quartzite, mica actinolite schist, minor marble.

HADRYNIAN

- C Micaceous quartzite, biotite psammite, silver schist.
- B Marble, micaceous marble.
- A Biotite garnet psammite, biotite quartzite, silver schist, amphibolite, biotite schist.

JURASSIC

- J Basalt, andesite, chert, dacite.
- I Siltstone, black, rusty; basalt, andesite, tuff, dacite.
- IT Tuff, felsic, aphanitic to coarse grained, varicoloured, argillized and altered; oxidized to 100 metres below surface in places; fractures with hematite stain, traces of particulate gold. K/Ar 119 + 4 Ma.

UPPER TRIASSIC

- H Augite basalt, basalt, tuff, volcanic breccia, siltstone.
- G Argillite, siltstone, minor sandstone, grey crystal tuff, graphitic shear zones, disseminated and massive pyrite, quartz veins, gabbro dikes.

Figure 8-3. Bedrock geology map.

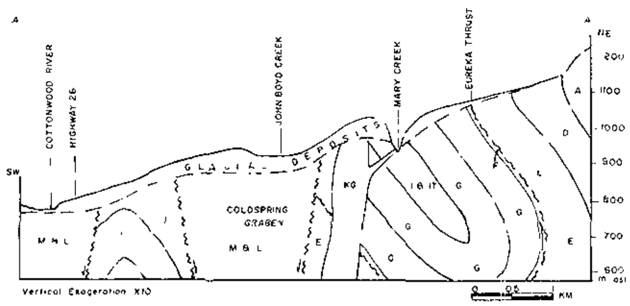


Figure 8-4. Generalized structural section A - A^{1}.

BEDROCK GEOLOGY OF THE COTTONWOOD MAP SHEET (93G/1E)

Bedrock outcrops are scarce, exposed mainly along creeks, rivers, highway and logging roadcuts, and on scattered ridge-tops. Figure 8-3 is a bedrock map adapted from Struik (1982), Rouse and Mathews (1979), Tipper (1961) and Rouse *et al.* (1990); Figure 8-4 illustrates the interpreted regional structure.

TERRAIN DESCRIPTION - SURFICIAL GEOLOGY

Quaternary surficial deposits of glacial and nonglacial origin cover over 95% of the map area. Glacial deposits consist mainly of ground moraine composed of till and glaciofluvial deposits in outwash plains, terraces, channels and kame (ice-contact) deposits. Extensive glaciolacustrine deposits composed of silt and varved clay are also present, mainly in the subsurface and underlying till. Nonglacial deposits of Holocene age include alluvial sand and gravel in bars and terraces of modern streams, sand dunes, alluvial fans, slope wash and landslides on colluvial slopes, peat in organic terrain and rock landforms which are extremely limited. The general distribution of most surficial units is shown in Figure 8-5 and described below.

GROUND MORAINE

Ground moraine mantles more than half the area. It consists of either a blanket of bouldery, sandy, clayey till (M) or a veneer of stony sandy till (Mv) from 1 to 3 metres thick over bedrock. Three tills have been recognized in the subsurface.

The most common till is a grey clayey till referred to as the upper till. It is from 0 to 5 metres thick and overlies bedrock directly in many localities, including much of the Cariboo Upland. However, in buried valleys (Figure 8-6), this till overlies thick sections of older glacial deposits [*e.g.* near Mexican Hill at Lover's Leap, Swan Valley; (Clague, 1991); Barry, Lightning, Alice, Mary and Norton creeks; (Levson *et al*, 1990) and at the Big Bend of the Swift River, along Umiti Creek, in John Boyd Creek, and in places along the Cottonwood River]. This till was deposited during the latest widespread advance of the Interior ice sheet, the Fraser glaciation. Grooves and flutings document that this ice sheet moved north across the area and spread laterally into the Cariboo Mountains over low passes and up valleys such as Lightning Creek.

Two other tills, termed the middle and the lower tills, are also known in the area.

All three tills are present in only one locality near Mexican Hill and below Lover's Leap and Swan Valley (Figure 8-6). This section has been studied in detail by Clague (1991). The middle till here is grey to brown in colour, up to 5 metres thick, and is very stony with numerous angular pebbles and boulders. It overlies a coarse bouldery gravel and silt (interglacial) and underlies a massive, blue varved clay in which tephra and organic layers have been found; twigs collected from the clay yielded radiocarbon dates of greater than 40 000 and 51 000, and one finite date of 32 020 (600 years B.P.; Clague, 1991). This till is at least Early Wisconsinan in age.

The lower till is exposed in numerous localities in other parts of the area. It overlies both bedrock and Tertiary deposits at Mexican Hill and it occurs at Alice, Mary and Norton creeks (Levson *et al*, 1990). It is up to 5 metres thick and underlies an interglacial gravel in many localities. The lower till is believed to represent a major glaciation, pre-Wisconsinan in age, that flowed to the south (Tipper 1971).

GLACIOFLUVIAL DEPOSITS

Glaciofluvial (GF) sand and gravel deposits are widespread in the area. They include extensive outwash plains that trend north, numerous shallow and deeply incised meltwater channels that form prominent valleys, terraces along old meltwater channels and along the valley slopes of present streams. These deposits are related to the progressive melting and retreat of the Fraser ice in Late Wisconsinan time.

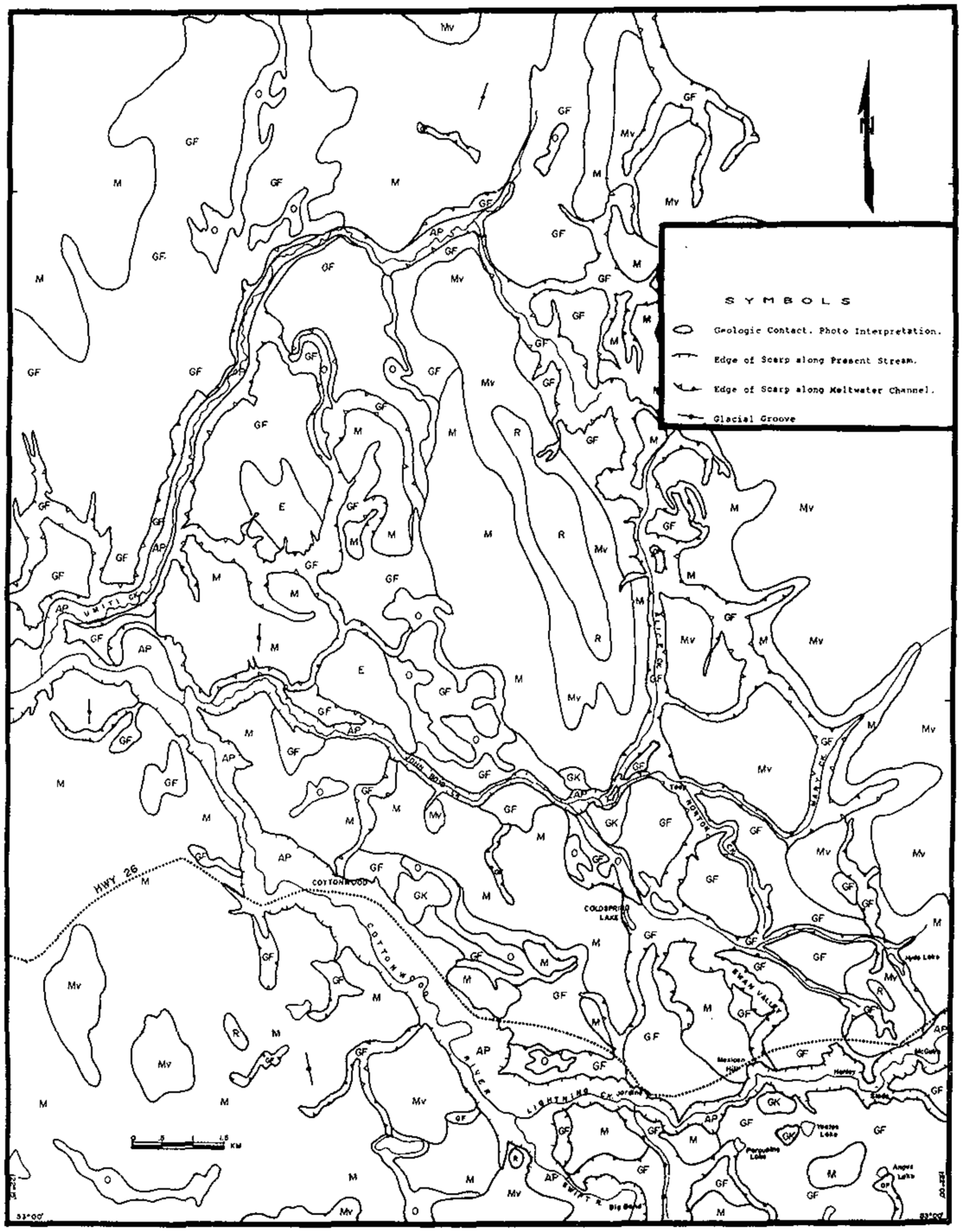
BURIED INTERGLACIAL DEPOSITS

An extensive fluvial gravel unit occurs in several localities in the area. At two localities (Figures 8-7 and 8-8), the unit is a rusty boulder-cobble gravel up to 20 metres thick. It contains more limonite than glaciofluvial gravel and is invariably stained with manganese. Bedding is poor and strata dip steeply to the north in the Lightning Creek valley. Two tills overlie it at the Mexican Hill section. This gravel is known to occur across a distance of 5 kilometres in Lightning Creek. It appears to be a canyon-fill material of interglacial origin, derived from a stream originating in the Cariboo Mountains. The bulk of the placer gold in the Lightning Creek valley is in this unit.

In some places, a fluvial sand unit underlies the upper till. At the Mexican Hill section it occurs as an extensive bedded sand 10 metres thick (Clague, 1991). A similar unit is exposed in Umiti Valley, and along Cottonwood River and John Boyd Creek.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine clays do not generally outcrop. Extensive glaciolacustrine silt and clay units are widespread in the subsurface along buried valleys in the area. The best exposed section is at Mexican Hill, but similar units occur at



HOLOCENE

O	ORGANIC	Peat, wet to moist depressions.
AP	ALLUVIAL PLAIN	Sand, gravel in flood plain and terrace deposits; includes steep valley slopes and and colluvial deposits.
E	EOLIAN	Sand, fine grained, in poorly formed dunes and as blankets.

PLEISTOCENE

GF	GLACIOFLUVIAL	Gravel, pebble to cobble, stratified; includes outwash plains and deposits in meltwater channels; some organic terrain and minor streams.
M	MORAINE	Till, sandy, stony, over 2 metres thick, undulating, low relief, fluted in places; includes minor gravel and organic.
Mv	MORAINE	Till, veneer, sandy, stony, less than 2 metres thick, overlies bedrock, moderate relief; includes some bedrock.
R	ROCK	Rock hill, knob, ridge or plain.

Figure 8-5. Surficial geology map

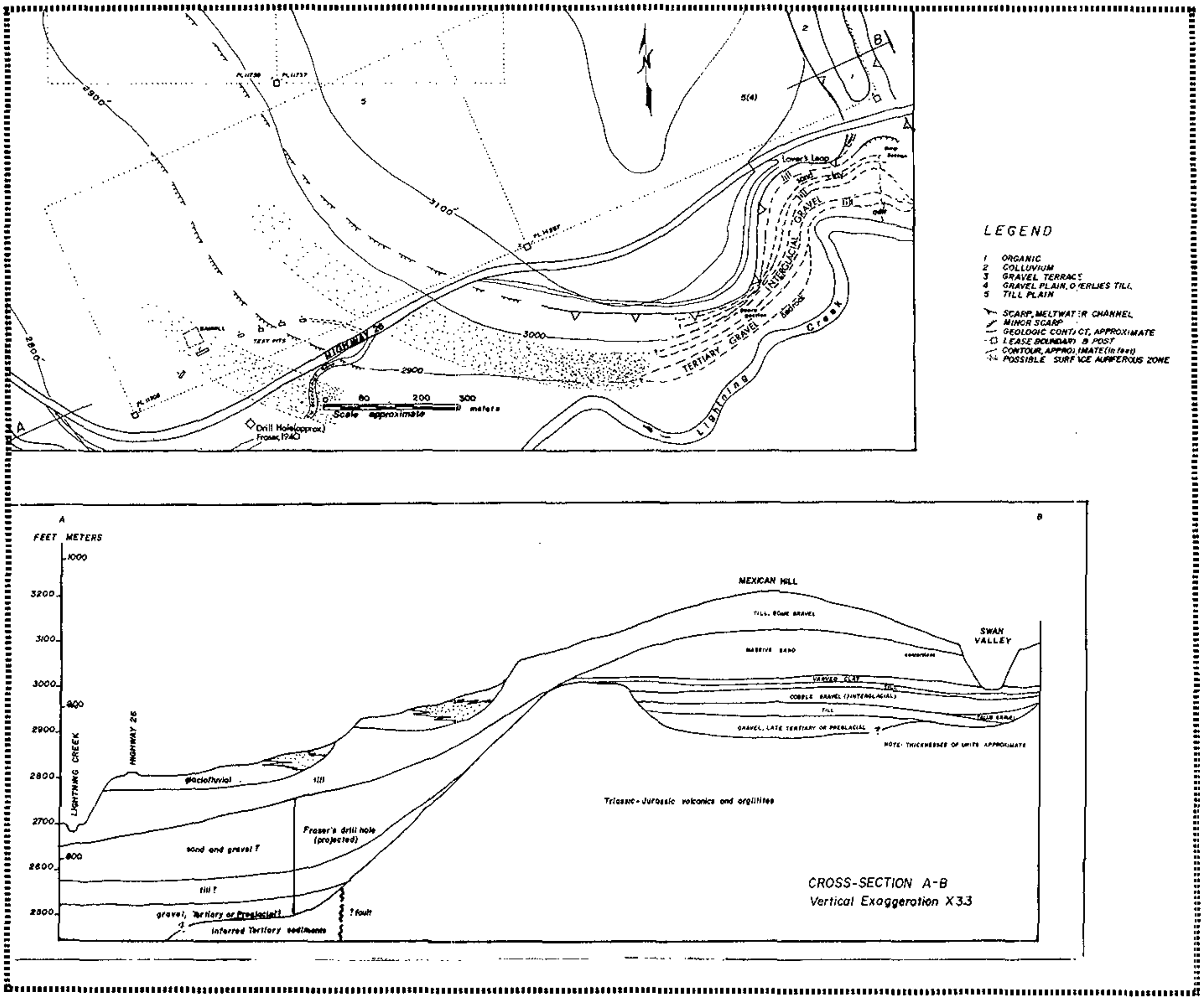


Figure 8-6. Map and section, Mexican Hill.

Alice Creek, along the Cottonwood River near the western boundary of the map area and in Umiti Creek valley.

The glaciolacustrine units represent major periods of ponding of meltwater, either near the end of a glacial retreat, or at the beginning of an advance when normal drainage becomes regionally disrupted.

ALLUVIAL DEPOSITS

Alluvial deposits (AP) consist of pebble to cobble-gravel bars along present stream channels, and gravel overlain by flood plain silt on low terraces adjacent to streams. Colluvial slopes are also included in this map unit.

EOLIAN DEPOSITS

Sand deposits of eolian (E) origin are restricted to the Umiti plain where sandy outwash deposits are overlain in places by dune sands. The dunes are indistinct in form and commonly consist of a 1 to 2-metre blanket of discontinuous fine-grained eolian sand.

ORGANIC TERRAIN

Extensive peat bogs (O), up to 30 metres thick in places, occur along major meltwater valleys in the area, especially those that are not presently occupied by well developed streams (*e.g.* Swan valley, Figure 8-4; Clague *et al*, 1990).

THICKNESS OF SURFICIAL MATERIAL

The aggregate thickness of surficial material, including underlying gravel of possible Tertiary age, is greatest in buried valleys. Overall, the data on thickness are sparse. Interpolation from field data in Lightning Creek valley indicates that at least 100 metres of "overburden" is common. At the confluence of Barry Creek and John Boyd Creek a shaft has been sunk 52 metres (John Hanley, personal communication, 1983) and the sequence encountered is nearly identical to that exposed 2 kilometres to the south in the Mexican Hill section. Up to 40 metres of material occurs above the bedrock in places at the Toop mine (Klein, 1976). Drilling by M. Roed (Table 8-2) intersected up to 98 metres of surficial

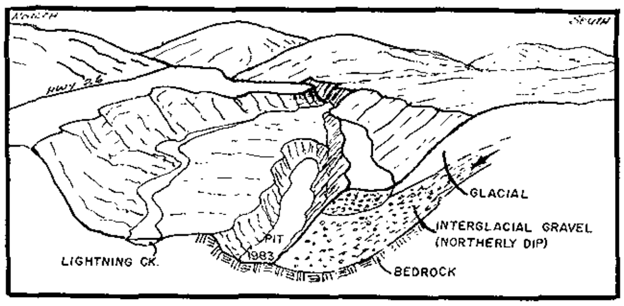


Figure 8-7. Diagrammatic cross-section, Hanley property, Lightning Creek.

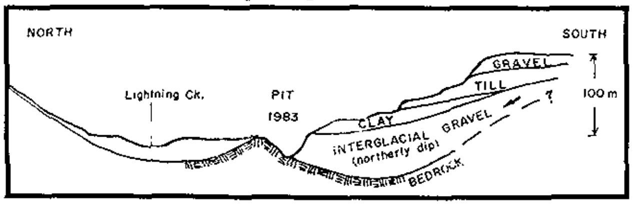


Figure 8-8. Diagrammatic cross-section, McGuire property, Lightning Creek.

material 1.5 kilometres south of the Toop mine. Several properties along Lightning Creek have been drilled, indicating surficial sediments in excess of 100 metres in thickness.

PEBBLE STUDIES

Pebble lithologies were recorded for most of the surficial units in the area, including the late Tertiary gravel and diamicton deposits (section 6.0). This information is summarized in Table 8-2. Older gravels are generally more angular than younger ones, and the lithologic composition is more restricted. For example, the clast composition of the diamicton at Mary Creek is very distinctive, consisting dominantly of felsic tuffs. On the other hand, gravel of interglacial origin is invariably stained with manganese and limonite.

PREGLACIAL COLLUVIAL PROCESSES

The intensity of colluvial weathering processes on preglacial highlands is demonstrated by an unconsolidated lithic gravel that was intersected in one of the exploratory test holes (#R-10, Figure 8-12) drilled to a depth of 162 metres in the Coldspring graben during 1986.

The discovery of this unit significantly changed the interpretation of the geologic history of the area. Originally the material was interpreted as a thin-bedded tuff, but later it was assumed to be talus-fill off the Coldspring graben (Roed, 1988). The author has interpreted this as a detrital deposit derived from a nearby paleo-high which is composed dominantly of varicoloured felsic tuffs. The evidence for this is summarized below.

The dominant (over 80%) lithology of clasts recovered is felsic tuff that ranges through a variety of colours. Grain size is mainly aphanitic, but some samples contain scattered crystals of pink or clear quartz and/or feldspar. Many of the particles are stained with limonite, some manganese, and hematite, all are soft, and some contain tiny vugs and resemble pumice. Others contain chalcedonic quartz (agate) and thin quartz veins or laminae. Some of the particles include argillite, grey silvery schist, mica schist, quartzite and sandstone, and fine to medium crystalline green trachyte. These rocks outcrop in an extensive northwesterly trending belt of metamorphosed Paleozoic sediments. Lignitized wood fragments were also recovered from this unit.

PARTICLE SIZE

The particles in the coarse, washed samples are remarkably uniform in size ranging from 0.5 to 1.5 centimetres in length. Larger clasts are absent. All tuff particles are angular to subangular in shape. All of the silvery schist particles and many of the quartzites and sandstones are subangular to marginally subrounded. The wood fragments are angular and usually elongate and tabular. All of the quartz is angular. Pockets of matrix were observed throughout the core. They are composed of a clay with coarser angular grains "floating" in the matrix.

PAN CONCENTRATE CHARACTER

The pan concentrates for the sampled intervals consist mainly of quartz and felsic fragments in about equal proportions. Pyrite is the only sulphide found, and it is mainly in the form of extremely fine grained massive aggregates associated with a black aphanitic rock (tuff or argillite), and rarely as cubic crystals. Remarkably, there is no magnetite or any other metallic heavy mineral present; indeed there are very few "heavy" minerals in the pan concentrates.

It is known from previous work that the deposit is situated at the eastern edge of a late Tertiary graben or trench, referred to as the Coldspring graben. In the only other location drilled in the graben, 2 kilometres to the south (Roed, 1988), the upper part of the graben is filled mainly with mudstones with minor lignite bands that are assigned to the Fraser Bend Formation.

It was originally assumed that the deposit was bedrock, consisting of a thinly bedded sequence of altered, Jurassic felsic tuffs. The presence of metamorphic lithic fragments, their rounded nature, and the presence of lignite and wood fragments invalidated this interpretation.

If the deposit is fluvial in origin, it reflects an extensive period of stable and constant hydrodynamic conditions, as the deposit is so well sorted and of substantial thickness (at least 160 m). The angularity of the felsic tuff fragments, given their softness, also argues against this interpretation. The deposit does not resemble any of the glacial deposits in the area, either in stratigraphic or lithologic character. For example, granite is absent. All of the lithologic types in the deposit occur locally in the bedrock.

The only other plausible interpretation is that the deposit is colluvial and represents a uniform accumulation of talus along a paleo-topographic scarp that was dominantly composed of easily eroded felsic tuff. This interpretation is in accord with the belief that this area was subjected to intense subaerial erosion during the late Tertiary. The deposit, therefore, is likely the initial infilling of the Coldspring graben which was later submerged, allowing the deposition of silt and clay of the Fraser Bend Formation. The recent work

TABLE 8-1
SUMMARY OF GRAVEL CHARACTERISTICS

Drill Hole #	Total Depth (m)	Overburden Depth (m)	Angle of Hole (degrees)	Bearing (degrees)	Collar Elevation (m)	Major Rock Type
D4	89.3	5.5	Vertical	Vertical	978	Tuffaceous Rocks
R1	189	65.5	Vertical	Vertical	981	Tuffaceous Rocks
R3	155.4	74.7	Vertical	Vertical	980	Tuffaceous Rocks
R5	167.6	97.5	Vertical	Vertical	981	Argillite
R6	190.5	35.1	Vertical	Vertical	94.6	Argillite
R9	152.4	44.2	Vertical	Vertical	981	Argillite
R10	199.6	39.6	Vertical	Vertical	917	Tuffaceous Rocks
R12	182.9	42.7	Vertical	Vertical	931	Argillite
D9-86	118.6	47.5	71	267	975	Argillite
D10-86	121.9	65.8	80	90	980	Tuffaceous Breccias
D11-86	135	74.7	82	60	980	Tuffaceous Breccias
D13-86	125.9	93	75	230	981	Tuffaceous Rocks
D14-86	136.2	62.8	80	332	981	Tuffaceous Rocks
D15-86	142.2	70.4	70	285	978	Tuffaceous Rocks
D16-86	151.5	46.3	68	330	980	Tuffaceous Rocks
D17-86	102.7	43.6	70	150	980	Tuffaceous Rocks
D18-86	47.9	16.2	50	59	978	Tuffaceous Rocks
MC 1-88	15.2	15.2	Vertical	Vertical	978	Clay
MC 2-88	61	22.9	Vertical	Vertical	978	Tuffaceous Rocks
MC 3-88	18.3	18.3	Vertical	Vertical	978	Till
MC 4-88	6.1	6.1	Vertical	Vertical	978	Till
Total Drilled: 2509 m						

TABLE 8-2
SUMMARY OF DRILL HOLES, COTTONWOOD PROJECT
(*See* Figure 8-12 for locations)

GRAVEL UNIT	TEXTURE	LITHOLOGY CLASTS	MATRIX	SEDIMENTARY STRUCTURES	STRATIGRAPHY
TERTIARY RESIDUAL	Angular to subangular clasts, rare subrounded; numerous flat broken clasts, shingle like in part; pebble up to cobble size, rare boulder size	Mainly very local bedrock; no granitic types, soft, or altered, iron and manganese stained; may be all one rock type, rusty in places, rotten clasts.	Absent to clayey and leached, silicous, limonitic	Unbedded to indistinctly layered; occupies cracks in bedrock, nugget accumulation.	Overlies bedrock directly, underlies younger Tertiary or preglacial material and all glacial material.
TERTIARY CHANNEL GRAVEL	Subangular to subrounded, some angular; numerous flat clasts, some broken, mainly pebble size, rare cobble.	Variety of local bedrock types, quartz, no granite, upper 1 metre commonly stained; very rusty in places; rotten clasts common.	Open work, leached to gritty and silty; rust and manganese stained, partly cemented	Poorly bedded to well bedded, parallel bedding, cross strata and pebble imbrication common; some fractures.	Underlies till and overlies either bedrock or older Tertiary deposit such as at Toop mine.
INTERGLACIAL GRAVEL	Subangular to subrounded, some rounded; pebble to boulder size, subspherical.	Variety of local bedrock quartz, some distant bedrock types such as granite, manganese and limonite stained, rusty in general, some rotten clasts.	Gritty and silty, some open work; rarely cemented, leached in upper part	Very steep massive layers to poor parallel strata, vague lineation and imbrication of large boulders, darker than outwash gravel.	Overlies brown till or bedrock; overlain by till, outwash gravel, or glaciolacustrine clay or alluvial gravel.
OUTWASH GRAVEL	Subrounded to rounded, some subangular, moderate to high sphericity; pebble, cobble and boulder sizes.	Variety of regional rock types. Varies from grey to light rusty brown in colour.	Silt and clay poor, gritty sandy, open work matrix in places; loose in general	Well bedded, cross strata, parallel bedding, pebble imbrication, interbed of sand, silt, clay, inclusion of till, high terraces along	May overlie till, glaciolacustrine clay, silt and sand, older gravel or bedrock. Commonly overlies other morainal material.
ALLUVIAL GRAVEL	Subrounded to rounded, some subangular & moderate to high sphericity; pebble to boulder size	Great variety of regional rock types; very few rotten clasts.	Silt and clay poor, mainly gritty sand, some open work structure; loose in general	Well bedded, cross strata, interbeds of silt, sand and clay; imbricated, curvilinear ridges, low terraces	Comonly overlain by flood plain silt, lacustrine clay, and/or organic peat and muck; overlies all older materials.

of Rouse *et al.* (1989) supports this proposal; they have suggested a Late Miocene age, based on palynology, for deposits such as the Fraser Bend Formation. The Mary Creek mudflows are considered to be contemporaneous with the upper part of the residual deposit found in R#10, and may range in age from Late Miocene to Pliocene and possibly even to early Pleistocene.

LATE TERTIARY AND PREGLACIAL DEPOSITS

Exposures in the area indicate that a substantial series of river systems developed in late Tertiary time. Preglacial or late Tertiary gravel occurs at Mexican Hill near Porcupine Lakes below Lover's Leap; near the big bend on the Swift River; in the Slade hydraulic pit on Moustique Creek; along Umiti Creek valley; along Coldspring Lake valley; and along the Cottonwood River.

Assimilating all available data and the results of this work, an interpretation of the size and distribution of these early channels is presented in Figure 8-9. All of the valleys shown are now largely filled with moraine, except for sections that coincide with present stream valleys. The interpretation is based on a minimum of subsurface data and will undoubtedly require perhaps major revisions as further exploration is completed.

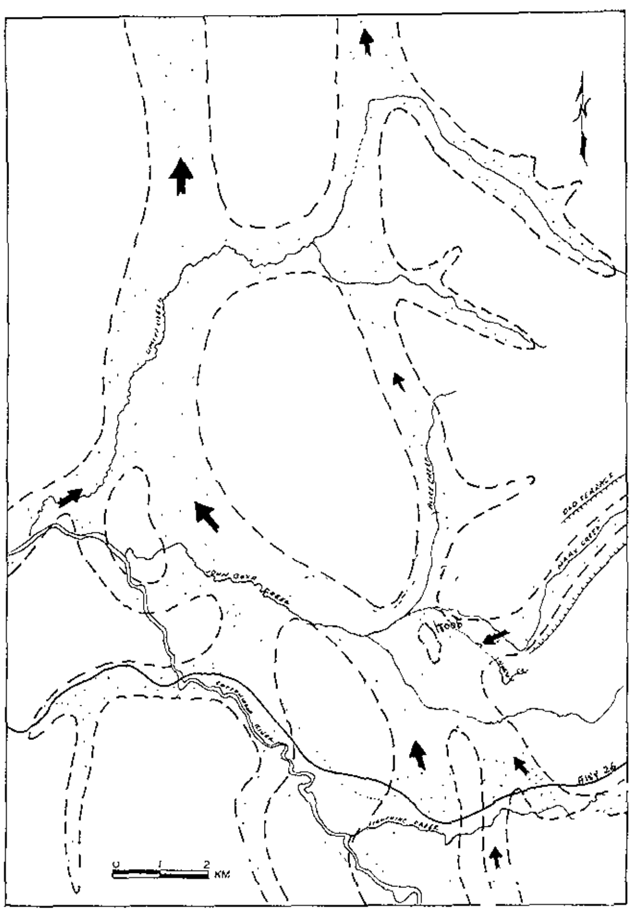


Figure 8-9. Principal early drainage channels.

Generally the gravels indicate that a series of north-trending channels developed along the flank of the Cariboo Mountains. As the land uplifted these channnels migrated westward and cut new valleys. The last phase is evident in the Cottonwood River valley, where a thin rusty gravel overlies bedrock and underlies glacial and younger nonglacial deposits.

A distinctive sequence of basal angular gravel, residual blue clay, three stony diamictons separated by two light grey clay beds, and an upper manganese-stained cemented gravel occurs on the west flank of Mary Creek at the confluence with Norton Creek. The site, known as the Toop mine, is approximately 40 kilometres east of Quesnel, and has been mined out completely for placer gold during the period 1972 to 1988. It first attracted interest due to the high grade of the deposits, the abundance of distinctive, flat, elongated gold nuggets, and the uniqueness of the varicoloured deposits from which the gold was produced. In one instance a pound of gold was recovered from a cubic yard of pay gravel (Barlee, 1974). The following is a summary of the data that have been accumulated for this unique deposit.

GENERAL DESCRIPTION

The general sequence of the "pay dirt" at the Toop mine is shown in Figure 8-10. This deposit occurs beneath two tills (Levson *et al.*, 1990) and overlies weathered Triassic black shale, siltstone, argillite (Tipper, 1961) and gabbro dikes at an elevation of approximately 940 metres (3100 feet). The contact with bedrock is very irregular. Bedrock topography has a local relief of 20 metres within 100 metres.

The basal unit varies from a discontinuous and lens-like layer of angular gravel, commonly less than 0.1 metre thick and composed mainly of local bedrock fragments (Table 8-2), to a blue clay with residual gabbro fragments and abundant pyrite cubes. The gravel fills fractures in the bedrock here and elsewhere in the Cottonwood area. This unit, in turn, is overlain by a soft, orange-brown, stony clay 1 to 1.5 metres thick. This lower clay contains clasts of local bedrock and numerous sharply angular tuff and lithic pebbles up to 10 centimetres in diameter. The basal gravel and residual blue clay are discontinuous so the basal unit of stony brown clay envelopes bedrock irregularities and overlies bedrock directly in places.

The lower stony clay is overlain by a white to light grey clay up to 0.5 metre thick, composed of illite (J. Pell, personal communication, 1987). Up to 10% of the material consists of floating angular particles of a variety of soft rock types including argillite and tuff fragments, black graphite (specks in hand sample), quartz shards up to 60 microns size, plates of muscovite (very thin flakes), soft, orange tuff, silvery white mica, and white to light grey quartz. Angular clasts of distinctive, altered, pale red fine-grained tuff and a mauve variety up to 10 centimetres in size occur sporadically, but do not outcrop nearby. Contacts are gradational, indicating some mixing due to compaction or postdepositional movement. Some convolute bedding was observed at the contact.

The lower light grey clay is overlain by a series of stony clay beds ranging from 0.5 to 2 metres in thickness.

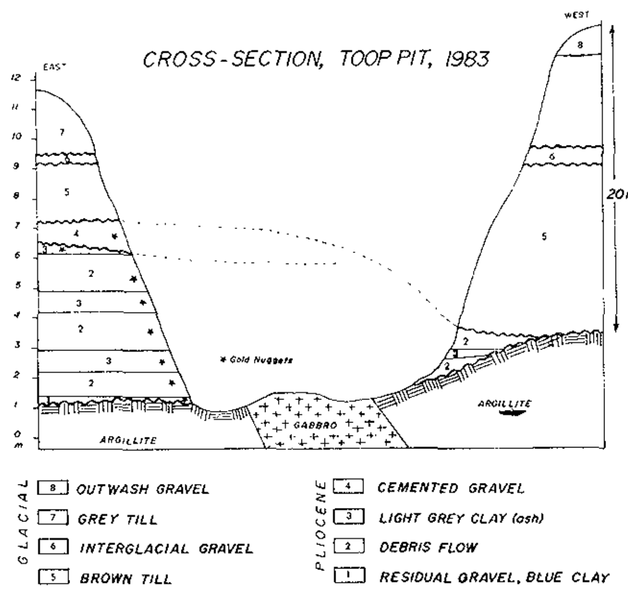


Figure 8-10. Cross-section and stratigraphy, Toop pit, 1983.

The uppermost stony clay is disconformably overlain by up to 1 metre of partly cemented open-work pebble gravel, which is strongly stained with black manganese oxide, is a deep rusty red to brown colour, and appears to have been leached and oxidized. Cement is siliceous, limonite rich and manganese stained. Pebbles in this unit are subrounded to subangular, indistinctly bedded and comprise a broad range of lithologies. The deposit is interpreted as representing a fluvial environment.

The cemented gravel is overlain by a glacial sequence in much of the pit area. This sequence consists of a lower, brown, dense clayey diamicton (tillo), covered by a thin layer of manganese-stained gravel, (interglacial age?) and an upper grey-brown diamicton (Figure 8-10).

The entire sequence slopes very gently (1% gradient) to the north. An angular gravel, equivalent to the cemented gravel, but 10 metres lower, is evident at an operating placer mine adjacent to Alice Creek 1.5 kilometres to the north. Here, the deposit consists of a poorly sorted, dense, pebble to cobble gravel with a variety of angular clasts. It ranges from 2 to 5 metres in thickness (Levson *et al.*, 1990).

At the Toop mine site the sequence thickens from 3 to 5 metres towards the southwest. At the south end of the Toop pit the cemented gravel unit is overlain by a light grey to mauve diamicton, 4 metres thick, containing cobble to boulder clasts (another debris-flow deposit?). This unit (not shown on Figure 8-10) is also distinctive in that it is massive and consists almost entirely of light coloured, altered felsic tuff clasts in a clay matrix. It appears to be a wedge-shaped deposit with a clast fabric orientation predominantly to the east and northeast. The mauve unit is overlain by till and other glacial deposits over 20 metres thick. It is probable that the entire sequence at the Mary Creek locality pinches out to the west beneath the upper till, and to the south and east the sequence has apparently been truncated by glacial and/or Holocene erosion.

CHARACTER AND OCCURRENCE OF GOLD IN THE MARY CREEK SEQUENCE

A great variety of gold nuggets occurs in the deposit. The richest part of the sequence is the bottom metre, usually within 0.5 metre of the bedrock surface. However, nugget gold was recovered from all units.

Most nuggets are flat, linear, smooth and subrounded, but some are rough, angular and crystalline in appearance, contain quartz and sand grains, are "cemented" to siltstone or argillite fragments, or are stained with iron and manganese oxides.

PETROLOGY OF THE STONY CLAYS

Petrologic analysis of numerous samples of stony clay of the Mary Creek unit show that 70% of its composition is matrix which, in hand samples, is granular in appearance, soft, and which breaks down to clay upon washing. Coarser grains are composed of mica, graphite, quartz shards, altered feldspar(?), and other unidentified fragments. The fragments and clasts constituting the remaining 30% of the unit are almost entirely distinctly coloured, altered aphanitic tuffs, sharply angular, and up to 10 centimetres in size. The pebbles are often coated with a red to yellow rind. Subrounded argillite pebbles and cobbles occur and angular to subrounded quartz pebbles are common.

Carbonaceous material is common in the deposit and varies from soft, black graphitic flakes in the light grey clays, to lignite, charcoal and delicate fragments of whole twigs in the stony clays; in one instance a part of a large fossil cedar(?) tree trunk was found that reportedly marked the site of an unusual concentration of nuggets close to bedrock (Terry and Gary Toop, personal communication, 1983).

SPECIAL FEATURES

Small twigs and pieces of branches (willow?) have been recovered from the lower stony clay. This suggests a mud-flow origin for the deposit, in which the organic debris "floated" during semi-liquid flow. The brightly coloured stony clays are thought to reflect periods of oxidation paleosol formation(?).

The open-work nature of the cemented gravel that caps the sequence is believed to be due to extensive leaching; hence, it is a diagenetic feature rather than a sedimentation characteristic.

OTHER MINERALS

Magnetite is rarely found in the sluice box. Numerous pans failed to recover any black sand of any type except for pyrite cubes. The lack of "heavies" and the comparative abundance of nuggets, is anomalous with respect to other placer deposits in the area. This and other characteristics support a non-alluvial origin for much of the gold at the Toop mine.

Malachite and cuprite are locally common in the residual layers at the base of the sequence, close to or at the bedrock contact. Euhedral pyrite is abundant in the argillite bedrock where intruded by gabbro and in residual clay at the base of the sequence. Minor chalcopyrite also occurs in gabbroic rocks. Pyrite was common in the sluice box.

AGE AND ORIGIN

The sequence described here is believed to be of Pliocene or late Tertiary age, as determined from a study of palynomorphs (Rouse *et al.*, 1989).

All of the stony clays observed in this sequence are interpreted as debris or mud-flow deposits. They were probably derived from an adjacent paleo-highland underlain by deeply weathered or hydrothermally altered varicoloured Jurassic tuffs. The strongest evidence for gravity-flow origin is the presence of organic remains, convolute structures, sharp and erosive basal contacts, texture of the deposit, and clast composition. Over 80% of the clasts are soft, felsic volcanics and pyroclastics which are easily abraded.

The materials were apparently deposited in a bedrock depression of the ancestral Mary and Norton Creek valleys. Three possible scenarios are listed as follows: flows eroded pre-existing gold-bearing alluvial deposits; the flows themselves were derived from weathered and hydrothermally altered bedrock that contained nugget gold; or the gold was of hydrothermal origin. There is little evidence for the first possibility. The second possibility presumes that gold-bearing bedrock occurs in the area. The third seems unlikely, as the flat, elongated and smooth nuggets, so common at the Toop mine and in Alice Creek, suggest that some form of erosion took place. On the other hand, the near crystalline appearance of some nuggets suggests a primary origin. However, Knight and McTaggart (1990) have discounted a hydrothermal origin.

The abundance of angular to subangular, altered and diverse felsic tuffaceous rocks as the main clast component of the stony clays suggests a nearby source. Similar rocks have been found within a kilometre to the south during subsurface drilling (Roed, 1988, 1993). Although some of the tuffs in the bedrock match the lithologic types in the stony clays, the pale red to mauve tuffs that are distinctive in the stony clays have no known counterparts in the bedrock of the area. Similarly, the mauve diamicton clast lithology has not been observed in the area.

The light grey clay layers are believed to represent one or more altered volcanic ash deposits which periodically washed off of an adjacent slope and redeposited. J. Westgate, of the University of Toronto, failed to positively identify shards in this altered material. Rouse *et al.* (1989) identified shards in units sampled, and another sample recovered unidentifiable shards.

The presence of angular pebble to cobble-sized tuff clasts in the light grey clays remains problematic. One possibility is that there was an explosive vent nearby but no supporting evidence has been observed. The presence of lignite, charcoal and wood fragments including delicate branches is strong support for a debris-flow origin. The flows may have disrupted a pre-existing lignite layer in, for example, remnants of the Fraser Bend Formation or the Australian Creek Formation, both of which contain coal and occur within 5 kilometres to the south and west. The debris flows could have incorporated charred vegetation. One C^{14} date on the wood gave an age of greater than 50 000 B.P. (V.M. Levson, personal communication, 1992).

Much of the argillite and gabbro bedrock is altered to a black sooty clay and clayey gabbro, respectively. The weathered and soft nature of the felsic tuffs and oxidation of recovered diamond-drill core samples (Roed, 1988) in the area suggests that considerable *in situ* erosion in a subtropical climate affected the area during middle to late Tertiary time (*cf.* Rouse and Mathews, 1979). This alteration could also be due to a hydrothermal event which may have affected the locality.

SOURCE HIGHLAND FOR THE MARY CREEK MUDFLOWS

An interpretation of the paleogeography near the Toop mine at the time of deposition of the Mary Creek mudflow sequence is presented in Figure 8-11. Formulation of this interpretation had to consider a complicated geologic history, not fully explained in the present text. In summary, these events include:

- allochthonous terrane emplacement (Quesnel Terrane) during the Early Jurassic along the Eureka fault;

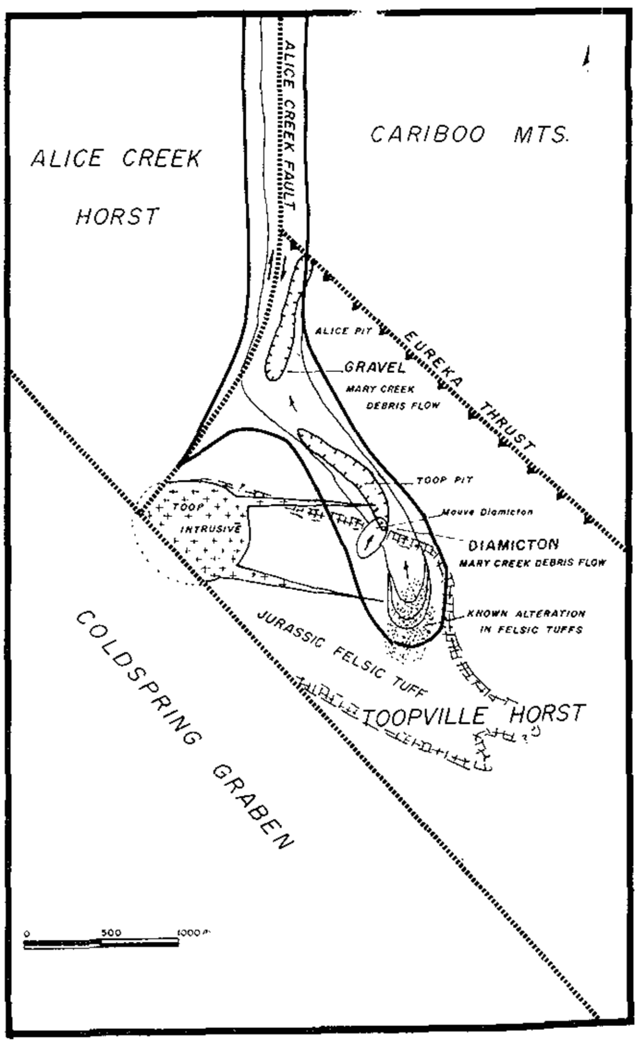


Figure 8-11. Paleogeography, Toop mine area.

- a Cretaceous intrusion event represented by the Naver pluton (Reese *et al.*, 1985) and the Columbian Orogeny;
- development of and deposition in broad shallow continental graben basins in Oligocene time;
- folding during the Laramide Orogeny;
- mild graben and horst tectonics in Early Miocene time along with clastic deposition in deep lakes in linear grabens (Rouse and Mathews, 1979);
- several periods of differential uplift during Pliocene to early Pleistocene time;
- at least three periods of Cordilleran ice movements, separated by an interstadial period with extensive erosion (Clague *et al.*, 1990); and
- modification by glaciofluvial erosion during deglaciation of the last ice sheet and erosion during the Holocene.

The paleotopography was characterized by horst and graben structures formed near the end of the Oligocene. The Coldspring graben is the largest and trends northwest. It is bordered on the east by highlands of the Cariboo Mountains and on the west by the Cottonwood Tertiary basin (Tipper, 1961). This is a major feature and probably continues to the south and joins with the Victoria Creek Tertiary basin. Sediments in this graben consist of over 200 metres of Miocene mudstone and alluvial sand and gravel (Roed, 1988) represented by the Fraser Bend Formation.

Two horsts appear to have existed in the late Tertiary, flanking the Coldspring graben on the north and east. One is an upland referred to as the Toopville horst. It is largely underlain by bedded felsic tuffs of Jurassic age and argillite of Triassic age in the core of an overturned syncline. From diamond drilling (Roed,1988) and rare surface outcrops, it is known that some of the tuffs are hydrothermally altered to a depth of at least 100 metres (Figure 8-11). The northern part of the Toopville horst is underlain in part by gabbro, referred to as the Alice Creek or Toop intrusive (Figures 8-4 and 8-11). The gabbro intrudes Triassic argillite in the Toop pit.

The Alice Creek horst is composed of Jurassic to Triassic metasediments, volcanics and pyroclastics. It is bounded on the east by a vertical hinge-type fault along Alice Creek, and on the west by the Coldspring graben.

An indentation in the Toopville horst is shown along Norton Creek. It appears that the Mary Creek debris flows originated at the head of this indentation in an area underlain predominantly by soft felsic tuffs. All of this terrain has since been eroded to a depth of up to 140 metres below the present surface (Roed, 1988). It is inferred that glacial ice removed this soft rock, although a remnant of the Mary Creek sequence escaped this erosion.

GOLD IN THE BEDROCK

The best indication of a nearby bedrock source for the gold in the Mary Creek sequence was derived from a diamond drill hole (D-4, Roed, 1988). This hole is located 600 metres south of the southern edge of the Toop pit. Particulate gold was recovered on the +100 mesh screen from ten intervals over 58 metres of HQ core in strongly altered varicoloured tuff. These gold occurrences were all within 70 metres of the surface. However, weighted average assays are in less than 0.085 grams per tonne gold. Some two metre sections in other nearby holes were in the range of 0.34 to 1.0 grams per tonne

Given the abundance of nuggets in the Mary Creek sequence at the Toop mine and an "equivalent" unit on Alice Creek, and the inferred origin as mudflows, the known indications of economic gold deposits in the bedrock felsic tuffs, presumed to be the logical source, offers only little encouragement. Despite this, there is simply too much coarse placer gold at this locality to abandon exploration. Ongoing research may improve the possibility of source discovery, but a different "model" may be required.

CONCLUSIONS

One of the main conclusions of this work is that the applicability of surficial geology studies and terrain analysis to mineral exploration is limited without bedrock and structural geology information. The second conclusion is that drift prospecting in British Columbia is clearly not a simple exercise, as several factors affect interpretations. Not enough is known about a major period of denudation between the Late Miocene and early Pleistocene, nor is sufficent information available on the character of pre-Fraser glaciations.

ACKNOWLEDGMENTS

Thanks are due to the staff of the B.C. Geological Survey Branch for greatly improving the manuscript and for the redrafting of the illustrations. The author is also grateful to Bert Struik for the many discussions over the years, to Jennifer Pell and Andrew Higgins for assistance in the field and, finally, to the Toop family and numerous miners in the Cottonwood area, for their hospitality.

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FOLKLORE + SCIENCE + PERSEVERANCE = DISCOVERY OF A GOLD-BEARING PREGLACIAL (TERTIARY) VALLEY, SOVEREIGN CREEK, CARIBOO GOLDFIELDS OF BRITISH COLUMBIA: A CASE HISTORY

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Pegasus Earth Sensing Corporation

HISTORICAL PERSPECTIVE

In the north Cariboo Mountains of central British Columbia, placer gold has been mined intermittently for 140 years (Figure 9-1). Stream deposits with suitable gradients were initially exploited by sluicing, followed later by dredging in selected areas. High-bench deposits and cut-off meanders were mined by hydraulicking. Many stream *channels, which contain placer gold in the surface gravels,* were subsequently found to be filled by glacial debris tens of metres thick. Shafts driven into some of these deeply buried channels demonstrated that auriferous gravels were often underlying, or less commonly, intercalated between layers of diamicton (till).

The richest deposits of the Cariboo, found in flat angular washed phyllite and quartzite-rich gravel below glacial sediments, were mined by shafting and drifting. Drift mining was often impeded by the catastrophic release of groundwater, as well as the instability of overlying till. Groundwater problems were initially handled by gravity and then later by mechanized pumps. Although churn drilling was usually used to check the depth of the channel as well as the underlying stratigraphy, actual sampling was accomplished by shafting and drifting. First, a shaft was sunk along side the stream into bedrock, to a depth where the subsequent drift would lie below the steam bed. Raises were inclined to the basal gravels allowing dewatering. The gravels were then mined by drifting upstream and downstream along the centre of the channel.

The greatest mining activity occurred between 1860 and 1925. After that period, the cost of shaft mining, together with a controlled gold price, made gold mining uneconomic. However, since then, some surface deposits have proven to be economical by the use of large-scale machinery. There is a considerable amount of literature on the subject of placer deposits in this area. The first comprehensive account of placer and lode gold deposits in the Cariboo district was by the Geological Survey of Canada (Johnston and Uglow, 1926). Recently, many individuals have studied the surficial geology and placer deposits of the region (*e.g.* Clague, 1989; Levson and Giles, 1991, 1994).

GEOLOGY OVERVIEW

Placer gold in the Cariboo region of British Columbia is assumed to originate primarily from auriferous quartz veins within metasedimentary rocks of the Snowshoe Group (Struik, 1988). During the early to mid-Tertiary, deep weathering under a humid climate encouraged oxidation of gold-bearing rocks and subsequent removal of soluble salts (Rouse and Mathews, 1979; Johnston and Uglow, 1926). Thus, gold was enriched in the oxidized parts of the veins. During the Tertiary, most streams and rivers in the Cariboo area were probably graded to a position of base level equilibrium and the area was probably characterized by low, rounded hills, separated by sediment-choked valleys. The Quesnel, Willow and Cottonwood rivers had probably established a position near their present courses by the late

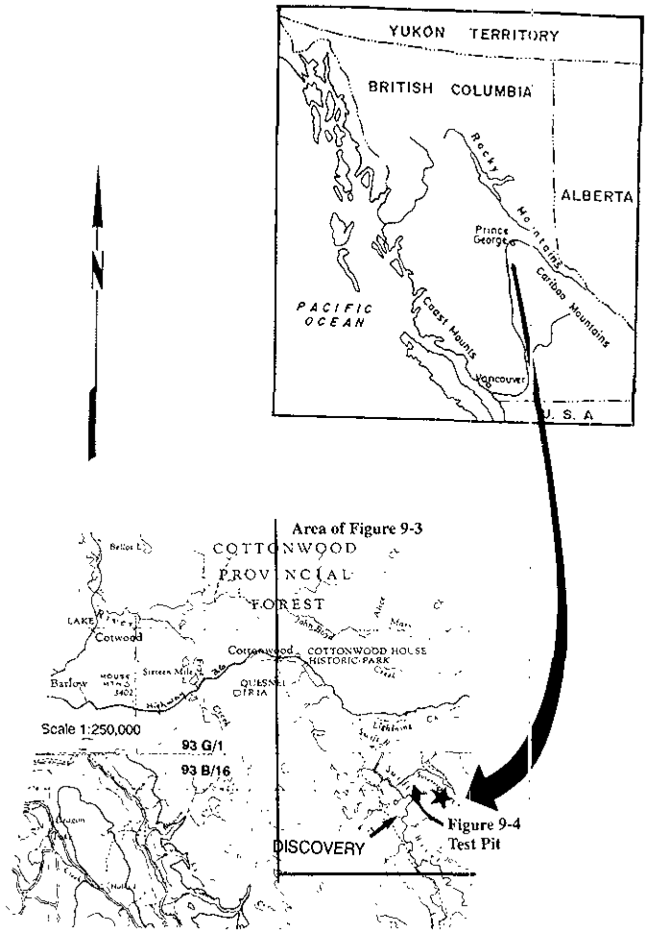

Figure 9-1. Location map.

Tertiary. Much of the gold that had been released earlier and deposited in the extensive Tertiary valley fill, thus became concentrated in valleys cut into the old erosion surface. During the late Quaternary, most streams and rivers incised their valley fill, creating numerous terraces (benches) and new stream channels.

Numerous anomalies in the present stream regime indicate that major changes in base level occurred during the Quaternary. Easily recognized on satellite imagery and large-scale topographic maps, some streams now occupy overly wide valleys. Rivers which drain the western side of the Cariboo Mountains, such as the Cottonwood, Lightning, Swift and Quesnel rivers, flow, in part, in their Tertiary channels, but depart significantly in other areas. Although this author, amongst others (Johnston and Uglow, 1926; Rouse and Mathews, 1979; Clague, 1989; Levson and Giles, 1991, 1994) has identified remnants of Tertiary-type sediments in several areas of the Cariboo, it has not been possible to reconstruct the Tertiary regional drainage pattern due to a lack of readily visible field evidence and other data. Such a reconstruction is basic to understanding the ancient geomorphology and distribution of gold placers.

During Quaternary glaciations, ice initially moved down Tertiary valleys and then later across low divides in a general northwesterly direction. Active subglacial erosion incorporated auriferous gravels into the ice. During deglaciation, areas of thin ice, such as drainage divides and hill tops, would have been the first to become ice free. Initially, meltwater streams would have flowed along the margins of ice filling the Tertiary valleys, cutting new channels into underlying sediments. As melting progressed, these side streams were abandoned, forming cutoff meltwater channels containing minor amounts of fine placer gold. Main valleys locally became so filled with glacial debris that drainage divides shifted, causing major stream diversions.

Through much of the Cariboo, meltwater channels occur on upper valley walls and in intermontane areas. Gold occurs in varying amounts in these late glacial and early postglacial valleys. Generally, the concentration of placer gold in meltwater channel deposits is too low to be economic. The origin of these channels is largely related to successive melting stages of thick glacial ice. Reworking and reconcentration of auriferous gravels has continued throughout the Holocene and is still active today.

TYPES OF GOLD PLACERS

Gold placers in the Cariboo area occur in three main types of surficial deposits, including:

- Tertiary gravels and debris-flow sediments;
- Pleistocene preglacial gravels;
- Postglacial gravels.

Paystreaks in Tertiary deposits tend to be very rich. Coarse nugget gold has mainly been retrieved from drifts along bedrock driven by miners in the early part of the 20th century or by hydraulicking machinery.

In Pleistocene deposits, gold is commonly concentrated on 'hardpans' scattered irregularly throughout both glacial and nonglacial sediments. During the Pleistocene most preglacial valleys were occupied by streams which flowed at higher elevations than present day streams. The reason these valleys have survived glaciation is that part of their path lies oblique to the main glacial flow direction and thus they escaped erosion. These buried channels are filled with Tertiary or interglacial gravels or combinations of the two. Gold distribution in glacial deposits is highly variable, and paystreaks are rare.

Where modern streams erode underlying auriferous deposits, reconcentration of placer gold may occur. Much of the early mining in the 19th and early 20th centuries centred on these materials, so that at present, locating 'virgin' postglacial stream gravels is difficult. Paystreaks in these deposits are discontinuous, commonly ranging from a few metres to several hundred metres in length. For example, high volume mining in 1985 (250 yards/hour) of postglacial surface gravels eroded from till on Lightning Creek recovered 405 milligrams of gold per cubic metre, whereas testing had indicated only 265 milligrams per cubic metre. In the same operation, gravels derived from the erosion of preglacial gravels resulted in a recovery of 680 milligrams per cubic metre, whereas testing indicated a value of 455 milligrams per cubic metre. This demonstrates the variability of placer gold concentrations in these types of deposits.

In summary, placer gold in the Cariboo occurs in a variety of sediments of varying ages and at variable elevations. Given the complexities of sediment reworking throughout the Quaternary, a good understanding of the local stratigraphy is essential for exploration success. As most surface and near-surface placers have been exhausted, attention should focus on Pleistocene preglacial gravels. These deposits offer the best opportunity for economic recovery of placer gold in the Cariboo.

CASE HISTORY: LOCATING PLEISTOCENE PREGLACIAL GRAVELS

BACKGROUND

The following case history is based on work performed since 1972 (74 projects) by the author using a multispectral scanner (MSS), both airborne and satellite sensor data and aerial photographs. All research was augmented by extensive fieldwork including drilling. Part of this work was presented in 1990 in a public forum at the RMS-ROSS Conference, Vancouver (Reimchen, 1990).

The multispectral scanner data, which gathers spectral data in the nonvisible and visible portion of the spectrum, can prove useful to the exploration geologist. This is especially true given a good understanding of the local geology prior to interpretation. For example, nonvisible infrared spectral data can be assigned a specific colour and viewed in conjunction with visible bands. The data can also be ratioed to highlight specific features. Several commercial and proprietary software programs are available which integrate complex digital data to enhance geological features which are not visible on black and white aerial photography, or from the surface.

In early 1984, while processing several LANDSAT scenes for vegetation classification in the Fraser

River/Quesnel area of central British Columbia, the author observed several broad linear features that were not glacial lineaments, cultural features or known geological faults. Previous experience suggested these features may represent deeply buried preglacial valleys. In 1984 and 1985 surficial geological investigations were initiated at 1:50 000 scale, for map sheets NTS 93G/1 (Cottonwood), 93B/16 (Quesnel River) and 93A/13 (Swift River; Figure 9-1). Air photographic interpretation relied on 1:20 000 and 1:30 000-scale photographs. Two satellite computer-compatible tapes (CCT) were obtained: an uncorrected August 1984 scene and geometrically corrected April 1981 scene. For purposes of regional mapping, a non-standard false-colour infrared image (August image) was produced using Bands 4-5-6 and printed at a scale of about 1:150 000 (Figure 9-2; *see* also map in Figure 9-1).

Field mapping in 1985 was interrupted by the accidental discovery of auriferous gravels during excavation of a tailings pond. The gravels, encountered on Lightning Creek near Cottonwood, overlie bedrock below 6 metres of till. Clast lithologies and stratigraphic position of the gravels indicate that they are of interglacial age. At the end of the field program, collected data were interpreted and final maps prepared. Outcrops of preglacial and Tertiary gravels were plotted on the image overlay. The broad linear features identified on the satellite images, were used to link outcrops of what appeared to be a broad drainage system which flowed to the west and north (Figure 9-2).

The April 1981 CCT (no leaves/snow) was the first image to be processed. Using bands 4 and 7, a computer assisted classification was performed on five training areas where it was known that preglacial gravels underlie surface glacial deposits. The resultant computer classification is shown as irregular polygons on Figure 9-3. The darkest circular polygons are designated "prime exploration targets" (PETS). This classification was superimposed on the Band 4-5-6 image so as to register the pictures to the landscape in preparation for further field exploration.

In August of 1985, it was decided to test some of the field and satellite intersections at several sites in the area with the intent of locating a placer gold bearing channel. The PETS were ranked in two levels--a "primary level priority" (PLP) where a geological and a satellite indicator was present and a "second level priority" (SLP) which was defined only by satellite indicators. Unfortunately, problems with land access precluded work on the PLP targets. Delays required work to focus on three nearby SLP targets on open (unclaimed) ground, for which a Work Permit was obtained on only one.

A test pit 23 metres deep was excavated in August, 1985 (Figures 9-1 and 9-4), in a meltwater channel eroded 7 metres into till. Samples averaging approximately 40 cubic metres were taken from each stratigraphic layer, washed through the recovery plant and the recovered placer gold was weighed. Squared-off logs were encountered 2 metres below ground surface. According to the 'locals' this site was the approximate area of an early prospector's (Gagen) shaft. The shaft extended down to till (2 m) at 907 metres elevation. A reddish "paleosol" horizon (at 901 m) was inter-

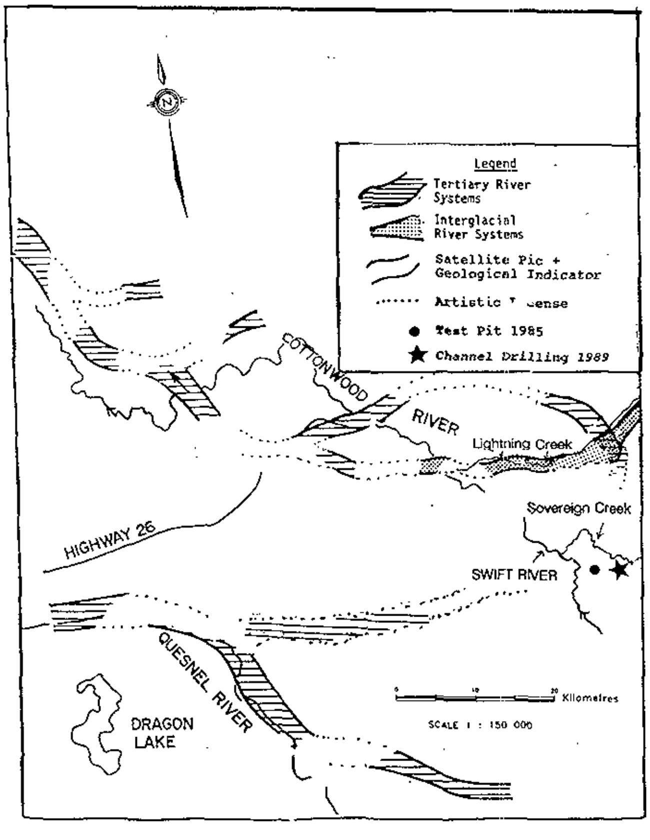

Figure 9-2. Satellite interpretation of ancient river systems in the Cariboo region, B.C.

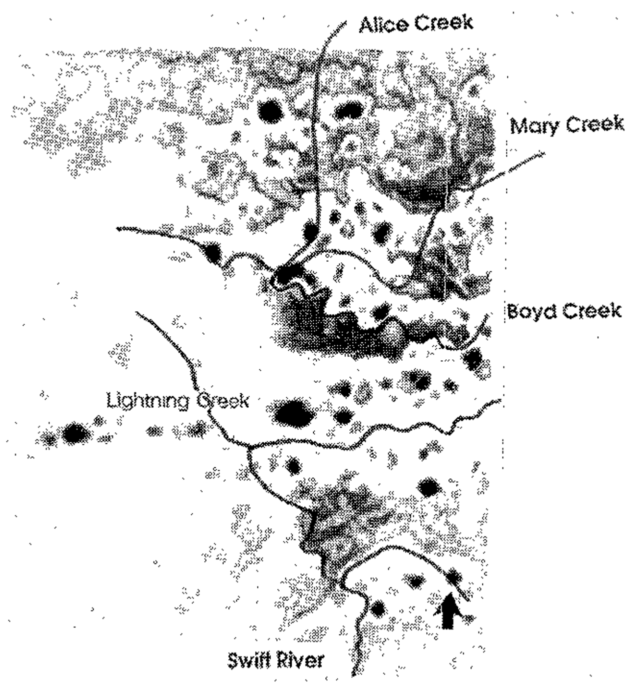

Figure 9-3. Computer classification, darkest polygons are prime exploration targets. 1:50 000 (*see* Figure 9-1 for location)

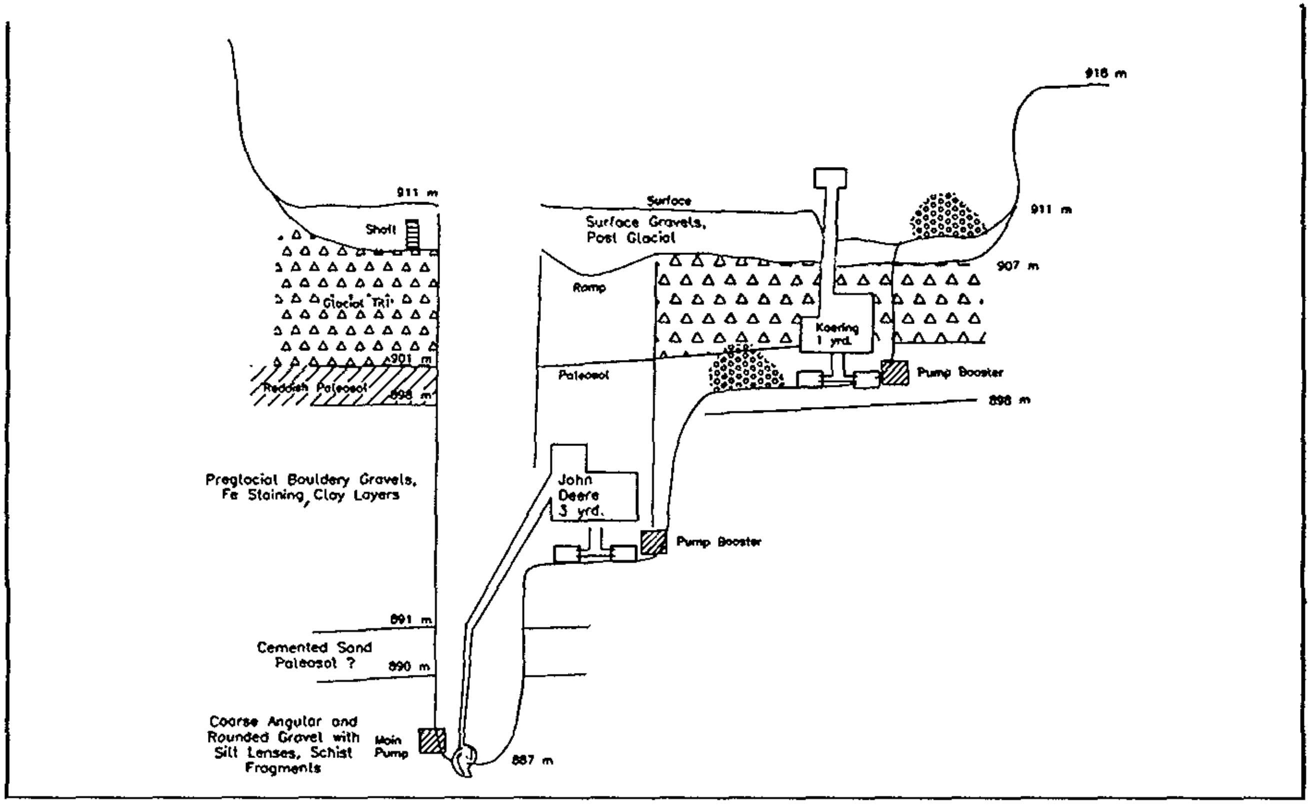

Figure 9-4. Meltwater-channel test hole, Auramet International Ltd., 93B/16E, August 12-16, 1985 (*see* Figure 9-1 for location).

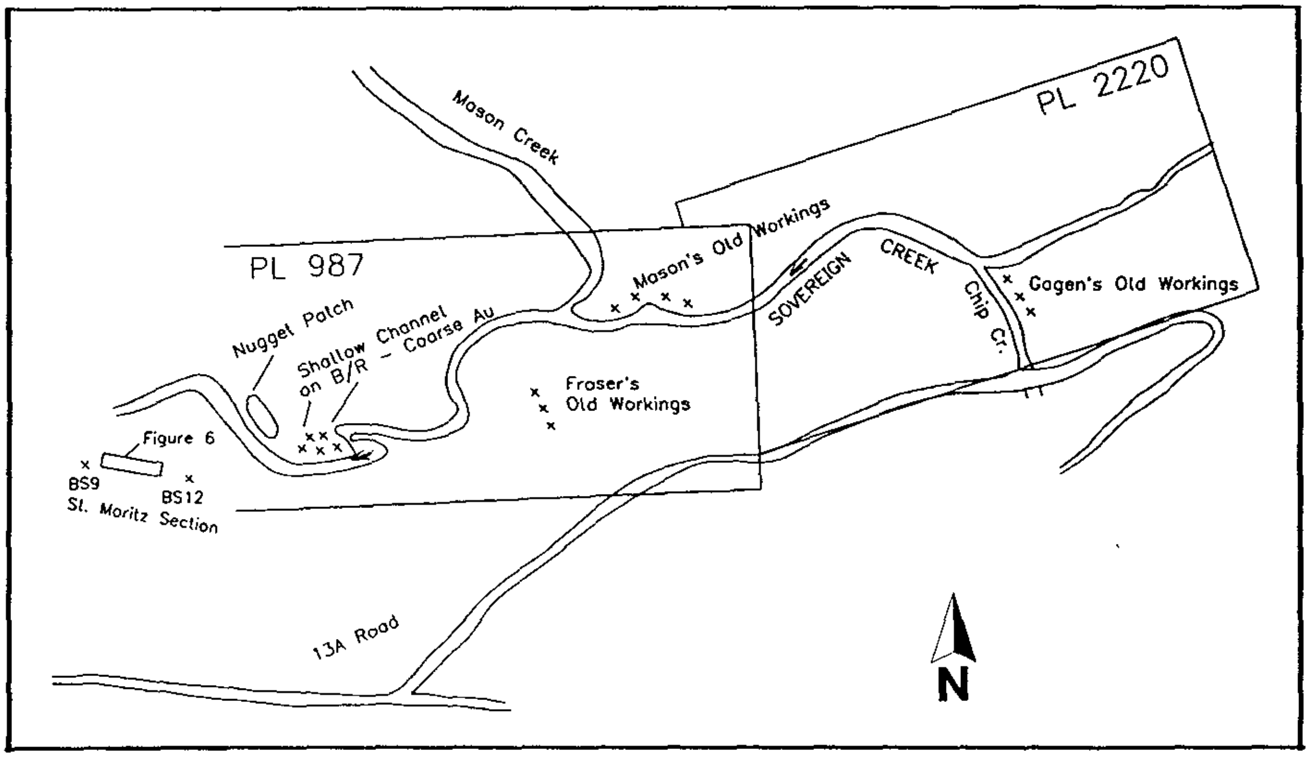

Figure 9-5. Sketch of old workings along Sovereign Creek, reputedly by Fraser, one of the local prospectors.

sected below the till. The soil was underlain by a coarse bouldery gravel layer at 898 metres elevation. The gravel is lightly stained by iron oxide, 7 metres in thickness, and overlies a cemented sandy clay layer, 1 metre thick, which is also heavily iron stained. Artesian conditions were encountered under the cemented sand unit. The lowermost unit, below the sandy clay, consists of pebbly gravels containing subrounded to subangular clasts. The unit is heavily iron stained and indurated.

A one-cubic yard (0.75 m^3) sample with visible gold was obtained from the bottom of a test pit at 886 metres elevation. The pit was located in an area well removed from all present-day river valleys. Analysis of additional samples from all stratigraphic layers below the till recovered placer gold.

SOVEREIGN CREEK

Additional field studies were undertaken on claims in the Sovereign Creek valley, approximately 2 kilometres east of the previous studies. Sovereign Creek is incised about 30 metres into the landscape and, in this location, flows at about 925 metres elevation. Bedrock is exposed in valley sides for much of its length. Several terrace levels are present, each capped with shallow gravels only a few metres in thickness. One mining operation had encountered acceptable paying gravel on terraces a few metres above the creek bottom. The lowermost terrace or bed of the stream contains 'dirty' gravels, varying in thickness from 1 to 3 metres, but with a random gold distribution (a variety of small-scale mining operations have mined the creek-bottom gravels on several occasions).

Some of the famous prospectors of the Cariboo settled in this area building cabins along Sovereign Creek. Old diggings can be seen along the valley, as well as on an old map reputedly sketched by Fraser (Figure 9-5). Hand workers before and after World War II, such as Mason, Gagen, Chipp and Fraser, worked in this area. Mechanical mining was implemented by Terry Toop in 1978, St. Moritz Gold and Platinum Ltd. (Vancouver) in 1987 and 1988 and Royal Sovereign Resources (Quesnel) in 1989. All of the above recovered gold by working surface gravels. An interview with one of the principals of St. Moritz Gold and Platinum in October of 1989, resulted in a statement that in the area "where the Sovereign Creek channel turns and runs to the northwest (just east of the Discovery star on Figures 9-1 and 9-2), ...on the final days of mining, the sluicebox was [found to be] covered with gold..."(personal communication, Ferdinand U. Vondruska, 1989).

Based on this information, the valley side at this location on Sovereign Creek was cleaned with a backhoe. Excavation was extended several metres below a line of imbricated boulders in till (Photo 9-1). The composite stratigraphy for section BS-9 (Figure 9-5) consists of the following (top to bottom): till (1 metre), glaciolacustrine sediments (2 metres), preglacial gravels (5 metres) and a boulder pavement overlying volcanic bedrock at an elevation of 917 metres. A second, deeper test pit (BS-12), located 100 metres east from BS-9 revealed the following (Photo 9-2, *see* also Figure 9-5): till (8 metres), glaciolacus-

Photo 9-1. Backhoe stripping along Sovereign Creek.

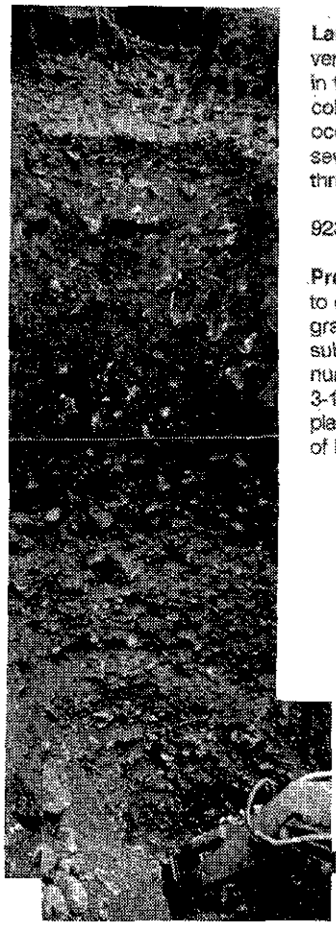

Photo 9-2. Section in test pit BS-12 on Sovereign Creek.

trine sediments (1 metre), preglacial bouldery gravels (8 metres), preglacial pebbly gravels (3 metres); the hole terminated at 912 metres elevation.

In an attempt to establish the paleoflow direction of the glacial ice which deposited the uppermost till, as well as the preglacial river channel which deposited the buried gravels, several pebble imbrications were measured. Fabric analysis of 25 clasts in the till indicated a preferred long axis orientation trending northwest and southeast (Figure 9-6a). This orientation approximately parallels the present course Sovereign Creek. Crossbedding structures in stratified materials intercalated in the till were also measured. Assuming that these features originated in subglacial streams flowing approximately parallel to ice movement, they also suggest glacial flow from southeast to northwest (Figure 9-6b). Finally, 21 small-scale drag folds were measured in the uppermost lacustrine sediments directly beneath the base of the till (Figure 9-6c). All of these measurements confirmed ice from the last glaciation advanced from a southeasterly direction.

Pebble fabric data from the preglacial gravels indicate a paleoflow from southeast to northwest (Figure 9-6d) in imbricated boulder gravels in the upper part of the sequence,

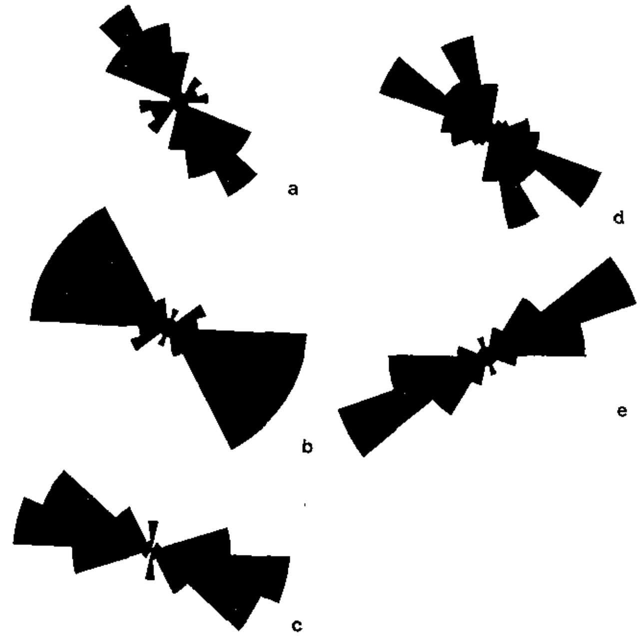

Figure 9-6. Rose diagrams in 20° divisions, on the orientation direction of: (a) the long axis of 25 pebbles of the St. Moritz till section (bulk sample 12); (b) the long axes of 15 beds of stratified materials in the till of the St. Moritz section; (c) 21 small-scale drag folds in the lacustrine sediments below till of the St. Moritz section; (d) the long axes of 30 pebbles measured in the upper gravels of 'preglacial' Sovereign Creek; (e) the long axes of 30 pebbles measured in the lower gravels of 'preglacial' Sovereign Creek.

directly below the lacustrine sediments. In contrast, fabric analysis of the lower gravels, which contain a higher percentage of well rounded sand grains and pebbles, indicate a paleoflow direction trending northeasterly (Figure 9-6e), oblique to the upper sediments.

DRILLING

Given the above stratigraphic and sedimentological evidence, a series of drill holes were collared along a trend paralleling the presumed preglacial valley channel. Step-out holes were drilled every 200 metres with infill where needed (Figure 9-7). Drilling was done with both a truck-mounted churn rig and a central-stem rotary (CSR) track-mounted rig. The section was sampled continuously with sample intervals of 1.5 metres. In the field, the materials were described geologically and geotechnically, then washed and processed using dulongs and conventional gold pans. Gravels and placer gold were sized and weighed. An example of the drilling results is provided in Figure 9-8. Schematic cross-sections through the buried valley, compiled from the drilling data, are provided in Figures 9-9 and 9-10.

PREGLACIAL (TERTIARY) SOVEREIGN CREEK – A SUMMARY

Thirty-six drill holes outline the remnant of a preglacial Tertiary valley buried by till (Figure 9-7). The buried Sovereign Creek valley (base at 886 to 890 metres) contains

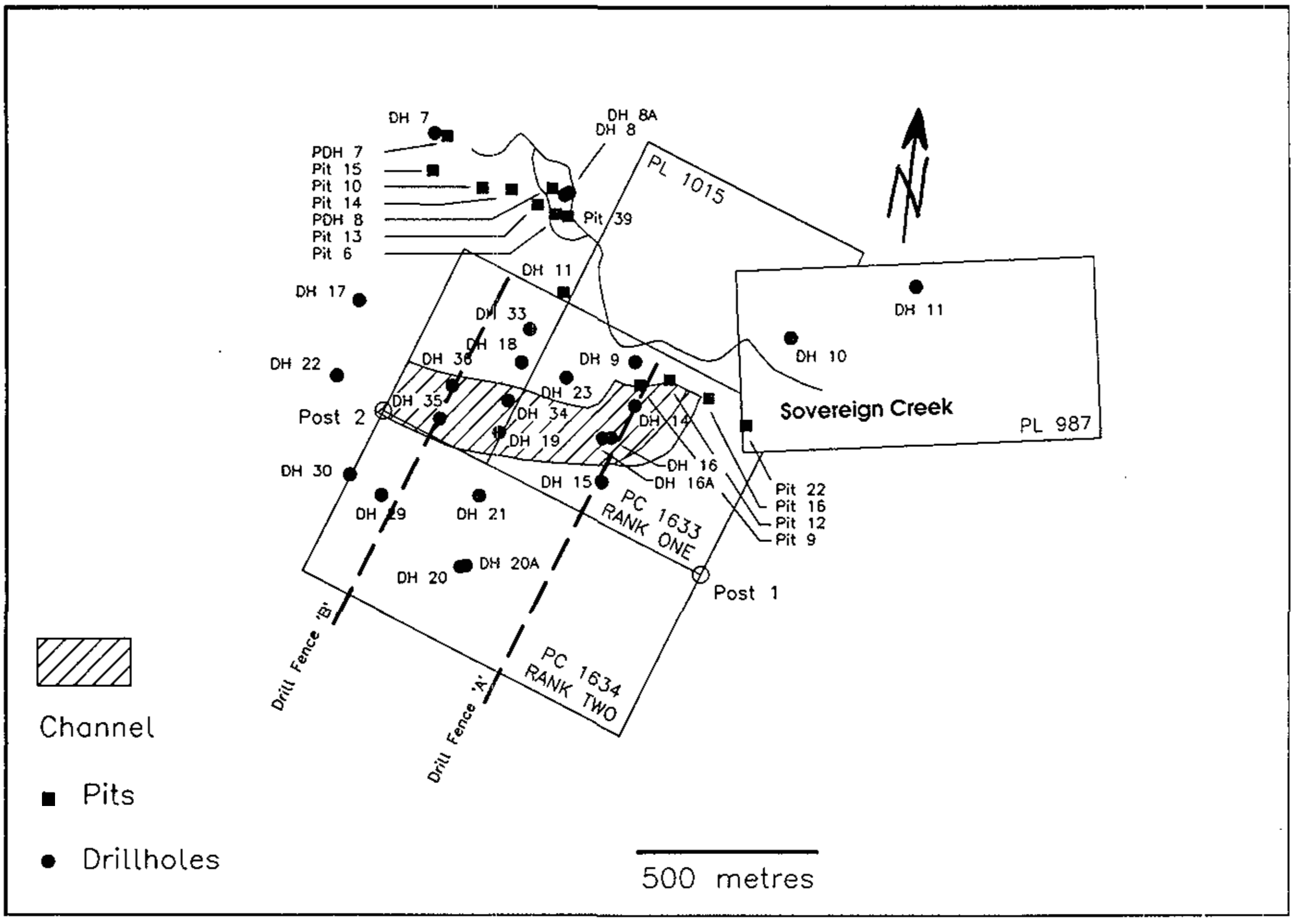

Figure 9-7. Drill hole locations.

rounded pebbly gravel in a fine to medium sand matrix. Based on pebble orientation and drill data, it appears that the Tertiary valley trends in an approximate east-west direction. The pebbly gravel section contains numerous sandy clay lenses resembling overbank deposits. Placer gold occurs throughout the section, but is concentrated near the top of these lenses as well as in coarse boulder pavement near the base of the valley.

Interglacial gravels trending northwest-southeast overlie the Tertiary sediments. The paleosol at the top of this unit confirms a lengthy subaerial exposure. In places, the gravels are overlain by glaciolacustrine sediments which indicate local ponding conditions occurred as glacial ice advanced into the area from the northwest. Till containing auriferous sediment was subsequently deposited over the lacustrine sediments.

During deglaciation, meltwater flowing along the edge of the glacial ice began incising the existing valley of Sovereign Creek which flows through a newly cut channel to the northwest joining Swift River (Figure 9-2). Postglacial erosion was accompanied by at least 40 metres of isostatic/tectonic uplift, as the Swift River now flows in a bedrock channel at 850 metres elevation, well below the base of the Tertiary valley.

CONCLUSIONS

Folklore + Science + Perseverance has resulted in the discovery of a gold-bearing preglacial Tertiary valley informally termed the 'buried valley of Sovereign Creek', Cariboo goldfield of British Columbia.

ACKNOWLEDGMENTS

I am indebted to my friend Dr. Stanley Hoffman, who told the editors that I could contribute a paper to this forum when I was out of the country. Paul McGuigan of Cambria Geological Services helped in removing some of the folksy comments. Michael Pond contributed his CAD skills to many of the illustrations. I have had numerous discussions with miners, prospectors and geologists, and wish to thank Auramet International Ltd, and FOMICO for giving me the opportunity of applying some esoteric ideas and machines to the study of the earth.

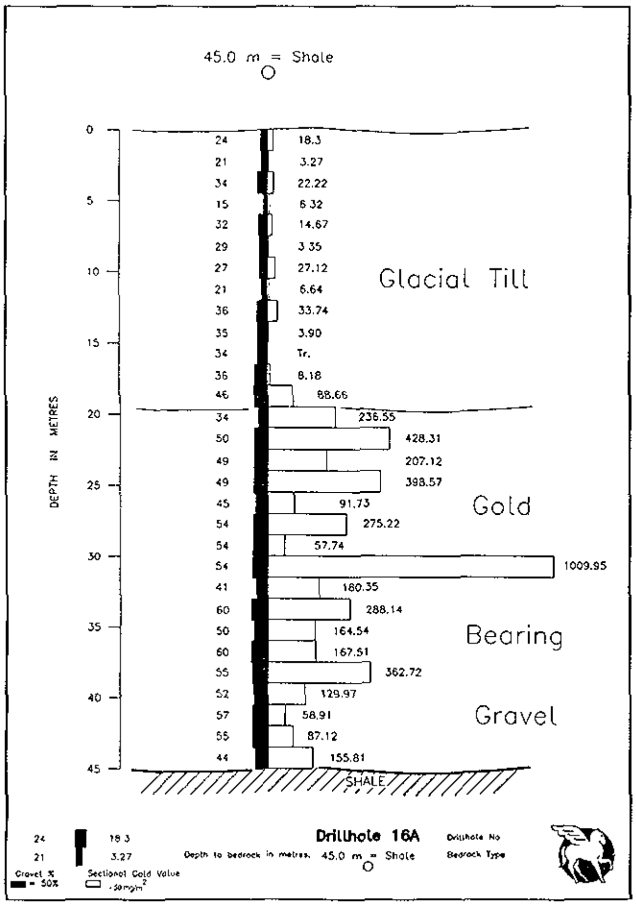

Figure 9-8. Drillhole 16A Sovereign Creek, Cariboo goldfield, B.C.

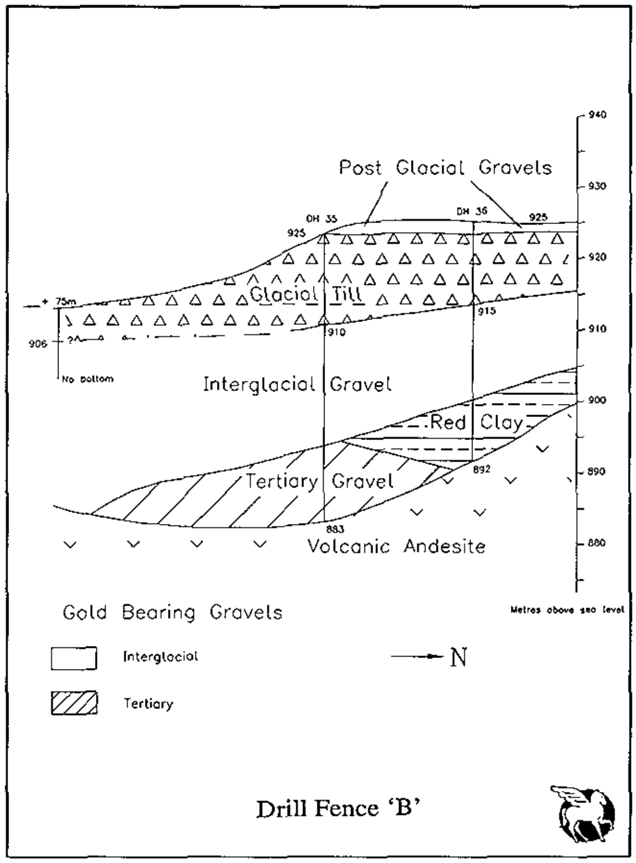

Figure 9-9. Drill fence 'B'. Schematic cross-section through "preglacial Sovereign Creek", Cariboo goldfield, B.C.

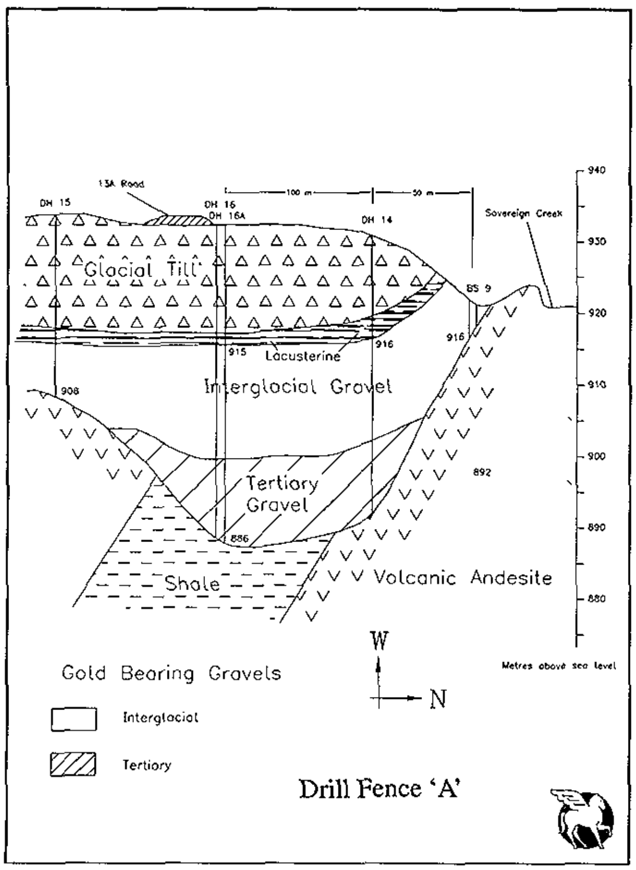

Figure 9-10. Drill fence 'A'. Schematic cross-section through "preglacial Sovereign Creek", Cariboo goldfield, B.C.

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GLACIAL DISPERSAL OF INDICATOR BOULDERS; SOME ASPECTS OF A CASE STUDY FROM THE LOWER SAINT LAWRENCE REGION, QUEBEC

By Martin Rappol, Geological Consultant

INTRODUCTION

A characteristic feature of the glacial debris transport system is that glacier ice, unlike most other geologic agents, has virtually no upper level of competency for the transportation of large particles (*cf.* Shaw 1983). Glaciers can transport huge boulders and at the same time incorporate material from fine-grained unconsolidated sediments. Moreover, boulders can be transported over very long distances (over 1000 km by Pleistocene ice sheets) without experiencing much mechanical or chemical alteration.

Large masses of bedrock as well as unconsolidated sediments may be transported over short distances by glacitectonic processes. If we exclude these, possibly the world's largest known glacial erratic is found near Tallinn in Estonia, where a block of rapakivi granite from Finland with a diameter of 56.5 metres is found over 100 kilometres from its source (Viiding, 1981; cited in Donner, 1989). Well known is 'Big Rock' near Okotoks, forming part of the Foothills erratics train in southwestern Alberta, consisting of three pieces considered to have been one block with dimensions of 41 by 18 by 9 metres, with an estimated weight of 16 400 tonnes, and a transport distance of approximately 500 kilometres (Prest, 1983).

In practice, ice-flow directions may vary considerably over time, resulting in indicator boulders from a given source occurring in a fan or ribbon-shaped area, down-ice from the source. This is well illustrated by the large-scale dispersal patterns of the Fennoscandian ice sheet (Figure 10-1). Also evident is strong deviation of the transport path from a straight line; ice movements in the southwestern sector of the ice sheet transported Åland rocks in a westerly and northwesterly direction. Establishing such dispersal patterns on large as well as local scales by means of systematic observations of distinctive rock types provides valuable information on the glacial history. Boulder counting is a typical field method, providing a first approximation of the directions of glacial transport. Where the opportunity exists, the method is normally combined with an analysis of erosional markings (glacial striations, rat-tails, etc.) and other data (geochemistry).

The method depends entirely on the presence of distinctive bedrock bodies with a relatively small areal extent. These bodies provide the glacially transported, so-called, **indicator boulders**. The indicators should be easily recognizable in the field, allowing a quantitative estimate of their frequency at observation sites. Many of the methodological procedures (*e.g.* boulder size limits, sample size, etc.), depend entirely on local circumstances and objectives of the investigation (*see* also Hirvas and Nenonen 1991).

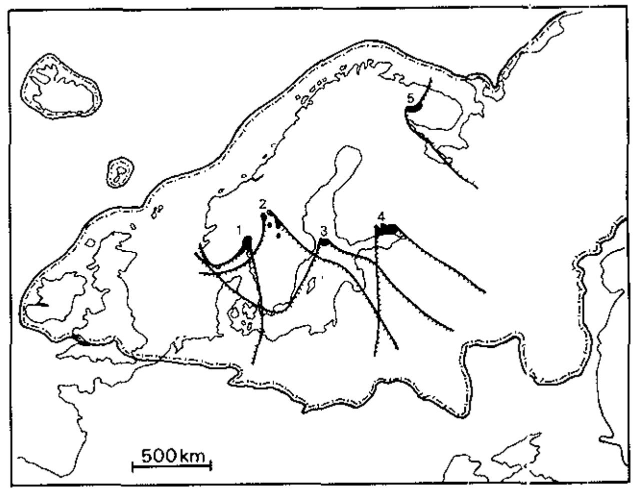

Figure 10-1. Maximal extension of the Fennoscandian ice sheet in northern Europe with dispersal fans of 1. Oslo area indicators, 2. Dalarna porphyries, 3. erratics from the Åland Islands, 4. Viborg rapakivi, 5. Umptek nepheline syenite. See text for comment on the peculiar distribution of Åland rocks.

FACTORS AFFECTING GLACIAL TRANSPORT OF BOULDERS AND THEIR DISTRIBUTION IN TILL SHEETS

The contact of an ice sheet with its bed represents a shear zone, where the highest strain normally occurs at the contact of the ice and its substrate (Figure 10-2b). Above and below this contact, the debris-rich ice and the subglacial materials are subject to strong deformation. Boulders, behaving as rigid bodies, tend to migrate away from the zone of maximum shear; hence, they are either pressed into the substrate or moved higher up into the ice. Several features of till sheets are related to this process. For example, some boulder pavements may have formed in tills or at the base of tills by this process. Secondly, the surface layers of till are usually markedly enriched in boulders. Moreover, collision among boulders transported in a debris-rich basal ice zone also tends to move boulders up, towards higher levels within the ice. Essentially, the mechanism may be considered similar to the shaking of a box filled with marbles of different size; when shaken in a horizontal direction, the larger marbles will eventually rise to the top.

Figure 10-2a shows that the velocity gradient in the basal debris-rich ice is very high. Material higher in the ice

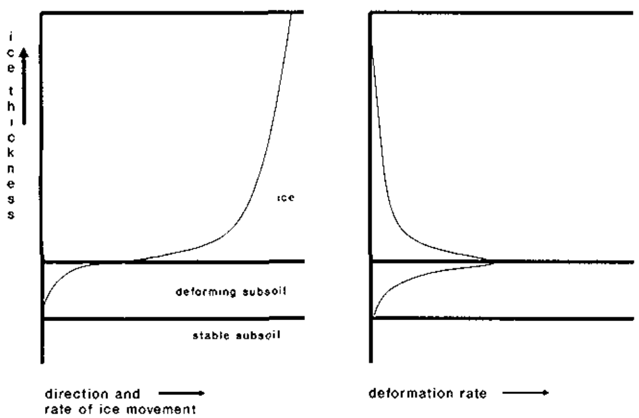

Figure 10-2. A. Flow velocity of ice through a vertical section of an ice sheet; B. Deformation rate (strain) in the same section.

moves much faster than that closer to the base. In a vertical section through the ice, material higher in the ice will, therefore, originate from farther up-ice. Consequently, the bouldery upper till zone tends to contain more far-travelled material than the underlying till material. Generally, however, the vast majority of boulders in a till sample from areas with shallow overburden reflect transportation over very short distances, to the extent that surface boulders of glacial deposits can often be used to map bedrock.

In large parts of Scandinavia and Canada, bedrock is obscured by glacial deposits, and in many areas the ground surface is strewn with boulders (Photo 10-1). These bouldery surface layers represent deposition during the final stages of deglaciation. The origin of such boulder surfaces may be variable, including non-glacigenic processes, such as till surfaces that have been washed by meltwater streams (Bouchard and Salonen, 1991). For example, in Alpine regions, where rockslopes extend above the glaciers, glaciers may transport large amounts of supraglacial debris (typically very angular), delivered by rock fall on top of the ice.

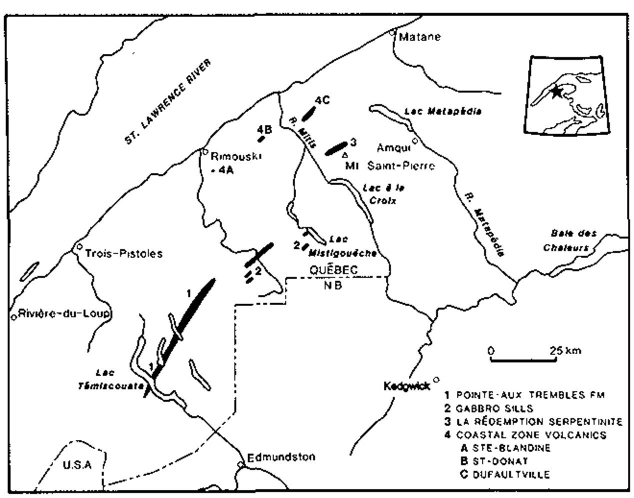

Figure 10-3. Location map of study area.

Photo 10-1. Bouldery surface layer of till.

GEOLOGIC SETTING

The study area is located on the south shore of St. Lawrence estuary (Figure 10-3), and comprises most of the Lower St. Lawrence region (Bas-Saint-Laurent) and part of adjacent Gaspésie, west of the Matapédia and lower Matane valleys, as well as some parts of adjacent northwestern New Brunswick. The St. Lawrence estuary lies along the contact of igneous and metamorphic rocks of the Canadian Shield and predominantly sedimentary Appalachian rocks of Paleozoic age.

On the basis of stratigraphy, glacial erosional features and dispersal patterns, the following sequence of events has been reconstructed for the last glaciation (*see* Rappol, 1993, for extensive reference to earlier work in the area). The first major event during the Late Wisconsinan glaciation was the invasion of Laurentide ice from across the St. Lawrence Valley. In the western part of the area, ice moved in from the west, originating in or moving across the area of Laurentide Park, north of Québec City. In the northern part of the study area, ice advanced from the north-northwest or northwest. At this time, local ice caps covered some of the higher regions of the Appalachians (*e.g.* central Gaspésie and the Miramichi Highlands of New Brunswick). Flow of Laurentide ice, colliding with these local ice masses, was bifurcated: towards the south and down the St. John River valley, and

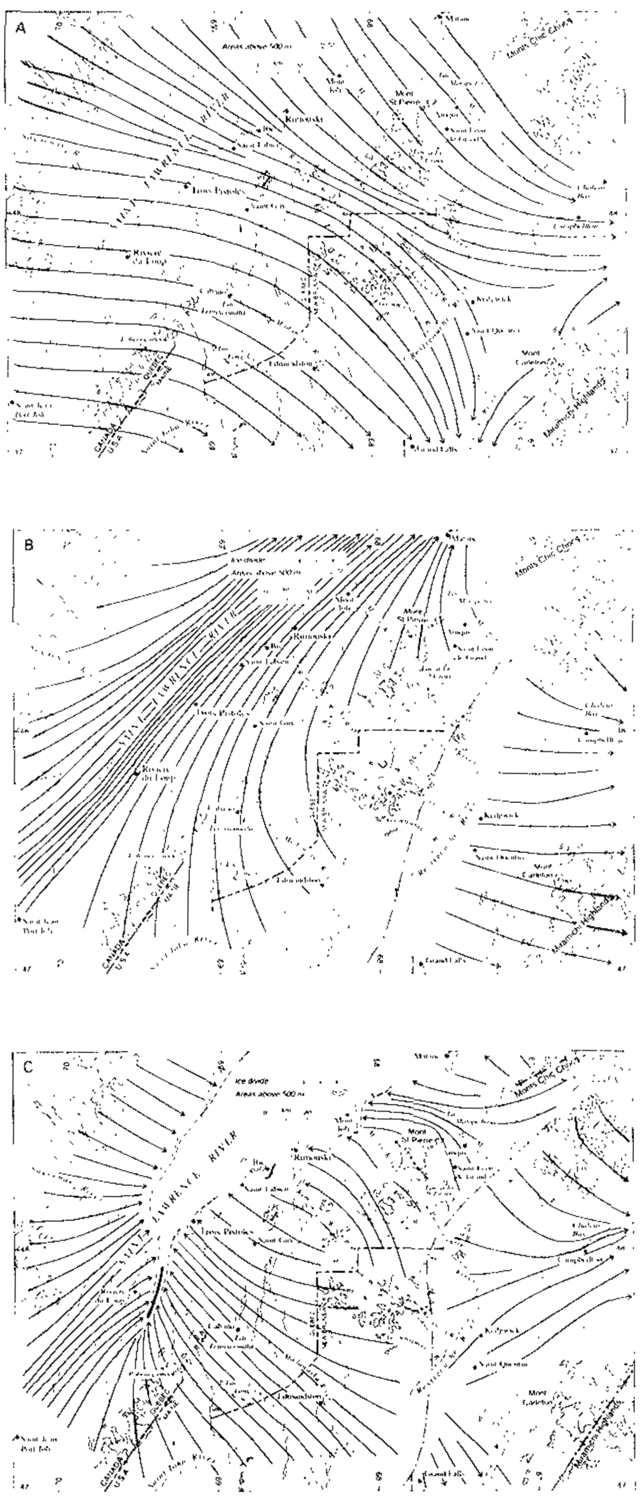

Figure 10-4. Main events of the Late Wisconsinan ice flow history in the Lower St. Lawrence region. A. Invasion of Laurentide ice; B. St. Lawrence Valley ice stream; C. Passing of calving bay.

eastward towards Chaleur Bay (Figure 10-4A). It is uncertain, however, exactly how far the influence of Laurentide ice reached in these areas. A third flow was deflected down the St. Lawrence Valley by the highlands of central Gaspésie and the ice cap which covered them.

The Gulf of St. Lawrence area may have been largely ice-free throughout the Late Wisconsinan (Dyke and Prest, 1987). With late glacial sea level rise, the topographic situation presented an ideal setting for the development of a marine ice stream in the St. Lawrence Valley. Drawdown caused by this ice stream resulted in the development of an Appalachian ice divide from which ice moved north or north-northeast over the study area (Figure 10-4B). On the other side of the Appalachian divide, drawdown may have occurred, to a lesser extent, towards the Gulf of Maine and Chaleur Bay.

Due to a decrease of discharge by the ice stream (as a result of diminishing ice thickness), and the rising sea level during the late glacial, a calving bay progressed up the St. Lawrence Valley, passing the study area between 14 ka and 13 ka (Figure 10-4C). After passage of the calving bay, Appalachian ice readvanced in the area near the town of Rimouski. At present, the maximum age of this readvance is dated at 12.3 ka, but it may well be as young as 11.8 ka, which would make it synchronous with readvances in other parts of the region. Laurentide ice readvanced from the west into the Rivière-du-Loup area, probably around 11.8 ka.

Boulder counts were incorporated in this study to establish the distribution of far-travelled Precambrian erratics and to define in relative time the transportation event responsible, and to see how the 'erosional stratigraphy', derived from age relationships among erosional detail forms, relates to the main transport and depositional phases of material from local Appalachian sources. The following is summarized from Rappol and Russell (1989) and Rappol (1993).

GLACIAL DISPERSAL OF INDICATOR ROCKS

Glaci-erosional detail forms give valuable and essential information for reconstructions of glacial history. However, for such practical applications as prospecting in glaciated terrains, it is generally more important to establish dispersal patterns of rocks and minerals. It is not uncommon to find that a youngest ice flow event may have effectively abraded exposed rock surfaces and yet was rather ineffective with respect to erosion and transportation of detectable amounts of glacial debris.

METHOD

Over 500 boulder counts were carried out during the 1988 fieldwork, more than 60% of these counts contained 1000 boulders and only three samples less than 500. The 10 to 30-centimetre fraction was chosen because it assured that a sufficient number of boulders could be found at most observation sites. Sample sites included gravel pits and road cuts, boulder piles in fields (Photo 10-2), surface boulders in cleared forestry areas, and a few natural exposures. At each site, the numbers of Precambrian erratics from the Canadian Shield and selected Appalachian indicator rocks were recorded.

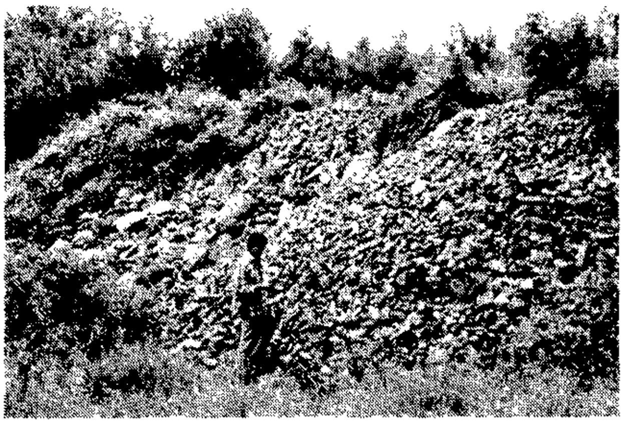

Photo 10-2. Inspection of pile of boulders cleared from a field.

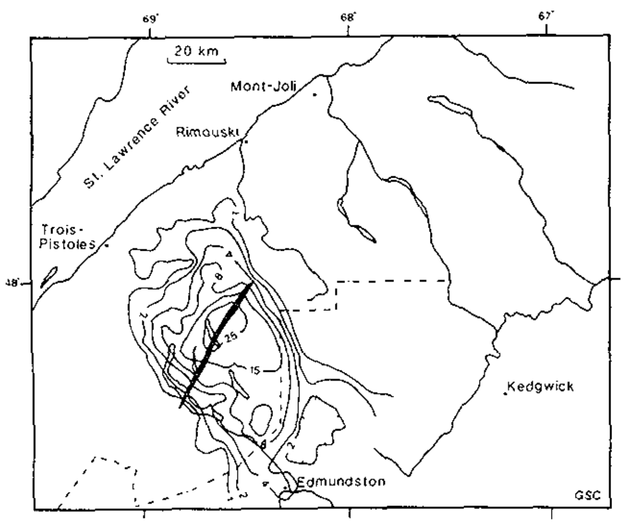

Figure 10-5. Disperal of volcanics from Pointe-aux-Trembles Formation. Frequencies in number per 1000 boulders.

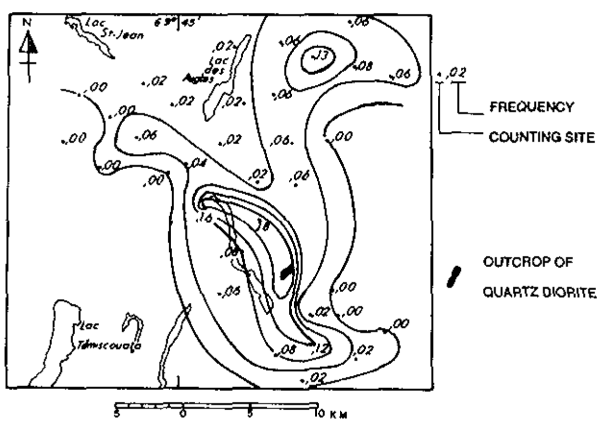

Figure 10-6. Dispersal from a small quartz diorite outcrop east of Lac Témiscouata (from Martineau, 1979).

DISPERSAL OF APPALACHIAN INDICATOR ROCKS

Two examples will be discussed below:

- Andesitic components of the Pointe-aux-Trembles Formation (Lespérance and Greiner, 1969; David *et al.*, 1985),
- Gabbro sills in the area between Lac-des-Echoes and Lac Mistigouèche (Béland, 1960; Lajoie, 1971).

Dispersal from the Pointe-aux-Trembles andesite is shown in Figure 10-5. It indicates a somewhat irregular train in a well defined southeasterly direction. This train extends into New Brunswick, at least to the Grand Falls area, well over 100 kilometres from the source. Dispersal trends towards the north and northwest decrease more rapidly than the southeastward dispersal train. Because of the elongated outcrop area, more or less transverse to ice flow, northward and northwestward dispersal, which is expected on the basis of striation evidence, cannot be clearly separated. However, both appear in the dispersal pattern from a nearby, more equidimensional outcrop of diorite (Figure 10-6) analysed by Martineau (1979). From the striations it follows that the northward flow preceded the northwestward flow and that both are younger than the southeastward flow event. The latter represents invasion of Laurentide ice during the early phase of the Late Wisconsinan.

Dispersal from gabbro sills exposed between Lac-des-Echoes and Lac Mistigouèche is depicted in Figure 10-7. At least four dispersal trains are apparent: east-southeast (Chaleur Bay area), south-southeast, north and northwest. These dispersal directions are supported by striation evidence, although such evidence is rather sparse in the southeastern part of the area.

The southeasterly trains must correspond with flow of Laurentide ice over the area. The presence of two distinct trains may be due to slight changes in the interaction between local ice and invading Laurentide ice (Rappol and Russell, 1989). It has also been suggested that Laurentide ice invading the area flowed first towards the southeast and later towards east (Hughes *et al.*, 1985).

Northward and northwestward dispersal of gabbro correspond with that found for the Pointe-aux-Trembles andesite. The northwestward dispersal falls off rapidly, but the northward flow event left a well defined dispersal train reaching as far as the present coast.

DISTRIBUTION OF PRECAMBRIAN ERRATICS

Figure 10-8 illustrates the frequency of Precambrian indicators in surficial deposits of the study area; considerable variation is evident. These erratics are present throughout the area and have been found close to the summit of Mont St-Pierre (907 m a.s.l.), the highest point in the area. Shield indicators comprise a wide variety of igneous and metamorphic rock types, among which, anorthosite (Photo 10-3), mangerite, gneiss and granite gneiss of the Grenville Province are most characteristic and distinctive. Precambrian erratics are most abundant in the southern part of the study area. In the area of Lac Témiscouata, counts of 2.5%

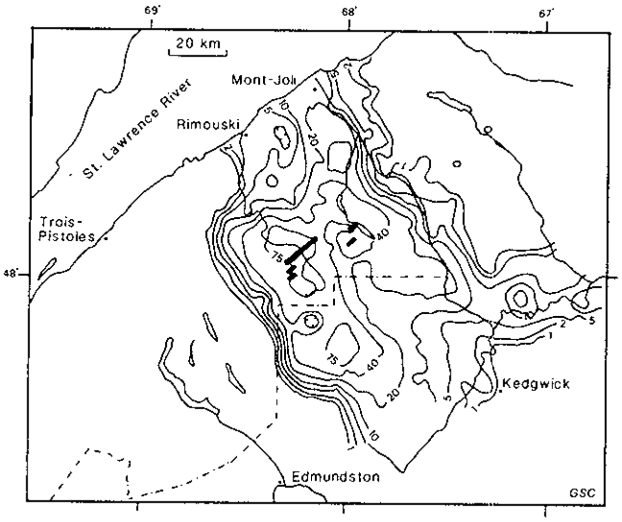

Figure 10-7. Dispersal of Lac Raymond gabbro. Frequencies in number of boulders per 1000.

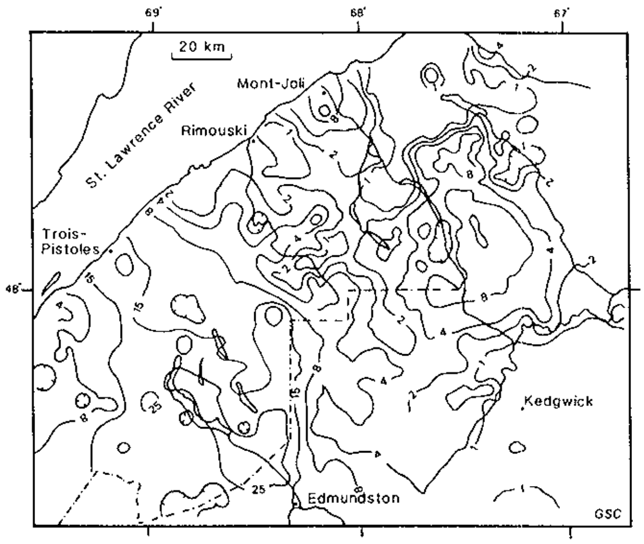

Figure 10-8. Distribution of Precambrian erratics in the study area. Frequencies are given in number per 1000 boulders counted.

are common, with a maximum of 5.0%. Precambrian erratics continue to be abundant farther to the southeast along the Saint John Valley. A few counts in the area of Grand Falls, New Brunswick, gave frequencies between 1 and 5%. Toward the coastal zone, values generally decline. Ice-contact deposits at and below marine limit (St-Antonin moraine and related deposits) contain generally less than 1% Precambrian erratics (*see* also, Dionne, 1971). A second area where Precambrian erratics are abundant is located south of Mont St-Pierre in western Gaspésie. In contrast, the area directly north of Mont St-Pierre is among the areas where these erratics are least abundant. In fact, in a broad coastal zone north of Trois-Pistoles, Precambrian erratics are rare, with the exception of an area near Mont-Joli. The latter area coincides with the well preserved northerly dispersal train from the gabbro sills.

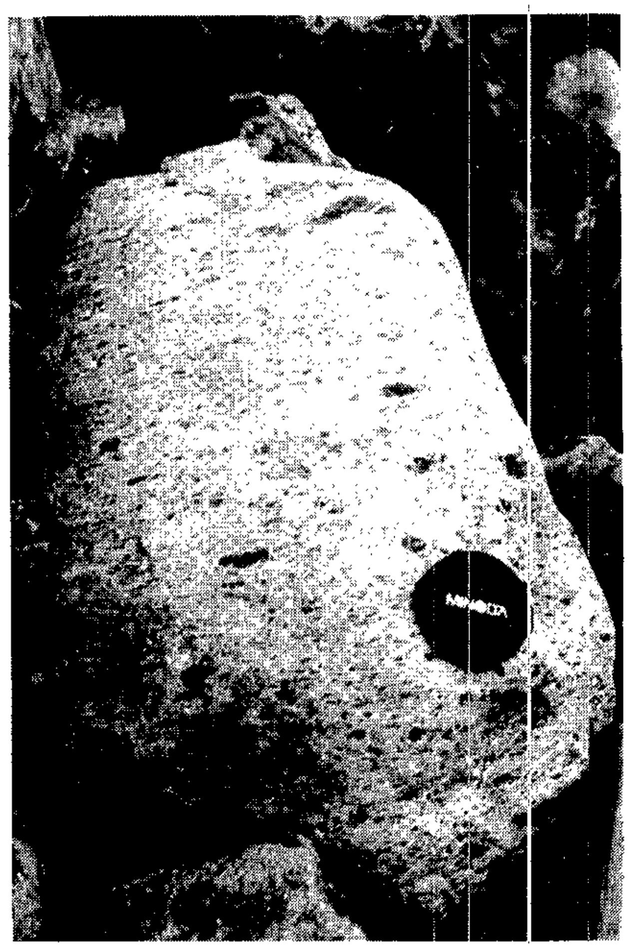

Photo 10-3. Sheared anorthosite boulder; characteristic Shield erratic.

In the southeastern part of the study area, Precambrian erratics are present, but generally rare. The limit of their occurrence could not be established by mapping. Late glacial flow from the Appalachian ice divide must have distributed Precambrian erratics over a large part of northern and southwestern New Brunswick, even when Laurentide ice *senso stricto* may not have reached these areas. Precambrian erratics may be less conspicuous in these regions, because of the abundance of local igneous and occasionally also metamorphic rock types. A few Precambrian indicators were found embedded in massive and dense till, but they appear far more abundant in thin bouldery surface horizons and in ice-contact deposits formed during deglaciation (Dionne, 1971; Lebuis and David, 1977).

CONCLUSION

The pebble count distribution indicates that most Precambrian erratics were introduced to the study area during the last glaciation and were deposited during a late phase of till formation. It also indicates that the Precambrian material was transported at relatively high englacial levels within the ice. Because flow velocities in active glacier ice increase rapidly from the base upwards, the Precambrian debris in high-level transport positions represents the most mobile element of the glacial debris assemblage and was, therefore, strongly affected and redistributed by late glacial flow from Appalachian ice divides. This is reflected in the present distribution of frequencies of Precambrian erratics in surficial deposits of the area.

Transport and erosion by late glacial Appalachian ice flows did not affect all parts of the area equally. Notably in the Appalachian ice divide zones, the effect of redistribution of material brought in by the Laurentide ice invasion has been minimal, and it is here that a high frequency of Precambrian erratics may be expected. Away from these ice divides, Precambrian material became progressively more diluted by Appalachian material as ice moved back towards and down the St. Lawrence Valley. For example, north of Mont St-Pierre, in the northeastern part of the study area, late westward and northward flow events removed virtually all evidence of an earlier Laurentide ice cover, whereas south of the mountain, an area with a high frequency of Precambrian indicators is evident.

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LITHOLOGICAL ANALYSIS IN DRIFT PROSPECTING STUDIES

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INTRODUCTION

The importance of detailed lithological analysis in the discovery of buried ore deposits is well established. The use of lithological analysis centres on the recognition that fragments of bedrock can occur as scattered clasts within the overlying or adjacent surficial sediments, or on the ground surface. If these fragments are mineralized and traced back to their provenance or source, and the deposit proves to be of economic importance, then the methodology of drift exploration using indicator clast dispersal is successful. On average the distance to source should be short, as Puranen (1990) states that approximately half of the boulders observed in a 'typical till' are derived from less than three kilometres in distance.

The study of clast lithology in Quaternary research is a common practice. In fact, geologists are quick to recognize Pleistocene erratics of exotic origin when they are of prominent size or significant transport distance (*e.g.* the 56.5 m 'Kabelikivi' rapakivi block in northern Europe and the 2500 kilometres transport distances of some Canadian Shield erratics; Donner, 1989). Briefly, *the purpose of clast dispersal* studies then, is to isolate the provenance of ore deposits by mapping the distribution and concentration of distinct lithologies within the framework of clearly defined geological contexts. The analysis of lithologically unique bedrock fragments, which are often referred to as indicator clasts, float, or mineralized erratics, typifies one often used approach to successful drift prospecting. Depending on the specifics of the methodology, the approach includes a number of related practices such boulder tracing, clast indicator tracing, pebble counts, or stone counts.

In contrast to geochemical methods, the use of lithological variations in surficial sediments for exploration purposes has a lengthy historical precedence. For instance, in Scandinavia, the use of ore fragments to trace bedrock sources dates as far back as 1740 (Strobel and Faure 1987). In Canada, one of the earliest published examples is that of Dreimanis (1958) who traced iron ore boulders at Steep Rock Lake, Ontario. In British Columbia, Day *et al.* (1987) provide a good case study of up-ice point source exploration work in the Windy Craggy area using clast analysis. Broster and Huntley (1995, this volume) illustrate the use of lithological work for regional mapping. Other good examples of lithological analysis from elsewhere in Canada (*e.g.* Rappol, 1995, this volume) and the rest of the world are well known, and several are referenced where appropriate in the following discussion. Few studies emphasize the glaciated alpine or mountain environment in drift exploration (*cf.* Evenson *et al.*, 1979), although such an environment is inherently unique when compared to the traditional research on continental areas glaciated by ice sheets.

This paper provides a detailed examination of lithologic indicator tracing with an emphasis on glaciated and mountainous terrain. I review the background behind the concept, discuss variations on the methodology and offer relevant interpretations which will assist drift exploration studies in the Canadian Cordillera. Many of the conclusions and implications derived from this work have broad applicability to other glaciated and mountainous terrains.

BACKGROUND

Clast lithological analysis in Quaternary studies is most widely used to address one or more of the following (Bridgland, 1986):

- Describe a deposit;
- Determine the provenance of a deposit;
- Differentiate deposits with a different genesis;
- Differentiate deposits of similar genesis but different age;
- Delimit facies within a deposit.

All of the above are important questions that must be answered in drift exploration studies. Fortunately, the potential to use clast lithological analysis is good in the glaciated mountainous terrain of British Columbia where the percentage of clasts in tills and other diamictons is usually high.

Clast lithological analysis in drift prospecting studies involves the study of surface erratics (indicator fans, indicator trains, *etc.*) or clasts derived from within the sampled media (preferably till). Terminology varies from the generic (*e.g.* clast indicator and stone count) to the size and shape specific (*e.g.* boulder fan and pebble plume) in clast lithologic studies. Descriptive terms such as boulder, cobble and pebble are often used in respect to the Wentworth (1922) size class scheme for clasts less than 256 millimetres, 64-256 millimetres, and 4-64 millimetres respectively. Gravel is also used to denote clasts less than 2 millimetres in size. Accompanying terms include **fan** for patterned accumulations of erratics observed on the ground surface, **plumes** for three-dimensional dispersal patterns from the source, and **trains** for generic down-ice patterns. **Float** also is sometimes used to denote a rock fragment which is detached and displaced from its source. Terms such as **indicator clast** and **stone count** are frequently used to indicate provenance study of materials coarser than silt, but without the connotation of a dispersal pattern.

The distribution of clasts from original source to final position on the ground surface is controlled by erosion, entrainment, transportation and depositional mechanisms of ice (Salonen and Palmu, 1989); hence the phrase *glacial dispersal* (Shilts, 1984). Figure 11-1 shows a hypothetical case where a buried but distinct lithologic bed is fractured, eroded, incorporated, transported and deposited by a glacier.

The abundance of any particular lithology is usually expressed as a percentage of the total lithologic assemblage and can be shown to be distributed in a patterned and predictable manner in glacial deposits. Krumbein (1937) was one of the first to explore this relationship when he observed that the maximum concentration of debris dispersed by a glacier occurs near its provenance and subsequently decreases exponentially in the direction of glacial transport (*see* section on Statistics). Shilts (1976) aptly generalized this distribution as consisting of a head, tail and dispersal curve to which a negative exponential function can be applied (Figure 11-2), whereas Salonen and Palmu (1989) divide the distribution in two, recognizing a proximal rise and distal decline (Figure 11-3) to which linear and lognormal curves could be applied, respectively.

DESCRIPTIVE PARAMETERS

Dispersal plumes, fans and trains can be described by a series of quantitative and qualitative parameters. For example, Batterson (1989) notes that for one sample of dispersal trains, the angle of climb (α) from the provenance source to the ground surface averages 1°50′ but ranges from 0°30′ to 3°50′. However, climb angles as high as 10° have been described in Quebec (DiLabio, 1990) and elsewhere (Salonen, 1992). On the surface documented fans and trains display dispersal sector angles ranging from 1 to 90° (Salonen, 1986), but the majority average about 10° (Salonen 1987). The assumption that fan direction parallels paleo-ice flow is not always the case, given examples of depositional trains up to 15° off the regional paleo-flow (DiLabio, 1990). Of 464 fans measured in Finland, most fans averaged 1-5 kilometres in length, but ranged in length from 0.2 to 600 kilometres (Salonen, 1986, 1992). The number of indicator clasts comprising these fans tended to consist of some 20-30 boulders (Salonen, 1987).

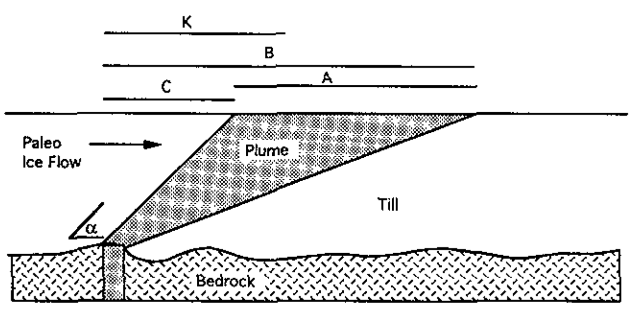

Figure 11-1. Schematic cross-section through hypothetical indicator plume summarizing descriptive parameters; all distances in km. Modified after Bouchard and Salonen (1990). K = distance from proximal contact of indicator source to maximum concentration of clasts, B = distance from proximal contact of indicator source and farthest travelled clast, A = total length of the indicator train from the apical clast to the 1% frequency limit, C = distance from proximal contact of indicator source and apical clast on surface, α = angle of plume climb from source to surface.

As the plume reaches the ground surface, the nearest indicator clast identified on the surface is referred to as the proximal or apical clast (Figure 11-1). The distance between this point and the proximal contact of the source (C) can be determined through observation or estimated using the angle of climb (Figure 11-1). Other surface measurements from the proximal contact of the source include the distance to the farthest travelled clast (B), the distance to the major concentration of clasts (K), and the maximum distance at which the frequency is greater than 1% (Bouchard and Sa-

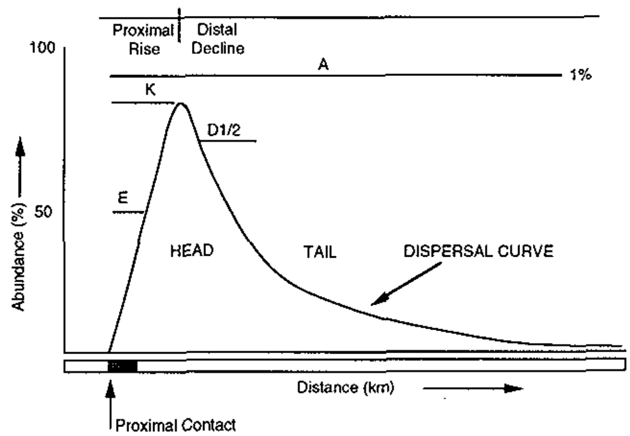

Figure 11-2. Generalized dispersal curve showing position of head and tail, proximal rise and distal decline and descriptive parameters; all distances in km. K = distance from proximal contact of indicator source to maximum concentration of clasts, A = total length of the indicator train from the apical clast to the 1% frequency limit, E = the distance from the apical clast to where the frequency reaches 50% of the total (renewal distance); $D_{1/2}$ = is the distance where the frequency of an indicator clast declines to 50% of its value (half-distance).

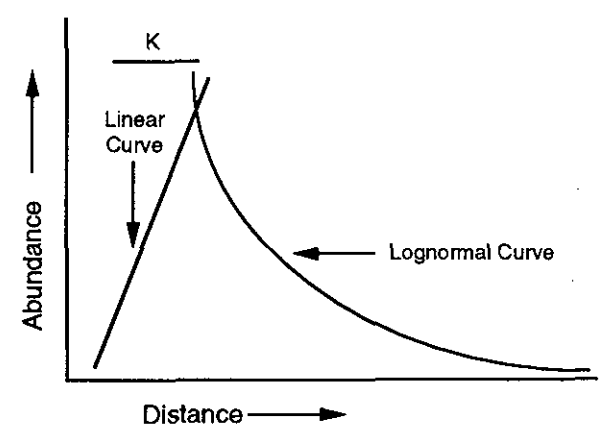

Figure 11-3. Schematic figure showing estimation of parameter K using proximal rise (linear function) and distal decline (lognormal function) for theoretical dispersal curve. Modified after Salonen and Palmu (1989).

lonen, 1990; Figure 11-2). The total length of the train (A) is measured from the apical clast to the 1% frequency point. The distance from the apical clast to where the frequency reaches 50% of the total is referred to as the renewal distance (E). Half-distance ($D_{1/2}$) is the distance where the frequency of an indicator clast declines to 50% of its initial value.

According to DiLabio (1990,) small dispersal trains are all extremely thin relative to their width and length; they are orders of magnitude larger than their bedrock sources and display abrupt contacts (vertical and lateral) with the enclosing sediments.

SAMPLES

A review of the literature indicates that the size and number of clasts collected as part of a clast lithological program is inconsistent. A number of studies report using exact counts ranging from 25 (Kerr and Sibbick, 1992) to 100 (Saarnisto and Taipale, 1985) to 200 (Aumo and Salonen, 1986). Other studies report ranges in sample size from 29 to 184 (Bouchard and Salonen, 1989) through 100 to 200 (Stea *et al.*, 1989; Shilts, 1981) and up to 385 (Alley and Slatt, 1976). To minimize proportional errors associated with small sample sizes, a minimum of 250 to 300 clasts has been recommended by Bridgland (1986) in traditional studies and 500 or more where rare lithologies are of interest. In lieu of such large samples, nomograms can be consulted or counting errors can be calculated (*see* section on Statistics). Error values for proportions based on samples below 100 clasts are so large that all attempts at interpretation are of little value.

Similar variability exists in the size selection of clasts. Moreover, such information is not always reported. In dispersal fan studies, the most common size used is boulder-size although smaller sizes have been studied (*e.g.* Bouchard and Salonen 1989). In deposit sampling, preferred clast size ranges are 2 to 6 centimetres, 6 to 20 centimetres, or over 20 centimetres (Saarnisto and Taipale, 1985, Hirvas and Nenonen, 1990). However, various sand and fine gravel sizes have also been used and broader ranges than those listed above have been examined (*cf.* Pertunnen, 1991). Finally, thin section studies are sometimes used and these rely on grains 1 to 2 millimetres in size and counts of 50 to 100 (Hirvas and Nenonen, 1990). Clast size is of critical importance, as it can be shown that dispersal patterns vary considerably in any one lithological study depending on the size of clasts collected (*e.g.* Saarnisto and Taipale, 1984). Several implications of clast size are discussed below.

CONTROLLING FACTORS

Dispersal curves and trains tend to approach log normality in their frequency distribution along some linear distance, but significant differences exist in the values of the descriptive parameters. In particular, variation in the maximum abundance or concentration, distance of transport, rate of change (decay constant) and half-distance ($D_{1/2}$). These differences are the result of influences from a number of factors.

Properties associated with the bedrock source influence the measurable parameters of a dispersal train. Outcrop area has been proposed by Peltoniemi (1985) as having some control on down-ice clast concentration. Although Salonen (1992) and Clark (1987) have both argued that the influence of outcrop width (area) is negligible. Intuitively one should expect the type of lithology to be a significant factor in the length of glacial transport. Salonen (1992) suggests that mica schists and gabbros should have short transport distances in contrast to limestones and quartzites which should have longer transport distances. A convincing example from New York is provided by Holmes (1952) who documented total transport distances of 6.4 kilometres for shale and 130 kilometres for quartzites. Transport differences due to lithology have also been demonstrated by Hirvas and Nenonen (1990). Clark (1987) believes that the relative ranking of lithologies from most resistant to least (*e.g.* crystalline>sandstone>limestone>shale) has merit, but the influence of lithology on dispersal patterns remains poorly understood in the absence of more empirical data.

Another observation regarding the bedrock source concerns the impact of jointing and fracturing on the incorporated shape of the rock fragments. For example, Laitakari (1989) believes that strongly jointed bedrock results in angular fragments, whereas rocks such as granites tend to be rounded prior to glacial transport. Similarly, the topography of the bedrock source is seen as contributing to the dispersal pattern by influencing basal ice conditions (velocity) which affect the erosive and depositional capabilities of the glacier. In Gaspé, Québec, for instance, David and Bedard (1986) observed greater erosion and longer transport distances from granite outcrops of high relief as compared to level source areas. Although generally down played in continental ice sheet discussions, topography plays an extremely important role in the mountainous regions such as the Cordillera. Topography controls the type of glacier ice which can develop: icefields, valley glaciers, cirques and variations of these in mountainous terrain. Equally critical is the influence of relief on generation of compressive *versus* extending flow, the net effect being reduced (deposition) *versus* accelerated (erosion) ice velocity, respectively (Sugden and John, 1976). In the mountainous terrain of British Columbia, fluctuations from compressive to extending flow are expected to be a typical characteristic along any single flow line.

Once incorporated into the ice, clast shape (Drak,e 1972) and grain size (Dreimanis and Vagners, 1969) influence the dispersal pattern. In one study in southern Finland, Pertunnen (1991) examined the dispersal pattern of five grain sizes of granite (20-2 cm, 2-6 mm, 6-2 mm, 2-0.6 mm, 0.6-0.2 mm) and determined that $D_{1/2}$ increases with decreasing grain size. This trend was confirmed elsewhere by Saarnisto and Taipale (1984) using three clast sizes (2-6 cm, 6-20 cm and 20 cm). More important is the observation that value of K is usually greater in clast lithology data as compared to geochemical data derived from the same matrix. This is because particles less than 16 millimetres and 0.008 millimetres are not easily entrained by ice (Boulton, 1975). It follows then, that the silt to pebble-sized particles are the most easily transported fractions.

The most important factor controlling sediment dispersal is the behavior of the ice. In this regard, rates of erosion, entrainment, transportation and deposition are all a reflection of glacier ice conditions (Figure 11-4). Clark (1987) argues the most important control of sediment dispersal is the basal ice velocity; where low sliding velocities can be associated with shorter dispersal distances in contrast to higher velocities which result in greater transport distances. Strobel and Faure (1987) view the position of sediment transport in the ice as the most important factor controlling dispersal patterns. For any ice mass, they propose that basal debris is deposited quickly whereas englacially transported debris is transported much farther. Although not discussed in detail, they imply also that supraglacial debris would result in still greater transport distances. Strobel and Faure's conclusions are based on their interpretation of Shilts' (1976) description of a typical dispersal curve where the head portion undergoes an exponential decrease and the tail portion approximates a linear reduction. The transition from head to tail in the curve is thought to reflect the transition in transport position in the ice mass from basal to englacial. The flat tail portion may also indicate convergent flow, streaming or even surging of the ice (Bouchard and Salonen, 1989). As most discussions of clast transport centre on ice sheet behavior, transport in the upper ice zone (supraglacial) is rarely emphasized, but in mountainous terrain, a significant portion of the debris transported by the ice is carried in the supraglacial position (Dreimanis, 1990). If the supraglacially transported clasts are exogenous in derivation, transport lengths are often considerable which contrasts with basally derived debris which can be transported both short (compressive flow) and long (extending flow) distances. Supraglacially transported debris can prove advantageous for mineral prospecting in certain situations as illustrated by Stephens *et al.* (1983).

Another implicit consideration is position relative to the ice divide. Donner (1989) provides examples of ice sheet

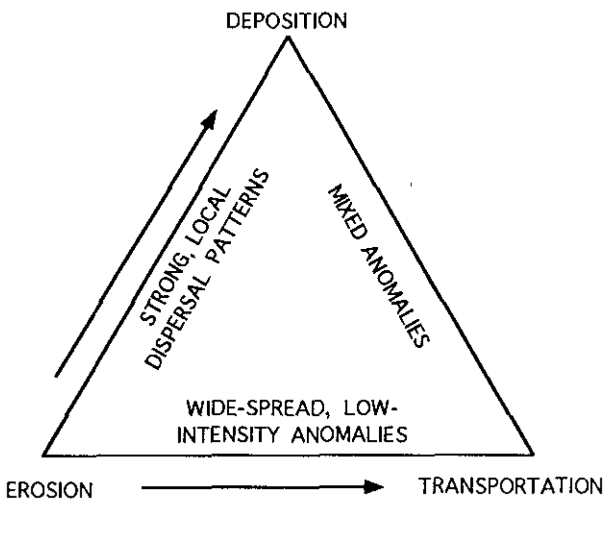

Figure 11-4. Ternary plot of glacial processes indicating relationship between erosion, transportation and deposition and effects on indicator dispersal patterns. Modified after Salonen (1989).

flow noting rates of 3 metres per annum near the ice divide and 135 metres per annum about 100 kilometres from the divide. Since basal velocity in ice sheets increases with distance from the ice divide, it is expected that transport distances increase correspondingly. In mountainous terrain ice-flow rates are different and significantly greater. The greatest basal ice velocity is expected to occur at the equilibrium line (Patterson, 1981), the position of which drops progressively in elevation as individual glacial cycles reach their maxima. Normal ice velocities as high as 1.2 metres per day have been recorded for alpine glaciers and these can increase by 10 to 100 times during surge events. The latter are important in the Cordillera, 209 surging glaciers have been recognized in western North America, (Patterson, 1981).

Several other complicating factor,s that are difficult to empirically evaluate also negatively affect sediment dispersal patterns by lowering maximum concentrations and increasing values of C, K, M, A and most importantly $D_{1/2}$ (Figures 11-1 and 2). These factors include, but are not limited to, increasing overburden thickness and redeposition (Drake, 1983), successive flow stages and genetically complex stratigraphy. The latter factors are particularly problematic in the interior of British Columbia where local Quaternary stratigraphy and glacial history is poorly known and is only inferred from air photograph interpretation and shallow exposures.

As a product of the above factors, glacial sediments most likely to be examined in an indicator-clast dispersal study often display different transport distances. According to Salonen (1989) increasing transport distances are evident progressing from hummocky moraines to cover moraines (till veneers) to drumlins and finally to ground moraines. As expected, even greater tansport distances are observed in glaciofluvial deposits such as eskers (Vallius, 1989). Aario and Peuraniemi (1992) examine a larger suite of morainic landforms for their drift prospecting potential. They provide a detailed summary of several controlling properties and conclude applicability to ore prospecting is good for cover (veneer), Rogen and Sevetti moraines, moderate for ground moraine and moderate to bad for drumlins, flutings, Pulju and end moraines.

STATISTICS

The distribution of any type of lithology in a down-ice direction from the source can be described mathematically by a negative exponential curve (Shilts, 1976). Furthermore, this description assumes that the proportions and percentages representing a lithology are an accurate reflection of some target population. Hence, there are two statistical components that are important in clast lithological analysis: proportional distributions and proportional confidence. Both aspects are briefly discussed below.

PROPORTIONAL DISTRIBUTIONS

Krumbein (1937) showed that in numerous sedimentary situations the analytical elements under examination conform to exponential laws. That is, dependent variables (y) tend to increase or decrease exponentially relative to an arithmetic increase in the independent variable (x). In terms of a frequency distribution, Krumbein showed that the debris dispersed by a glacier will show its highest frequency near the source and then decrease in abundance in an exponential manner in the down-ice direction. He described this distribution as follows:

$$y = y_o e^{-ax}$$

where:

y_o = frequency of y when x is zero (y intercept)

e = base of the natural logarithm (2.71828)

a = coefficient of x (particle distribution or transport constant)

x = distance in kilometres from the source.

The above curvilinear distribution is often linearized using a natural logarithm transformation of the y variable and application of Model 1 least squares regression:

$\ln y = \ln y_o - ax$ (Strobel and Faure 1987).

Although never applied, confidence limits about the specific regression equation must be determined. The value of a can be shown to be related to the transport half-distance ($D_{1/2}$) using:

$$D_{1/2} = \ln 2/a$$

The relationship between $D_{1/2}$ and a is critical,as a decreases as a function of decreasing particle size and increasing half-distance values (Salonen, 1992). $D_{1/2}$ is important to the mineral explorationist as it represents the measure which best provides a guide to locating the provenance distance of a particular lithology. Clark (1987) generalized the pattern of dispersal curves and the scale of dispersal by illustrating that $D_{1/2}$ increases in value from local to continental scales (Figure 11-5). A similar generalization can be developed for glacial landforms described earlier where

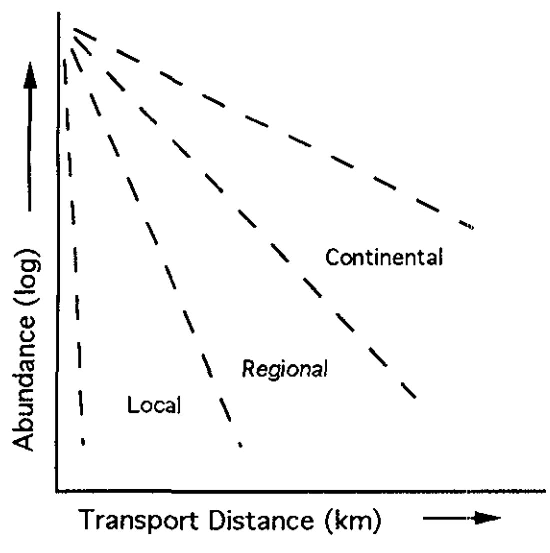

Figure 11-5. Transport distance ranges for three scales (local, regional and continental) of dispersal curves. Adapted from Clark (1987).

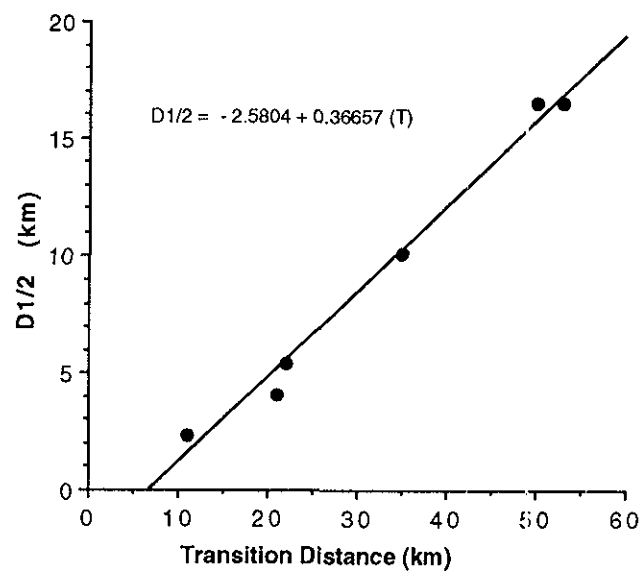

Figure 11-6. Schematic figure illustrating the relationship between glacial landforms commonly sampled for clast-indicator studies and expected transport distances. Data from Aario and Peuraniemi (1992).

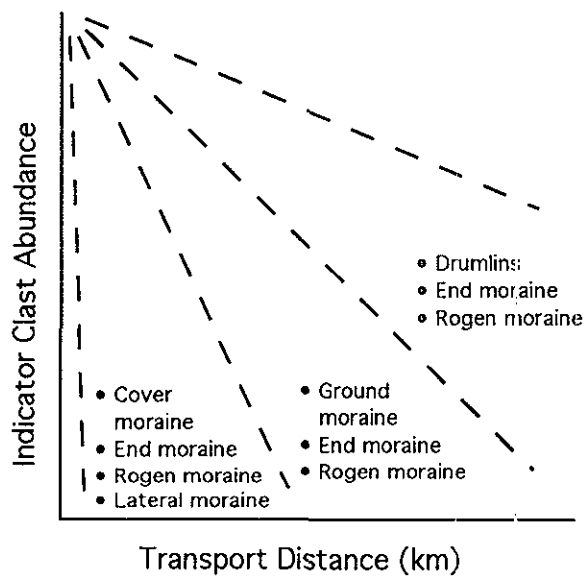

Figure 11-7. Bivariate relationship predicting $D_{1/2}$ from transition distance (km) based on data in Strobel and Faure (1987). The function is highly significant with $r^2 = 0.987$

$D_{1/2}$ increases in value from hummocky moraine to ground moraine (Figure 11-6).

An ability to estimate $D_{1/2}$ in the field would assist explorationists in the search for mineralized bedrock. Strobel and Faure (1987) showed there is a positive correlation between the transition distance (exponential to linear transport modes on distal decline of dispersal curve) and the half-distance. Figure 11-7 is a plot of their data with the variables reversed, so that $D_{1/2}$ can be estimated from knowledge of the trasition distance using the equation:

$D_{1/2} = -2.58 + 0.367\ (T)$

where

$D_{1/2}$ is the half distance measured in kilometres and

T is the transitional distance measured in kilometres.

PROPORTIONAL CONFIDENCE

All values of abundance and frequency in lithological studies represent some characteristic proportion (p) out of a total suite of characteristics ($1-p$). The value of p is estimated (x) from a sample of clasts of size n which is less than the total population of clasts N. Although the characteristic observed as x/n is a good estimate of p, counting errors exist because $n<N$ (Howard, 1993). By definition, the sampling distribution of x is approximately normal with a mean of p and a standard deviation of | p($1-p$)/n if the following conditions are met: n is greather than or equal to 30 or np and 1($1-p$) are larger than 5.

Probable error associated with the proportional counts can be determined from nomographs or calculated using the equation:

CE =± | p(1-p)n,

where

CE is confidence interval about the mean,

t is the value of Student's t distribution (n-1 degrees of freedom and confidence level $a/2$),

p is the observed proportion of a characteristic lithology, and

n is the total number of clasts counted (Howard 1993).

CONCLUSIONS AND IMPLICATIONS

Lithological analysis is a successful method of drift prospecting that compliments other data collected through till geochemical sampling. The method involves the collection and interpretation of indicator-clast frequency data retrieved from a sampling medium (till) or on the ground surface. Analysis consists of the recognition of glacial dipersal trains, delimiting the boundaries and establishing provenance source areas. Clasts of any size and shape can be used, but consistency in both clast size and shape must be maintained in a sampling design. Glacial landforms of any type can be sampled but again consistency must be maintained as certain deposits have greater applicability to successful drift prospecting. Sample size is very important and when possible, should consist of at least 250 clasts per sample. Samples sizes consisting of less than 100 clasts are of no utility to drift studies. Confidence estimates should be assigned to all frequency data regardless of the sample size.

A number of factors are known to control the nature and character of glacial indicator-clast dispersal trains in the mountain environment including but not restricted to bedrock lithology and structure, outcrop area, relief, topography, clast shape and size, glacier ice thickness, velocity, distance from equilibrium line, style of sediment incorporation, transport position and history, redeposition and complexity of underlying stratigraphy.

Glaciated mountainous terrain is fundamentally different from the flat, rolling terrain which is typically considered in the evaluation of glacial dispersal under ice sheet conditions. In the Cordillera of western Canada, confined valleys, steep gradients, rugged high-relief topography and rapidly changing landform deposits strongly influence the expected and observed dispersal patterns of glacially transported debris. Many of the controlling factors recognized as insignificant in the continental ice sheet environment assume a more prominent role in influencing the clast dispersal pattern in the mountain glacier environment. Several generalizations concerning drift prospecting in glaciated mountainous terrain can be offered, including:

1. For a typical valley glacier the greatest velocity (least deposition, greatest erosion and potential subglacial input) occurs at the equilibrium line; slower velocities occur up and down-ice of this position.
2. Fluctuations between compressive (high velocity) and extending flow (low velocity) are expected to be more common because of the high relief.
3. Glacial debris is dispersed farther down valleys than across intevening highlands and the compositional isopleths often mimic the topography.
4. Supraglacial debris is an important component in the sediment load of glaciers.
5. Dispersal trends are usually longer and narrower in valley situations as compared to continental ice sheets.
6. Ice streaming, convergent and divergent ice-flow patterns are expected to be greater.
7. Redeposition or dilution ('inwash') is more significant in the alpine environment where tributary glaciers contribute to the main trunk systems.
8. Glacial landforms show considerable variability in their potential utility for ore prospecting and certain morainal deposits are more common in mountainous terrain, whereas others are less common to absent when compared to continental situations.

ACKNOWLEDGMENTS

I appreciate the comments of Dave Huntley and John Newell to improve this manuscript.

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EFFECTIVE LOW-COST RECONNAISSANCE DRIFT PROSPECTING IN AREAS OF VARIABLE TERRAIN: AN EXAMPLE FROM THE SOUTH-EAST TASEKO LAKES AREA, CENTRAL BRITISH COLUMBIA

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University of New Brunswick

INTRODUCTION

For many, drift prospecting is the straightforward collection of samples at locations defined by a grid drawn at a predetermined scale on a base map. This is rarely a satisfactory technique for the delineation of anomalies in areas of alpine or subalpine glaciation. Such areas are characterized by highly variable terrain that is the product of glaciation associated with growth of individual cirque glaciers and their coalescence into larger valley glaciers and/or complex ice sheets. Subsequent drift deposits may represent deposition from a unique ice-stream that can be traced for some distance to a (lithologically) unique source. More often, the deposits are a mixture of material from several contributory glaciers that defy source identification.

In this type of terrain, conventional sampling programs can be time consuming and expensive. However, as a preliminary study and with only a rudimentary understanding of glacigenic processes and up-ice lithologies, it is often possible to delineate dispersal patterns and target areas from examination of physiography, directional landforms and selected lithologies. Here we present an example of this low-cost approach to drift prospecting from our field studies (1991 and 1992) in central British Columbia.

STUDY AREA

The southeast Taseko Lakes area, British Columbia (Figure 12-1) is an area of complex geology and variable terrain. Although it has a long history of small-scale placer

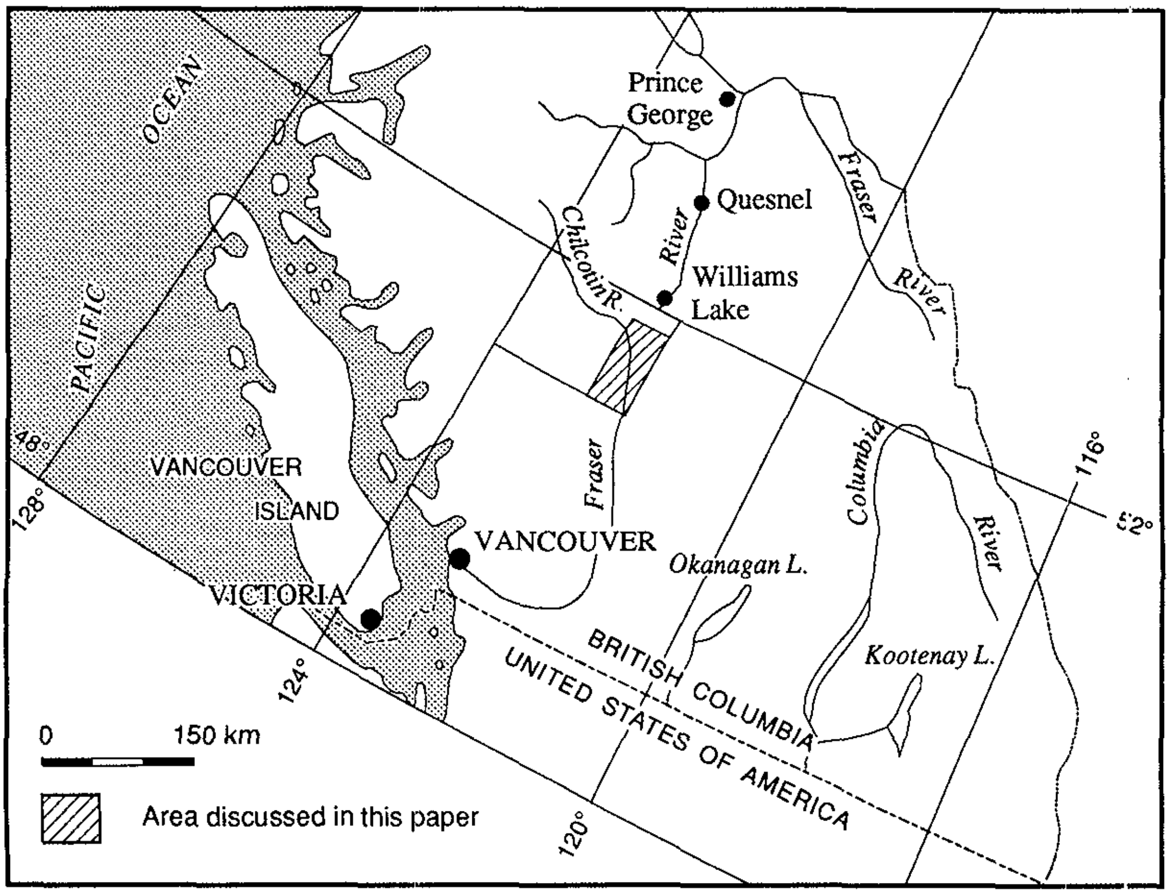

Figure 12-1. Location of study area indicated by hatching, shown in greater detail in Figures 12-2, 3 and 4.

and bedrock gold production, a systematic regional economic evaluation of the Quaternary drift cover has yet to be undertaken. Previous reconnaissance studies of the Quaternary drift precluded detailed investigation of sediments and glacial dispersal patterns (Tipper, 1971; Heginbottom, 1972). Recent investigations have focused on glacial processes, detailed stratigraphy, glacier dispersal patterns and glacial geomorphic history (Broster and Huntley, 1992, 1993; Huntley and Broster, 1993a, 1993b, 1993c). Quaternary sediments have now been mapped at a scale of 1:50 000 (Huntley, 1994) and logged in vertical profiles (Broster and Huntley, 1992). We emphasize the importance of these studies as a basic contribution to further prospecting within the area. However, inexpensive cursory dispersal analysis as described here, can be conducted within a few weeks by examination of indicator clasts and physiography as delineated by topographic maps and/or aerial photographs.

PHYSIOGRAPHIC AND GEOLOGIC SETTING

Three principal physiographic elements are recognized in the study area upland and plateau areas, valleys, and mountains (Figure 12-2). The northern two-thirds of the study area is dominated by the Fraser Plateau. This is a gently undulating plateau between 920 metres and 1070 metres elevation, with isolated hills rising above 1800 metres. To the south are the Camelsfoot and eastern Chilcotin ranges; an alpine landscape, with major peaks rising above 2400 metres elevation (Figure 12-2). These regions are dissected to a maximum depth of approximately 700 metres by the south-flowing Fraser River and its tributaries (Figure 12-3a).

The bedrock geology of the plateau is complex. West of the fault-controlled Fraser River, Eocene and Miocene mineralized volcanic and sedimentary rocks, with inliers of Jurassic granodiorites dominate (Figure 12-3b). East of the Fraser River, Triassic and older metasedimentary, metavolcanic as well as Permian limestone rocks outcrop and are overlain unconformably by Miocene to Pleistocene plateau basalts. In the Camelsfoot and eastern Chilcotin mountain ranges, Lower Cretaceous clastic sediments (Jackass Mountain Group) are the dominant rock type (Figure 12-3b).

In alpine areas, over the plateau, and upper reaches of tributary valleys, the Quaternary cover varies in thickness from 1 metre to approximately 50 metres. Between 150 and 300 metres of Quaternary sediments are exposed in vertical sections along the Fraser River valley (Figure 12-2: location F). Pre-Wisconsinan fluvial sediments and Early Wisconsinan (deglacial) lacustrine sediments (Eyles and Clague, 1991) are preserved, overlying bedrock along sections of the Fraser River and major tributaries.

Late Wisconsinan Fraser glaciation sequences are found in all physiographic settings. In many valleys, advance stage glaciolacustrine sediments are truncated and overlain by basal and ablation till and lacustrine sediments. In alpine and plateau areas, Late Wisconsinan till overlies bedrock or advance stage glaciofluvial sediments (Huntley and Broster, 1993c). Holocene fluvial, eolian and lacustrine deposits are restricted to major valleys and plateau areas.

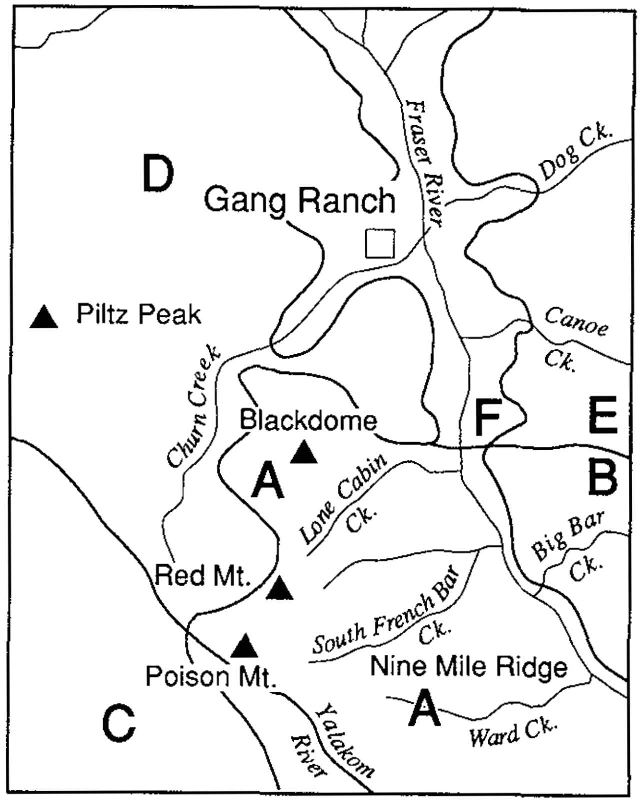

Figure 12-2. Physiographic regions adjacent to the Fraser River between latitudes 51°N (bottom) and 52°N (top): A - Camelsfoot Range; B - Marble Range; C - Chilcotin Range; D - West Fraser Plateau; E - East Fraser and Green Timber Plateau; F - area of thick glacial sediments; Gang Ranch - open square; peaks - solid triangles; accurate ground scales presented in Figures 12-3 and 4.

METHOD OF DISPERSAL ANALYSIS

Erosional glacial landforms, glacigenic sediments, till fabrics and indicator clast provenances were examined to determine glacial dispersal patterns (Figure 12-3a). Additional information was provided by mapping palaeochannels and glaciofluvial landforms. These fluviatile deposits are, in their own right, important exploration targets for potential placer mining (Levson *et al.*, 1990; Levson and Giles, 1991). However, this report is concerned only with the importance and use of clasts in till for drift prospecting.

Dispersal trains are formed by anomalous concentrations of debris during glacier flow and are distinguished by an enriched fan or ribbon-shaped zone in the resultant till (Dreimanis, 1958; Shilts, 1976; Hicock, 1986; Coker and DiLabio, 1989; Puranen, 1990; Hornibrook *et al.*, 1992, 1993; Balzer and Broster, 1994). An elongated down-ice dispersal pattern, or train (*e.g.* DiLabio, 1990), is recognized by drawing concentration contours of distinctive components of the till on a base map. The source of glacial entrainment is expected to be under, or a short distance up-ice of, the highest concentration (for examples *see* Kujansuu and Saarnisto, 1990). The length of train defined by this spatial plot is dependent upon a number of factors related to both

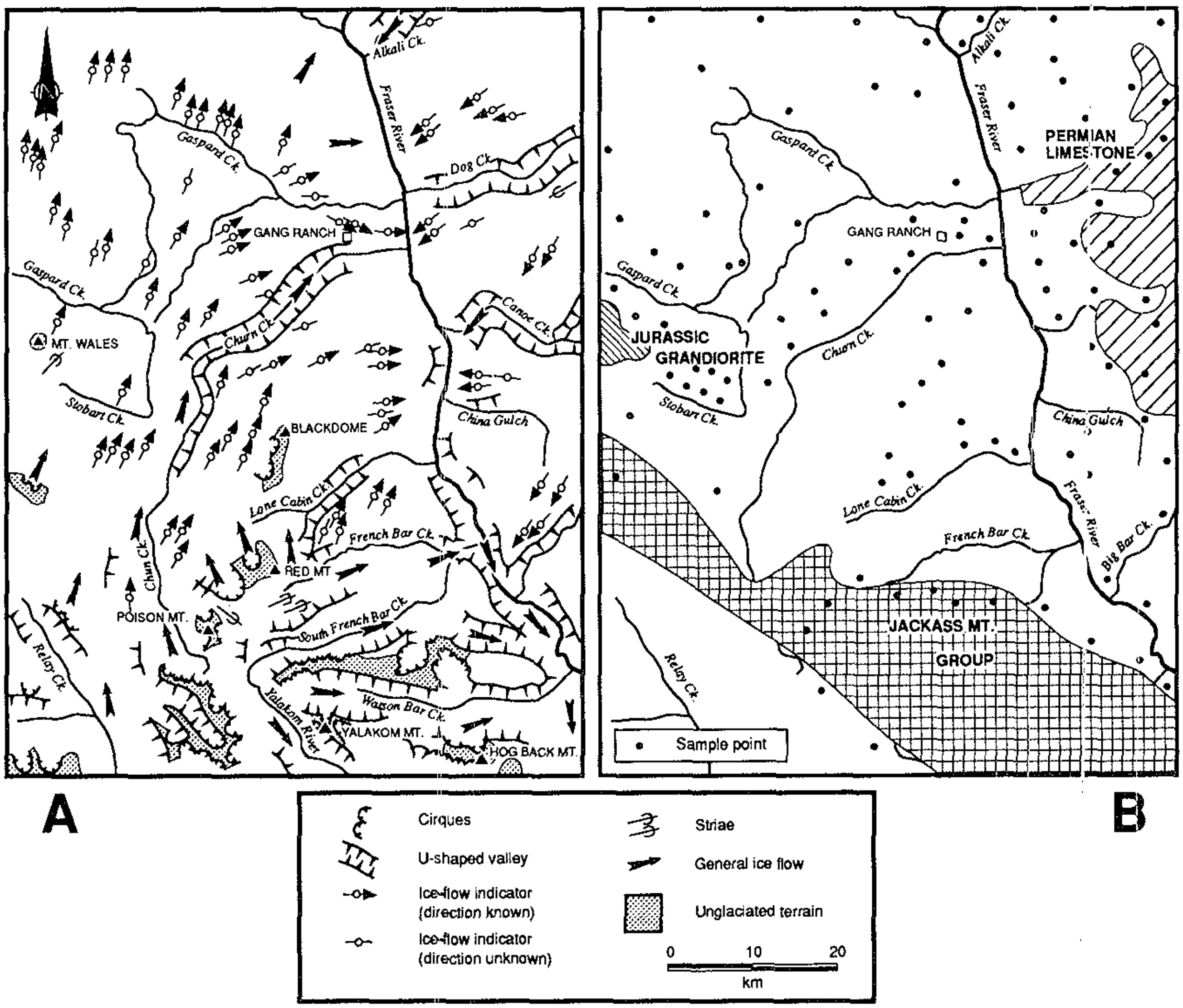

Figure 12-3. (a) Glacial dispersal patterns. (b) Distribution of indicator lithologies and sample sites.

glacier dynamics and bedrock exposure (Broster, 1986; Hornibrook *et al.*, 1993; Balzer and Broster, 1994).

The examination of till-clast lithology was considered the most economical and accurate approach to defining glacial dispersal patterns in this part of the Canadian Cordillera because of the following: studies in subalpine terrain with variable physiography (Hornibrook *et al.*, 1992, 1993; Balzer and Broster, 1994) suggest clast lithology delineates larger dispersal trains than matrix components; clast trains can often be defined by relatively fewer samples than commonly needed for matrix component trains; and the only expense for analysis is the time required for lithology identification, which could be done while still in the field.

DIRECTIONAL GLACIAL LANDFORMS AND LITHOLOGIES

Ice-flow directions were initially determined by mapping drumlins, roches moutonnées and flutes observed on 1: 10 000 and 1: 60 000-scale air photos. These directions were plotted on a base map so that subsequent ground traverses could be directed to areas requiring further information. At ground locations, glacial striae orientations were measured on bedrock outcrops and depositional transport paths were determined by measuring orientations of long-axes of 50 prolate clasts in basal till.

Additional important dispersal data were derived from the examination of source lithologies represented by clasts in basal till. Approximately 150 till samples, ranging from 2 to 5 kilograms each, were collected within the study area at 102 sample locations (Figure 12-3b). The collection of additional samples at some sites allowed us to examine vertical mixing and lithological variability within the till.

The samples were dried and passed through a 2-millimetre sieve. From each sample, a minimum of 100 clasts more than 15 millimetres in diameter were identified and grouped according to lithology. Permian limestones, Jurassic granodiorites and Cretaceous clastics were selected as

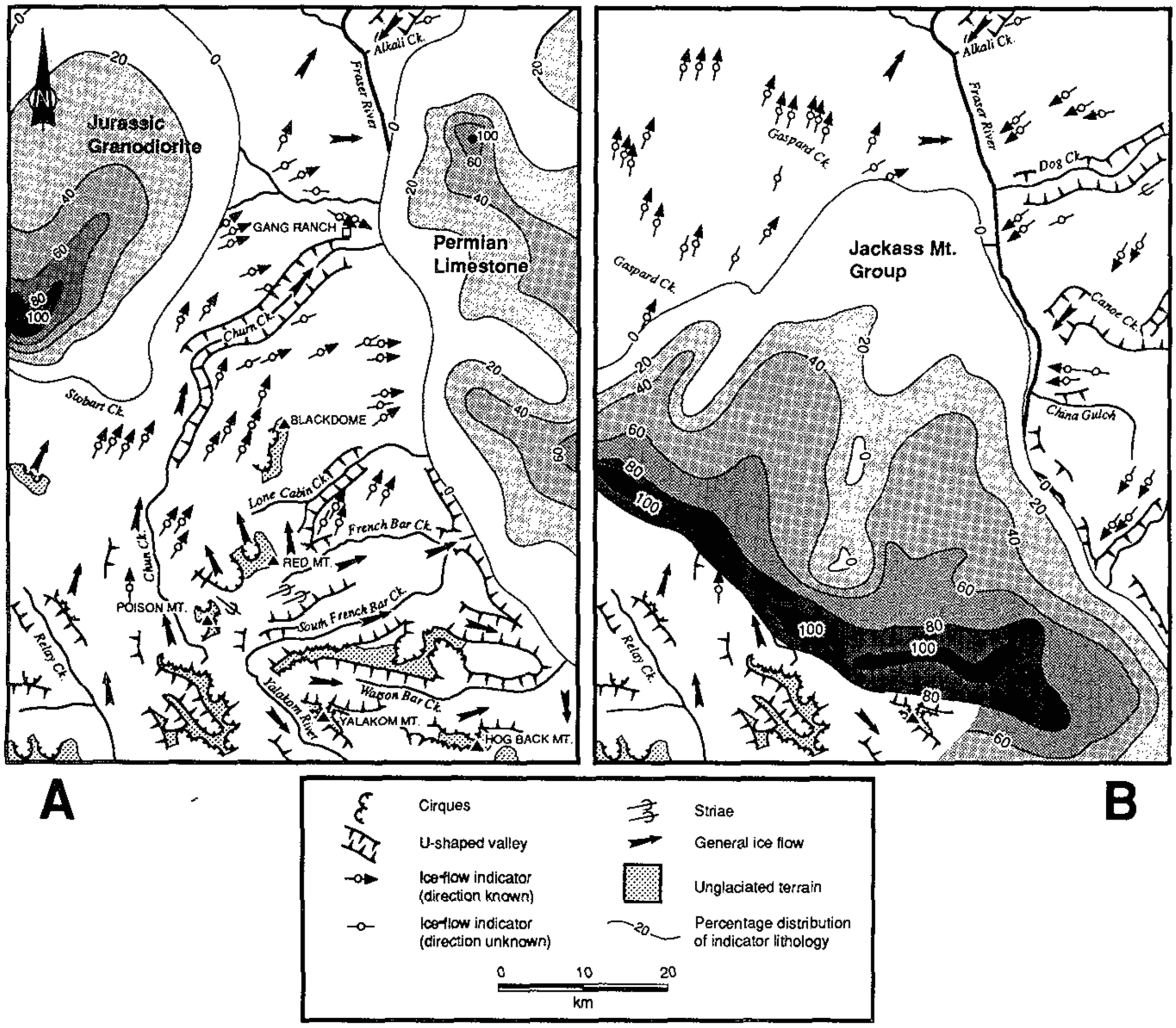

Figure 12-4. Dispersal patterns of clast lithologies in till, for: (a) Jurassic granodiorite and Permian limestone, (b) Jackass Mountain Group clastic sediments. Note change in glacigenic directional indicators and paucity of clast dispersal due to an ice divide at the Fraser River.

indicator lithologies, as published maps (Tipper, 1978) indicate that these rock types have known and restricted geographic distribution (Figure 12-3b). Percentage distributions of indicators were subsequently plotted on a base map of the study area (Figure 12-4a, b).

RESULTS AND INTERPRETATIONS

Glaciation of the Fraser Plateau was typical of the process in mountainous areas of British Columbia (Clague, 1989) and elsewhere, involving formation of cirque glaciers and their coalescence into valley glaciers and, eventually, large ice sheets. Although glacier coalescence can produce complex dispersal trains and interlayered ground moraine (till deposits; *cf.* Broster and Dreimanis, 1981), subtle deviations and limits to individual glacier movements were apparent by careful examination of glacigenic indicators.

Basal till showed a preferred fabric (clast alignment) similar to ice-flow patterns determined from striae and directional landforms (Figure 12-3a). The till fabric data and bedrock striae enabled identification of subtle deviations in local ice flow. Although these data were important for our detailed study, major ice-flow patterns were clearly identifiable by recognition of directional glacial landforms on aerial photographs.

During glaciation, ice accumulation occurred in the Camelsfoot and eastern Chilcotin ranges (Figure 12-3a). Major valley glaciers from these sources coalesced with Cariboo Mountain ice along the Fraser River valley. In the northwest quadrant of the study area, drumlins and flutes indicate northward ice flow with crude radial dispersal as ice advanced over the Fraser Plateau (Figure 12-3a). Relict periglacial landforms on peaks in the Camelsfoot and eastern Chilcotin ranges indicate a minimum limit of the Cordilleran ice sheet during the Fraser glaciation (Huntley and Broster, 1993a).

Clast dispersal patterns support other ice-flow data (Figures 12-4a, 4b). For example, a northeastward dispersal pattern occurs in the northwest quadrant where granodiorites were eroded by ice flowing over the western Fraser Plateau (Figure 12-4a). Here, a broad dispersal train reflects radiating flow associated with piedmont glacier lobes from the eastern Chilcotin Range.

In general, there is an apparent concentration of indicator lithologies in drift deposited along valleys and homogenization of drift lithologies in till overlying plateau areas. This was recognized both in replicate sample analysis and plots of indicator lithology percentiles. For example, dispersal of clastic sediment lithologies reflects lobe-shaped concentrations associated with northwest transport of debris along major valleys from the Camelsfoot Range in the south (Figure 12-4b). Maximum concentrations occur over peaks of the same lithology that were ice-free during glaciation. Minimum concentrations occur in ice-free areas with contrasting geology, and in ice-distal settings along the Fraser River. The maximum train observed in this area is over 50 kilometres in length and is associated with valley-controlled flow along Churn Creek.

Unlike the granodiorite and clastic sediment trains that decrease to the north, the limestone content in the eastern part of the area diminishes westward, to become rare or absent at the Fraser River (Figure 12-4a). The dispersal pattern of Permian limestone indicates westerly transport over the eastern plateau and along tributary valleys draining to the Fraser valley (Figure 12-4a). Together, the dispersal patterns of limestone and clastic sediments indicate that a major ice divide occurred along the Fraser River valley in this area.

CONCLUDING REMARKS

Our research provides the first attempt at systematic examination of glacial dispersal patterns in the southeast Taseko Lakes area and provides essential baseline data for subsequent mineral exploration. Here, ice flow and sedimentation occurred in alpine and plateau terrains with complex geology. Consequently, the area is a challenging environment for conventional methods of drift prospecting.

However, the combination of landform and sediment mapping with clast fabric and lithological analyses provides an effective low-cost method of regional exploration. This approach to preliminary drift prospecting involved:

- Identification of directional landforms from analysis of aerial photographs.
- Identification of indicator lithologies for assessment of spatial distribution of clasts.
- Ground reconnaissance to collect samples and on-site directional data (striae and till fabrics).
- Identification of patterns and limits to spatial distribution of indicator lithologies.

From these data we conclude that more detailed prospecting surveys in this area must consider the effects of greater mixing of drift during deposition on plateau areas, contrary to the concentration of distinctive up-ice sources in drift along valleys, and the separation of ice bodies and relative lack of transport across the Fraser River valley. We further believe that this approach can be applied successfully in other regions of variable terrain and complex geology.

ACKNOWLEDGMENTS

Logistical and financial assistance during data collection was provided by Dr. C.J. Hickson (Geological Survey of Canada). Support for travel and preparation of this paper was received from Supply and Services Canada, Contract No. 23254-1-0145/01-XSB and a Natural Sciences and Engineering Research Council of Canada operating grant to B.E. Broster. We are grateful to A.G. Pronk for suggestions to an earlier draft. Thanks are also extended to Irene Alarie for field assistance over the 1991 and 1992 seasons, and to Angel Gomez and Bob McCulloch for drafting and photographic reproduction.

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THE USE OF THE CHARACTERISTICS OF GOLD FOR EXPLORATION IN GLACIATED MOUNTAINOUS AREAS, WITH AN EXAMPLE FROM THE KOOTENAY DISTRICT, SOUTHEASTERN BRITISH COLUMBIA

By John Knight, Geological Consultant

INTRODUCTION

Many exploration programs have been conducted in the Kootenay district of southeastern British Columbia (Figure 13-1) since the discovery of placer gold in the 1870s. Spurred on by the discovery of associated lode occurrences, the search for additional sources continues today. As with many gold exploration ventures conducted in glaciated, mountainous areas where a number of lode showings occur, the interpretation of results is one of the weakest links in the exploration process. This study illustrates how the characteristics of a limited number of gold particles recovered from heavy mineral sampling programs can be used to reduce the interpretive uncertainty.

The characteristics of gold found in the surficial environment are the product of inherited characteristics from the lode and the post-depositional processes acting on the gold. Gold particles from bedrock sources are commonly spheroidal (equant) in shape with a specific composition related to

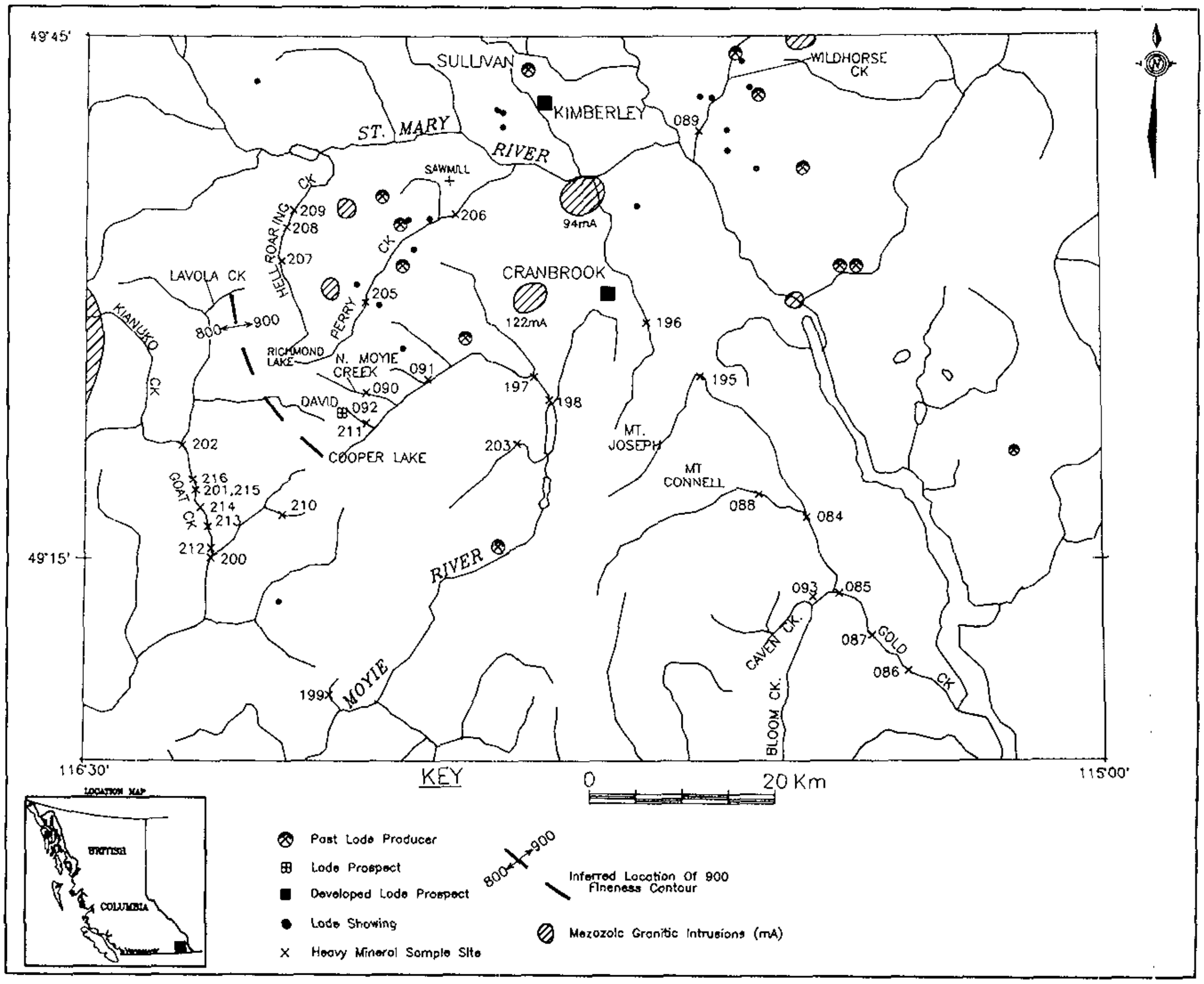

Figure 13-1. Sample locations.

conditions of formation (Morrison *et al.*, 1991). Weathering liberates gold particles from the lode. In the surficial environment, weathering and erosion alter both the chemistry and morphology of the particles. Mercury, copper and silver are removed from the surface of gold particles to form a thin (up to 20 µm) coat or rim of pure gold around a core (Knight and McTaggart, 1990; Knight *et al.*, 1994). The core preserves the original or bedrock source composition of the gold (Knight and McTaggart, 1986, 1989, 1990, Knight *et al.*, 1993, Nelson *et al.*, 1990). In the fluvial environment, hydraulic reworking of sediment causes gold particles to become flatter and rounder with time. Under certain conditions the increase in flatness and roundness can be related to distance of transport (Herail *et al.*, 1989; Knight *et al.*, 1994). The chemical and physical characteristics of gold can, therefore, be used to fingerprint the bedrock source of the gold and make an estimate of the distance of transport in the fluvial environment.

METHODS

The samples used in this study consist of gold recovered from a regional heavy mineral sampling program, and, for upper Moyie and Gold creeks (Figure 13-1), samples which were specifically collected for a study of the characteristics of gold. The objective, in both cases, was to locate the source(s) of gold found in the creeks.

Only an outline of the data collection procedure is given in this paper. For more details see Knight and McTaggart (1986, 1989, 1990) and Knight *et al.* (1994). Gold particles were sized, and for samples in which the majority of the particles were greater than 0.2 millimetre, were sorted into flatness and roundness categories. The flatness was estimated by visual inspection and the roundness by comparison to a standard chart. The particles in the sample were mounted in plastic with their long axes perpendicular to the sample mount surface in order to consistently expose the short - intermediate axis plane when the mount is polished (Douma and Knight, 1993). This procedure ensures that the measurements made of the rim features accurately reflect the rim characteristics and are consistent between samples. Inclusions and the internal structure were studied using a reflected light microscope. Each particle was then analyzed by electron microprobe for gold [detection limit (D.L.) = .019 wt%], silver (D.L. = .013 wt%), copper (D.L. = 0.025 wt%), and mercury (D.L. = 0.065 wt%). The detection limit is calculated using three standard deviations of the background. Data are displayed as fineness *versus* mercury plots (Figure 13-2), where fineness=1000 x (Au/(Au+Ag)).

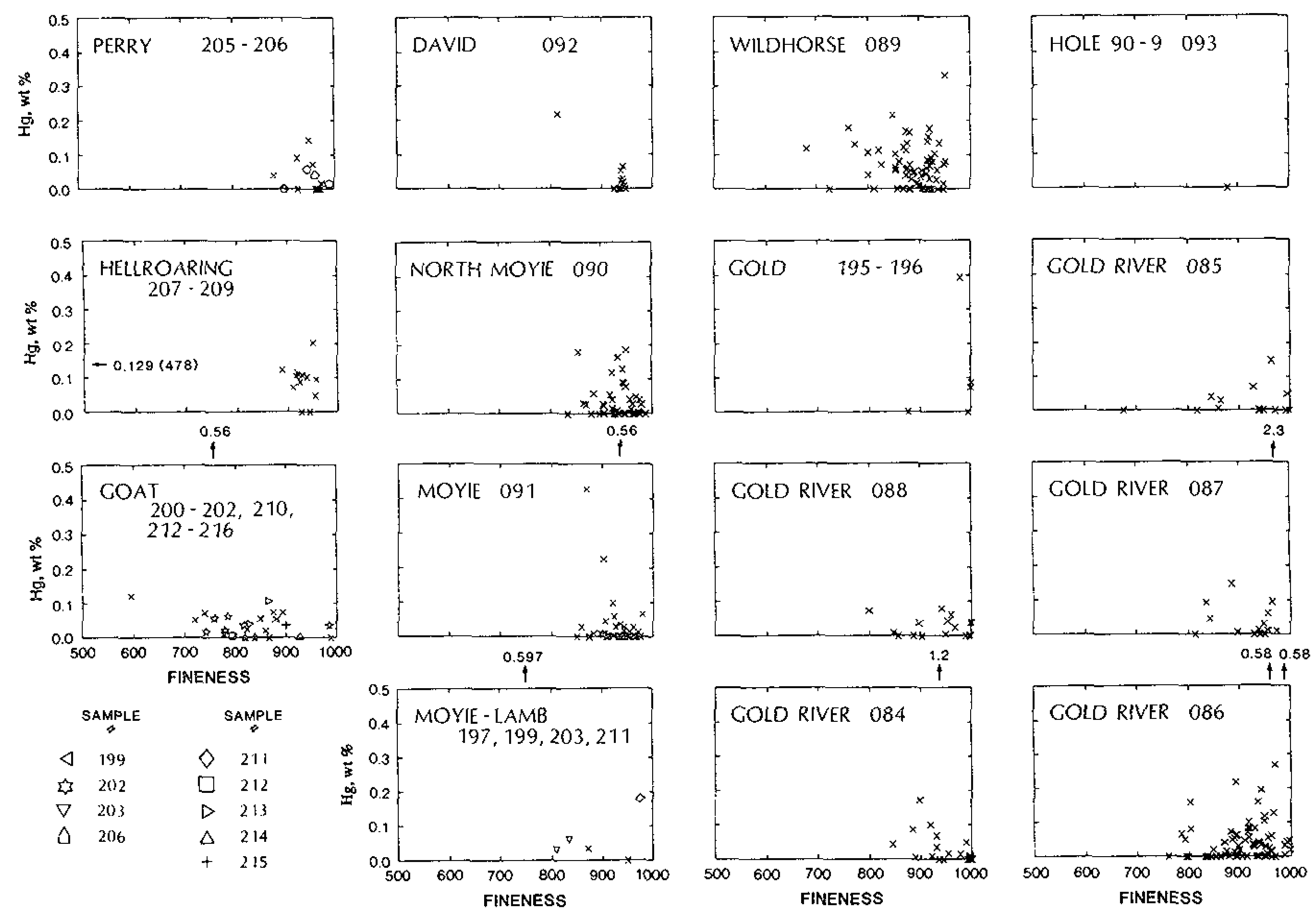

Figure 13-2. Scatter plots of fineness versus wt% mercury for the samples in Figure 13-1. Detection limit for mercury is 0.065 wt%.

GEOLOGY

The area to the west of the Rocky Mountain Trench is underlain by limestone, quartzite, dolomite and sandstone of the Proterozoic Purcell Supergroup (Kitchener-Siyeh, Creston, Aldridge and Fort Steele formations; Höy, 1989b). Proterozoic Moyie intrusions, which comprise sills and dikes of basaltic composition, intrude the Purcell Supergroup rocks. In the area enclosed within the bend of the Moyie River, andesites and basalt lava flows of the Nicol Creek Formation are interbedded with the sediments. At the western edge of the study area, Purcell rocks are intruded by Mesozoic (post-Triassic) granites and granodiorites (Leech, 1958; Reesor, 1956, 1981; Höy, 1984, 1989a; Rice, 1941). East of the Rocky Mountain Trench the major units include limestones, quartzites, dolomites and siltstones of the Precambrian Fairholme, Gateway and Roosville groups.

Known gold mineralization occurs as gold-silver quartz veins hosted by Purcell Supergroup rocks. The David occurrence (MINFILE 082F 092), for example, is a gold-quartz vein hosted by a northeast-striking shear zone. Sulphides such as galena, pyrite and chalcopyrite are often significant accessory minerals in the veins. The age of mineralization is unknown. The Sullivan deposit and similar stratiform massive sulphide deposits are found to the north. Quartz veins carrying galena and silver minerals (including tetrahedrite and native silver) are also scattered throughout the area.

RESULTS AND DISCUSSION

SAMPLE MORPHOLOGY

The distance of transport of the placer gold can be estimated by using the curves of Knight *et al.* (1994) which relate the average flatness, roundness, rim thickness and percentage of the particle which is rimmed, to the average distance of transport (Figure 13-3). Estimates of the distance of transport could only be made from Gold Creek and upper Moyie River samples, as only these samples had a sufficient number of particles in the required size range (0.2 to 1.5 mm). Results for the Gold Creek area are shown in Table 13-1. As Knight *et al.* (1994) concluded that flatness is the most reliable indicator of the distance of transport it is these values that are taken to represent the transport distance for Gold Creek gold. Rim characteristics are strongly influenced by the immediate past history of the gold particle and are therefore a less reliable indicator. Specifically, the rim characteristics are thought to more accurately reflect the time since the last active alluvial transport during the formation of the host gravels of probable Holocene age, abrasion of the gold and consequent preferential removal of the rim, rather than the distance of transport (Knight *et al.*, 1994).

The presence of numerous indentations and, in section, smearing of the gold at the edges of the particles, is consid-

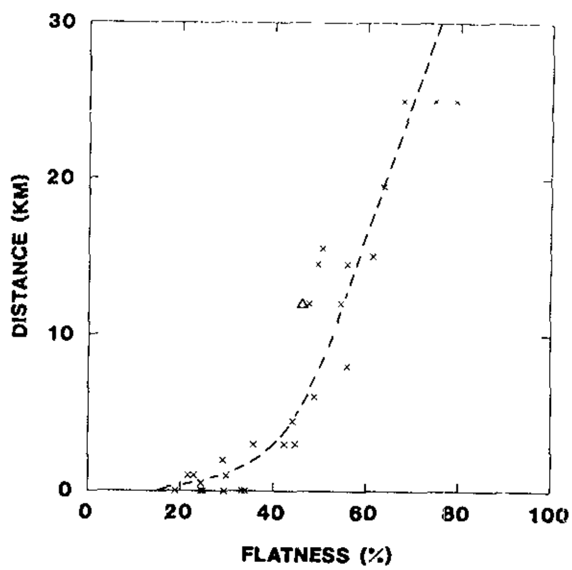

Figure 13-3. The relationship between gold particle flatness and distance of transport from the lode source for the Klondike. The triangle represents a sample containing some gold which originated in the White Channel gravel paleoplacer (Knight *et al.*, 1994).

TABLE 13-1
CHARACTERISTICS OF GOLD PARTICLES AS DETERMINED BY REFLECTED LIGHT MICROSCOPY AND THE RESULTING PREDICTION OF DISTANCE TO SOURCE

									Estimate of distance (km) using			
Drainage	Sample Number	Largest Size	Smallest Size	Total Number of Particles	Flatness	Roundness	Rim %	Rim Thickness (microns)	Flatness	Roundness	Rim %	Rim Thickness
David	92	ND	ND	14	45.2	69.0	0.0	0.00	4.0	0.5	0.0	0.0
Moyie	90	0.2	0.5	27	47.5	38.9	0.0	0.00	6.0	2.0	0.0	0.0
Moyie	91	0.2	0.8	48	62.5	27.1	4.5	0.50	18.0	5.0	0.5	0.5
Gold	88	0.2	0.5	15	83.3	16.7	28.0	2.45	35.0	>30.0	4.0	2.0
Gold	84	0.2	1.0	28	76.2	19.0	35.6	2.54	30.0	20.0	7.0	2.0
Gold	93	1.0	1.0	1	ND	ND	ND	ND	ND	ND	ND	ND
Gold	85	ND	ND	13	83.3	24.4	55.0	2.93	35.0	7.0	18.0	3.0
Gold	87	ND	ND	16	81.2	18.8	41.3	2.27	34.0	25.0	10.0	2.0
Gold	86	0.2	0.5	78	81.2	20.5	66.2	3.74	34.0	10.0	30.0	5.0
Wildhorse	89	0.2	0.5	58	68.4	37.9	7.2	0.79	24.0	2.0	1.0	0.5

ND = not determined

In addition:
Sample number 89 was seen to be contaminated with mercury on the surface.
Most contaminated paricles were removed during sample preparation and the remainder did not affect the results.
Inclusions of chalcopyrite and galena were seen.
Sample number 90 has inclusions of pyrite and galena.
Two compositions of gold in a single particle were present in samples 84, 85, 86, 87, 89 and 90.

ered to support this conclusion. A similar situation exists in the Cassiar area where the gold is associated with gravels formed during the last deglaciation of the area (Nelson *et al.*, 1990). Higher roundness values are more suited to an estimate of short distances of transport (<10 km; Knight *et al.*, 1994). Large errors associated with estimates of longer distances based on roundness are thought to be, at least in part, responsible for the discrepancy between the estimates of distance based on roundness and flatness. A final complication in this study is the relatively small number of particles in each sample.

The gold from the David (MINFILE 82G 092) bedrock occurrence (sample 92) has a significant primary flatness possibly related to its origin in a shear zone. The curves of Knight *et al.* (1994) are based on gold in the bedrock source which had a near spheroidal or equant shape. This primary flatness accounts for the distance of 4 kilometres to the source predicted for this sample rather than the expected 0 kilometres. Despite these complications, the flatness of gold from Gold Creek indicates a minimum transport distance of 30 to 35 kilometres from the projected lode source.

SAMPLE COMPOSITION

The copper content is low and shows an increase in concentration with increased fineness. The data fall within the range reported by Knight *et al.* (1994) and Knight and McTaggart (1990) as representing the expected normal increase in copper content with increased fineness for lode deposits. Except for the pure gold (fineness = 1000) particles with no copper or mercury (*see* below), all particles recovered are considered to be weathered from a bedrock source. The chemical compositions of the particles, as illustrated by the plots in Figure 13-2, are therefore a chemical signature of the bedrock source.

The most striking feature of the data is the fact that, despite the regional glaciation (Clague, 1975), gold particles in creeks separated by major divides have a distinct chemical signature (Figures 13-1 and 2; Table 13-2). Therefore, as dispersion of the gold from the lode source was confined to those parts of a drainage with a well defined watershed, the dominant source for the placer gold lies within the drainage basin of that stream.

The gold compositions in this area are unusual for British Columbia in that they report a consistently high (>900) fineness. High fineness values are reported from other gold producing areas of Canada with Precambrian hostrocks (Guindon and Nichol, 1982). Based on the work of Morrison *et al.* (1991) these fineness values are most compatible with slate belt, Archean age and plutonic-hosted deposits. The gold is also unusual because of the common occurrence of zones of low fineness (<800fine) within the gold particles. These zones vary in shape from irregular to vein-like. Their presence implies that the gold composition in the source lodes varied over time. Further, it suggests that the signature from gold in the fluvial environment will show a wider variation than if the lode had a restricted composition range. This common heterogeneity also suggests that larger samples may be needed to resolve some of the uncertainties in the data presented in this paper.

TABLE 13-2
GENERALIZED CHARACTERISTICS OF GOLD FOR EACH CREEK

Drainage	Number of Particles	Fineness	Hg	
Moyie	92	929	Below detection limit.	
Gold	121	910	Below detection limit.	
Upper Gold	26	922	Below detection limit.	
Lower Gold	95	906	Below detection limit.	
Perry	13	950	Below detection limit.	
Hellroaring	13	895	0.080	
Hellroaring	12	930	0.070	*
Wildhorse	58	885	0.065	**
Goat	22	821	0.060	***

* One particle at 478 fine not used in the average.
** Around detection limit, significant number of two phase particles.
*** Around detection limit.

The Moyie placers [sample numbers 90 and 91, Average fineness (avg.) = 929, Hg detection limit, (D.L.)] reflect the composition of the David lode source (92, avg. = 933, Hg D.L.). Distance to the lode source of the gold in sample 90 is predicted to be 6 kilometres, suggesting that the David showing (92) or an area a few kilometres upstream may be the source. An estimated distance to source of 18 kilometres for the sample 91 is in agreement with this conclusion. Although the lode source may have gold with a flattened morphology, the possibility of a source farther up the Moyie River cannot be ruled out (*see* Figure 13-2; Tables 13-2 and 3). It is significant that the single particle recovered from sample 211 (Figures 13-1 and 2) predicts the characteristics of the David showing.

Some of the gold particles in the Gold Creek samples have a fineness near 1000, with no copper or mercury present. Based on the work of Knight and McTaggart (1990), this composition indicates that the original particle has been completely transformed to rim composition by the removal of silver, copper and mercury. These particles and the five particles with significant mercury are removed from the

TABLE 13-3
RESULTS OF THE MICROPROBE ANALYSIS OF GOLD PARTICLES. THE DETECTION LIMIT FOR MERCURY IS 0.065 WT% AND FOR COPPER IS 0.025 WT%

Drainage	Sample Number	Particles	Average Fineness	Average Hg wt%	Total	Notes
David	92	17	933.0	< D.L	99.77	
Moyie	90	46	931 0	< D.L	99.97	A, D
Moyie	91	46	926.3	< D.L.	99.45	B
Gold	88	13	919.4	< D.L.	99.78	A
Gold	84	13	924 9	< D.L.	99.75	A, B, D
Gold	93	1	883.2	< D.L.	99.22	
Gold	85	13	903.1	< D.L.	99.51	A, D
Gold	87	14	915 8	< D.L.	99.44	B
Gold	86	67	905.0	< D.L.	99.45	B, D
Wildhorse	89	68	885.1	0.065	100.02	D
Moyie-Lamb	197-198, 203	5	844.5	0.14	99.93	
Goat	200-202, 210-216	22	821.4	< D.L.	99.92	
Hellroaring	208-209	13	895.3	0.09	99.91	
	208-209	12	930.1	0.07	99.94	C
Perry	205-206	13	947.8	< D.L.	100.08	
Gold	195-196	5	969.7	0.11	99.94	

NOTES:
A) Particles with composition of rims removed
B) Particles with Hg>0.5 removed (<2 particles per sample)
C) One particle at 478.0 fineness, Hg 0.129, removed before averaging.
D) Second phases of the following fineness were seen in these samples

Sample	Fineness
90	835, 899
64	759
85	675
86	541
89	776, 514, 692, 787.

compilation of the averages given in Tables 13-2 and 3. The complete data set is presented in Figure 13-2.

The upper Gold Creek samples (84 and 88, avg. 922, Hg D.L.) are similar in composition to the Moyie samples suggesting that they have a similar source in the upper Moyie drainage. Conversely, the lower Gold Creek samples (85, 86, 87, avg. 906.0, Hg D.L.) have a lower fineness than both the Moyie and upper Gold Creek samples (see Figure 13-2; Tables 13-2 and 3). The following discusses potential sources of the gold and possible explanations for the compositional differences between the gold from the upper and lower Gold Creek samples.

A significant proportion of the gold in the lower Gold Creek samples may have been transported from the Wildhorse Creek area (89, avg. = 885, Hg = .065) to the lower Gold Creek area by glaciation. Topographically this seems reasonable. For the Wildhorse area, the flatness of the gold in sample089 suggests that it has been transported about 24 kilometres, which is in keeping with a lode source up Wildhorse Creek in the area of the known gold-bearing lodes (*see* Figure 13-1; Table 13-1). The limited variation in composition supports this conclusion. For the gold from Wildhorse Creek to reach lower Gold Creek, it must cross the Rocky Mountain Trench. Clague (1975), and Broster and Dreimanis (1981) concluded that during the last glaciation the debris from tributary glaciers was confined to the same side of the Rocky Mountain Trench as the tributary source. In addition, the topography of the Gold Creek - Columbia River watershed suggests that gold from the Wildhorse side of the Columbia valley would not be added to Gold Creek by postglacial fluvial reworking of the glacial debris. It is therefore unlikely that gold from the Wildhorse watershed reached the lower Gold Creek drainage.

Undiscovered or unsampled sources contributed gold of a lower fineness to lower Gold Creek. The data in Figure 13-2 and the change in composition at Bloom Creek suggest that a source in the Bloom - Caven drainage is possible. The average distance-of-transport estimates from Table 13-1 provide part of the answer. Accepted transport-distance estimates, based on the flatness of the particles, of 30 to 35 kilometres, are less than the expected 45 to 65 kilometres, if the David area or upper Moyie drainage is the source of the gold. In addition, the predicted distances are quite similar to one another and do not reflect the 20-kilometre distance between the samples at the head and mouth of Gold Creek. Although a second source may account for the difference, it is felt that a more significant cause has to do with the mechanism of transport. Material which is moved englacially can be transported long distances without being deformed (Strobel and Faure, 1987). Gold from lode sources in the the upper Moyie and Perry - Hellroaring Creek areas were transported alluvially and glacially down their respective valleys. Once the transporting glaciers left the tributary valleys and merged with the main Rocky Mountain glacier, the debris were transported englacially rather than basally. This process would limit the deformation of the gold particles. The 30 to 35-kilometre distance of transport given in Table 1 would then represent the distance of transport from the source to the point at which englacial transport commenced. It is implied in this argument that preglacial placer or placers existed up to 30 to 35 kilometres from the lode source. Rims form slowly in the surficial environment, therefore, the presence in the Gold Creek samples of particles of the order of 50 microns in thickness with the composition of rims (inferred rim thickness of the order of 25 m) supports the conclusion that at least some of the gold weathered in a preglacial environment. If the David area is considered the likely lode source, 30 to 35 kilometres of transport would place the maximum distance of placer development in the area where the Moyie River changed slope as it left the mountains to enter the Rocky Mountain Trench. This is a reasonable location to propose a limit of placer formation. Finally, the presence of two-phase particles in the Moyie and Gold Creek sample supports the idea that the upper Moyie is the source of Gold River gold.

Differences between the average composition of the upper and lower Gold Creek gold would result from each of these areas being dominated by different englacial debris trains. Clague (1975) invoked a similar mechanism to explain the distribution of mafic pebbles from the St. Mary watershed and the distribution (from a more general source) of garnet and staurolite in the coalesced ice sheet which filled the Rocky Mountain Trench. Distribution patterns, defined by Clague for mafic pebbles from the St. Mary River watershed, support the idea that the gold from above the Perry - Hellroaring area would dominate in lower Gold Creek around the Bloom - Caven Creek confluence. His data also suggest that the change in ice direction reported by Broster and Dreimanis (1981) along the Moyie River near Moyie Lake would not affect this conclusion. There is, therefore, no need to predict a nearby source of gold in the Bloom - Caven Creek drainage in order to lower the average distance of transport and fineness for the gold in lower Gold Creek. The larger spread in the data for the samples in lower Gold Creek as compared to upper Moyie (Figure 13-2) can be taken as evidence to support the argument of some mixing of sources.

The Perry Creek samples (205 and 206 in Figures 13-1 and 2, avg. = 950, Hg D.L) and Hellroaring Creek samples (207, 208, 209, avg. = 930, Hg 0.07) have a different signature to Moyie River (avg. = 929, Hg D.L.) and to one another (Figure 13-2; Tables 13-2 and 3) indicating that each creek has a unique source. However some similarities in the signatures suggest that the sources might be related. The tight clustering of points forming the signatures also suggests that either the samples are near source or that the source has a limited composition range (or both). Mineral occurrences in the vicinity suggest that the samples are close to source. It is concluded that the gold in each of the upper Moyie, Perry and Hellroaring watersheds has been eroded from a different source, of which the David occurrence (sample 92) is but one example. Similarities in composition suggest a genetic link between the sources. It is possible that Perry and Hellroaring creeks could have contributed gold to Gold Creek, but it is expected that if these creeks had been major contributors, then the distance estimate would be larger and the average fineness higher than reported. The limited dispersion of glacially transported debris also suggests that gold from Hellroaring and Perry creeks is to the east of Gold Creek.

The Goat Creek signature (avg. = 821, Hg .<D.L.) is distinctly different from the other creeks. Because the number of particles in each sample is small and the size of the particles is also small, it is not possible to subdivide the area based on gold characteristics. As no samples were available from above the Kianuko - Goat Creek confluence, it is not clear if the lode source is above this location. The source may lie anywhere within the Goat Creek watershed. Samples 215 and 210 suggest that the most probable location is on the west side of the Cooper Lake - Richmond Lake segment of the divide. Gold with a fineness of 861 has been reported from Lavola Creek (Holland, 1950); if verified, this conclusion would change slightly. The Goat Creek source does not seem to be represented in the samples from rivers flowing to the east of the divide.

The predicted location for the lode sources for Goat, Perry and Hellroaring Creek gold all lie in the same area; it would be natural to propose a genetic connection. Skryabin (1978) has shown, for one area of eastern Russia, that granitic bodies involved in mineralization are outlined by contouring the fineness of gold from placers and their quartz vein sources. In these examples, fineness decreases towards the intrusion. Although the data from this study are incomplete, the inferred location of the 900 fineness contour (Figure 13-1) suggests that the Mesozoic granitic and granodioritic plutons to the west, and the small intrusions near Hellroaring Creek provide a genetic link between the lode sources in this area and the variation in gold fineness. The implication of this conclusion is that the mineralization is of plutonic origin. The fineness range is in agreement with the plutonic type deposits of Morrison *et al.,* (1991).

The Moyie-Lamb sample (197, 199, 203, 211, 198) is too small for a definite statement to be made about the origin of the gold. Variation in ice-flow direction near Moyie Lake (Broster and Dreimanis, 1981) complicates the interpretation. The possibility (based on topography) that the Moyie River near Moyie Lake has changed direction as a result of a drainage reversal is an added complication. The composition range is consistent with other samples from the area, but the average is considerably lower (Figure 13-2; Table 13-3). Four of the six particles are less than 900 fineness, and the two particles exceeding 900 fineness are from sample 197, about 9 kilometres below sample 91 and 6 kilometres above sample 211. Gold particles in samples 197 and 211 probably come from a David-type source in the upper Moyie area. There are, from the data at hand, at least two possible sources for the particles less than 900 fine. The gold may have come from the Goat-Moyie divide. Alternatively, there is the possibility of a source on the Gold Creek - lower Moyie divide in the vicinity of Mount Joseph and Mount Connell (Figure 13-1) which, if true, could account for the differences seen in the Gold Creek samples. Gold-bearing mineralization near Moyie Lake, such as the Midway and St. Eugene deposits, are also possible sources. The thick till cover in the vicinity of Cranbrook, the variation in transport direction of the glaciers in this area, the possibility of drainage reversal and the small number of particles for the Moyie-Lamb area make further discussion about the source of the particles and the possibility of undiscovered sources in this area speculative.

CONCLUSIONS

Gold in the upper segments of each major drainage in the study has a unique signature suggesting that the source of the gold in each creek lies within its drainage basin. Glacial dispersion of the gold in the upper segments of the creeks was controlled by topography.

The most likely source for most of the gold in the district lies in an area of approximately 20 kilometres radius centred on Richmond Lake (Figure 13-1). The David gold-quartz vein occurrence exemplifies the type of source to be expected for the Moyie placer gold and perhaps, based on the similar compositions, for the other placer deposits in this area. The evidence to date suggests a Mesozoic plutonic affinity for the gold sources. The second phases present in most samples support the idea of a relationship between the lode sources and the evolution of the lode source with time. Not all the lode gold sources for the placers in the area have been discovered.

The gold in the Wildhorse Creek has its source within that watershed. Gold from this creek is not thought to have contributed to Gold Creek. However, the composition range and presence of second phases suggest that the lodes may be genetically related to those in the Moyie watershed. Gold in the Gold Creek drainage basin is thought to have come from the upper Moyie and Perry - Hellroaring Creek areas. The David occurrence is one source for this gold. The gold was probably transported, in part, englacially into the Gold Creek area. This mode of transport explains both the similarity in the distance of transport predictions for all the samples and the consistently low distance to source predictions based on the morphology. The downstream variance in composition is thought to be caused by different debris trains supplying gold from different sources to parts of Gold Creek. A study of the characteristics of gold, even in the small quantities recovered from heavy mineral sampling programs, can provide data which are useful in the search for lode deposits.

ACKNOWLEDGMENTS

The author would like to thank BP Canada, Selco Division and Brian Grant for the gold recovered from a heavy mineral sampling program, and Dragoon Resources for the samples from the Gold Creek watershed. I thank them for their permission to publish these results. Thanks are due to M. Bapty and L. Eccles for helpful discussions about the possible origin of the gold in Gold Creek. I would also like to thank Westmin Resources Limited who provided part of the funding for this study, Quest Canada who provided Figure 13-1, Dr. K.C. McTaggart for his encouragement, and Dr. C.H.B. Leitch for his constructive comments on early drafts.

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SAMPLE REPRESENTIVITY AND GOLD DETERMINATION IN SOILS AT THE FISH LAKE PROPERTY, BRITISH COLUMBIA

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INTRODUCTION

The particulate nature of gold often causes difficulties in obtaining representative samples for exploration (Clifton *et al.*, 1969; Harris, 1982; Nichol *et al.*, 1987). Although increasing sample size can resolve many of these problems, the size of sample that can be analyzed efficiently is often limited (for example, to 30 grams for fire assays). Recently, the use of the bulk leach extractable gold technique has allowed larger samples to be processed. This technique uses cyanide to leach gold from bulk (5 to 10 kg) soil and stream sediment samples. The cyanide solution is then analyzed for gold, often following concentration of the gold by solvent extraction. Cyanidation is a partial extraction technique dependent upon the accessibility of gold to the cyanide solution. Moreover, solution of gold by cyanide may be inhibited by certain components of the sample, such as organic matter and sulphides (Hedley and Tabachnick, 1968).

Elsewhere, we compared the size distribution of gold in C-horizons (Delaney, 1993; Delaney and Fletcher, 1993) and results of cyanidation (Delaney and Fletcher, in preparation) for six different areas of gold mineralization in North America. For one of these areas, Fish Lake, British Columbia, we present the size distribution of gold in B-horizons and one A-horizon, and the results of cyanidation analysis.

PROPERTY DESCRIPTION, GEOLOGY AND PHYSIOGRAPHY

Fish Lake is a porphyry copper-gold deposit located 128 kilometres south-southwest of Williams Lake, British Columbia, in the subalpine area east of the Coast Mountains (Figure 14-1). Access to the area is via the Bella Coola Highway (Highway 20) from Williams Lake, west to Hanceville, then southeast about 90 kilometres. The deposit is located approximately 800 metres north of Fish Lake.

The Fish Lake deposit is in the Tyaughton Trough, a narrow, northeast-trending subsidence basin which was active from the mid-Jurassic to mid-Cretaceous (Jeletzky and Tipper, 1968). The area is underlain by marine sediments and volcanic rocks of the Kingsvale Group which are exposed along a north-south window, 3 kilometres wide and 20 kilometres long, in the overlying Miocene plateau basalts. The deposit, which is roughly 900 metres in diameter, is centred on a calcalkalic intrusive complex underlain and flanked by andesitic tuffs and debris flows (D. Piroshco, personal communication, 1992). Crosscutting, coarse-grained quartz diorite porphyry and quartz feldspar porphyry dikes predate mineralization, but constitute only a small portion of the deposit. Approximately 60% of the mineralization is hosted in the tuffs and debris flows.

During the Late Wisconsinan, glacier ice advanced from the southwest and deposited 1 to 2 metres of glacial till over the property. Soils developed on these glacial deposits, or on subcrop, are primarily orthic dystric brunisols, although orthic humo-ferric podzols are present in areas with more organic matter, and orthic grey luvisols have developed where the soils are poorly drained.

SAMPLE COLLECTION, PREPARATION AND ANALYSIS

Sample sites were selected on the basis of a previous B-horizon survey for gold, and were located generally within 10 metres of earlier sample sites. Five pits were dug near anomalous gold concentrations and two in background areas. Ten to fifteen kilogram samples of A and B-horizon soils were collected from each site. Splits of the field samples (approximately 2.5 kg each) were wet sieved to four size fractions (-2000 +212µm, -212+106µm, -106+53µm and -53µm). Material from the three finest fractions was then split into 30-gram and 200-gram analytical subsam-

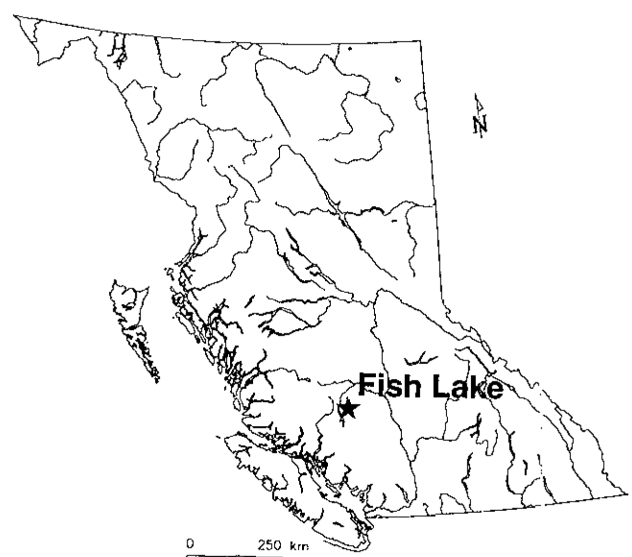

Figure 14-1. Location of Fish Lake property, British Columbia.

ples. The 30-gram subsample was analyzed, unground, for gold using cyanide - atomic absorption spectrometry (CN-AAS). The 200-gram split was pulverized to approximately 74 microns (200 mesh ASTM) in a steel ring mill. A 30-gram subsample of the ground material was analyzed for gold by fire assay - atomic absorption spectrometry (FA-AAS). All analyses were conducted by Chemex Labs in North Vancouver, British Columbia. The cyanidation technique used is described in Delaney and Fletcher (in preparation). Analytical precision, estimated using duplicate analyses of approximately 10% of the samples, was generally better than 20%.

RESULTS

On average, more than 42% of the A and B-horizon material resides in the -53-micron fraction (Table 14-1). Gold concentrations determined by FA-AAS are listed in Table 14-2. Samples representing background sites have gold concentrations below the 5 ppb detection limit. However, samples 32-106, 32-107 and 36-125, collected from sites anomalous in gold, also have analytical results at or below the detection limit. Gold concentrations in the remaining B-horizons range from 5 to 2320 ppb, with values distributed erratically across size fractions. For example, sample 33-110 has its highest gold concentration in the -212+106 micron fraction, whereas samples 32-106, 32-102, 35-118 and 37-128 have their highest gold concentrations in the -106+53 micron fraction. The single Ae-horizon sampled (32-105) has its highest gold content in the -212+106 micron fraction. The proportion of gold contributed by each size fraction, calculated from gold concentrations (Table 14-2) and sample weights (Table 14-1), is shown in Figure 14-2. Generally, more than 58% of the total gold content resides in the -53 micron fraction, although samples 31-102, 32-106, 35-118 and 37-128 also have high proportions of gold in the -106+53 micron fraction.

TABLE 14-1
GRAIN SIZE DISTRIBUTION, IN WEIGHT PERCENT, OF THE -2000μm FRACTION OF A AND B-HORIZON SOILS

Sample Number	Horizon	Size Fraction (μm)			
		-2000+212	-212+106	-106+53	-53
31-102	B	43.73	10.46	12.26	33.54
32-105	Ae	32.01	11.19	12.40	44.40
32-106	Bt	32.95	11.89	10.12	45.03
32-107	Bt	28.08	9.24	7.54	55.13
33-110	B	52.33	8.99	8.94	29.74
34-113b	B	29.95	11.27	10.98	47.80
34-114b	Bt	31.90	10.40	9.35	48.35
35-118	Bhf	32.94	14.02	15.09	37.95
35-119	B2	36.47	15.91	13.67	33.95
36-125	Bt	21.17	12.16	13.17	53.51
37-128	Bf	31.31	15.06	11.56	42.06
Mean		33.9	11.9	11.4	42.9
Standard Deviation		8.2	2.3	2.3	8.3

b=background

TABLE 14-2
CONCENTRATION OF GOLD (ppb) IN EACH SIZE FRACTION OF A AND B-HORIZON SOILS AS DETERMINED BY FA-AAS

Sample Number	Horizon	Size Fraction (μm)		
		-212+106	-106+53	-53
31-102	B	5	95	30
32-105	Ae	200	<5	10
32-106	Bt	<5	15	5
32-107	Bt	<5	<5	5
33-110	B	2320	1490	505
34-113b	B	<5	<5	<5
34-114b	Bt	<5	<5	<5
35-118	Bhf	<5	190	80
35-119	B2	81	130	200
36-125	Bt	<5	<5	10
37-128	Bf	60	300	155

b=background

TABLE 14-3
CONCENTRATION (ppb) OF GOLD IN EACH SIZE FRACTION OF A AND B-HORIZON SOILS AS DETERMINED BY CN-AAS.

Sample Number	Horizon	Size Fraction (μm)		
		-212+106	-106+53	-53
31-102	B	20	50	20
32-105	Ae	5	<5	<5
32-106	Bt	<5	<5	15
32-107	Bt	5	10	20
33-110	B	530	1150	335
34-113b	B	<5	<5	5
34-114b	Bt	5	<5	25
35-118	Bhf	75	75	10
35-119	B2	35	145	95
36-125	Bt	10	40	20
37-128	Bf	20	75	65

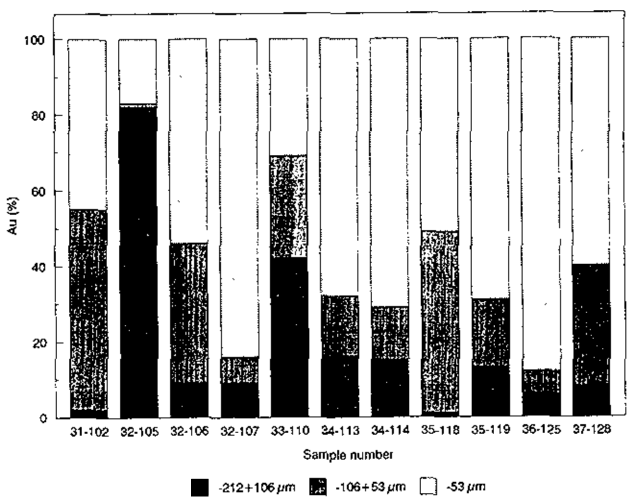

Figure 14-2. Proportion of gold in the -212+106μm, -106+53μm and -53μm fractions of A and B-horizons

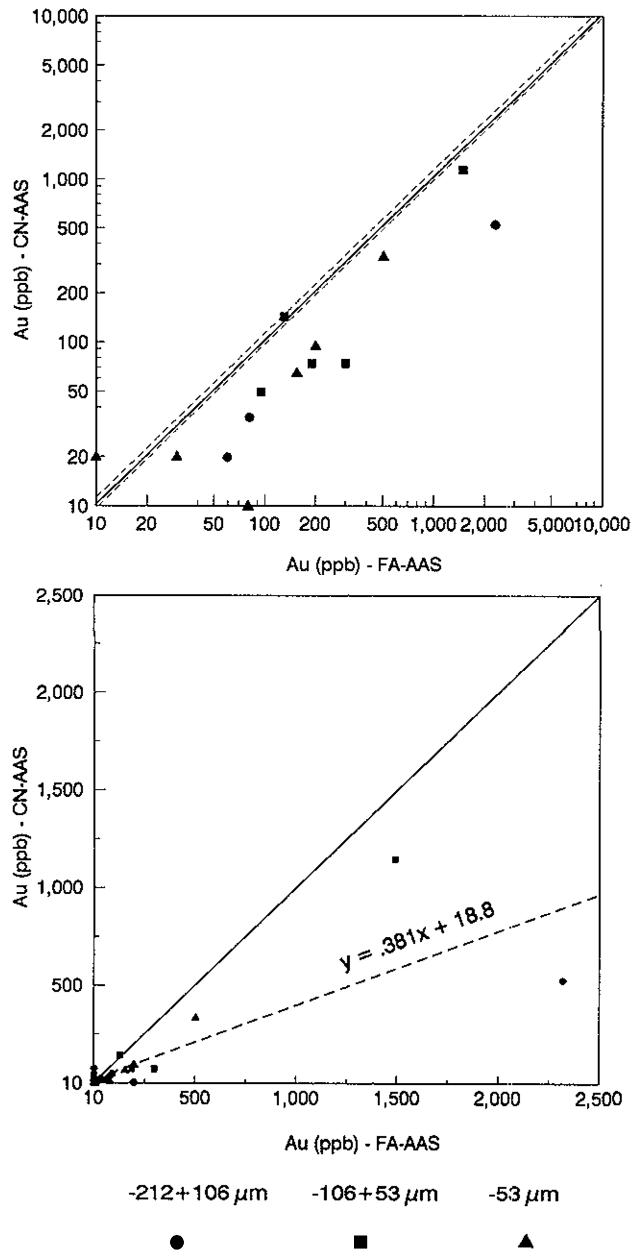

Figure 14-3. Comparison of analyses by CN-AAS and FA-AAS for each size fraction. Samples with gold values <10 ppb are excluded. For both figures the solid line represents the x=y line. (a) Data shown on a logarithmic scale. Dashed lines represent 20% limits. (b) Data shown on an arithmetic scale. Results of regression analysis (dashed line and equation) conducted at the .05% confidence level.

To determine the efficiency of cyanidation, results of gold determinations by CN-AAS (Table 14-3) are compared to corresponding FA-AAS analyses (Table 14-2) in Figure 14-3a. FA-AAS values are assumed to represent total gold concentrations. Values less than 10 ppb have been excluded, because of analytical errors in both methods occurring near the detection limit. On average, gold recovery by CN-AAS is 44% (ranging from 13 to 77%) of the total (FA-AAS) gold present in each size fraction. Recovery by CN-AAS shows the same concentration trends, generally increasing with increased total gold concentration. Figure 3b shows the same data with results of linear regression analysis. Statistically, both the slope and intercept of this regression line were indistinguishable from the x=y line, although the slope of the line (.370) is much less than 1. Acceptance of the null hypothesis probably results from the wide scatter in the data.

DISCUSSION

SAMPLE REPRESENTIVITY

To study the distribution of gold in C-horizons (Delaney and Fletcher, 1993), we separated samples into heavy and light mineral fractions prior to analysis for gold. Estimates of gold particle numbers were then made for the heavy mineral concentrates of the -212+106-micron and -106+53-micron fractions of C-horizons, based on field sample weights. These estimates were made assuming that the gold particles occur as spheres with diameter equal to the geometric mean of the bounding mesh sizes. Because of possible variation of gold concentrations and particle shapes these calculations can vary by a factor of 5 in either direction. However, they serve to illustrate the trends in the possible number of gold particles.

Estimates showed that for the -212+106-micron fraction, all but one concentrate contained insufficient gold to form one particle. This suggests that anomalous gold concentrations in these samples cannot result from the presence of free gold. Although the possibility of free gold particles is more likely in the -106-53 micron range, these calculations show that much of the gold is present as inclusions in the heavy minerals rather than as free particles. Moreover, light mineral fractions of the C-horizons were found to contain up to 22% of the total gold content of the samples. Because free gold particles would partition to the heavy mineral concentrates, gold in this fraction must be present as inclusions.

Examination of the distribution of gold across size fractions in the A and B-horizons indicates that the highest proportion of gold exists as particles less than 53 microns in diameter (Figure 14-2). This indicates that, as with C-horizons, much of the gold is present as inclusions. On this basis, numbers of ideal gold particles in 30 grams of all three size fractions of A and B-horizons have been modeled with the assumption that they behave as spheres 50 microns in diameter (Table 14-4). This assumption results in a very conservative (minimum) estimate for the number of gold particles in the -53 micron fraction.

Based on the requirement of 20 particles of gold to obtain a representative sample (Clifton *et al.*, 1969), our estimates indicate that, except for sample 33-110, 100-gram subsamples of the -106+53-micron and -53-micron fractions would be necessary to insure representativity in samples containing anomalous gold concentrations. Larger samples would be required if the -212+106 micron fraction were to be used, and nearly 2 kilograms of material would be needed if all samples having gold concentrations above the detection limit were to be representative. Therefore, some of the erratic gold values obtained in this study prob-

TABLE 14-4
ESTIMATED NUMBER OF GOLD PARTICLES WITH DIAMETER EQUAL TO 50μm IN EACH SIZE FRACTION OF A AND B-HORIZON SOILS

Sample Number	Horizon	Size Fraction (μm) -212+106	-106+53	-53	Total in -212 μm fraction
31-102	B	0.15	2.90	0.92	1.21
32-105	Ae	6.11	0.09	0.31	1.22
32-106	Bt	0.09	0.46	0.15	0.19
32-107	Bt	0.09	0.09	0.15	0.14
33-110	B	70.93	45.55	15.44	31.55
34-113b	B	0.09	0.09	0.09	0.09
34-114b	Bt	0.09	0.09	0.09	0.09
35-118	Bhf	0.09	5.81	2.45	2.71
35-119	B2	2.48	3.97	6.11	4.74
36-125	Bt	0.09	0.09	0.31	0.24
37-128	Bf	1.83	9.17	4.74	4.85

Based on a 30 gram-subsample.

ably result from analysis of subsamples that are too small to be representative.

Also listed in Table 14-4 is the estimated number of ideal gold particles in the -212 micron fraction. Obtaining material in this size fraction requires less effort than does sieving to the -106+53 or -53-micron fractions and similarities in numbers of gold particles in all three size fractions indicate that samples will remain representative if the coarser size fraction is used. However, the possibility of errant gold values resulting from the presence of free gold particles would increase in the -212-micron fraction.

RECOVERY OF GOLD BY CYANIDATION

Gold concentrations in A and B-horizons as determined by CN-AAS are about half the corresponding FA-AAS value, indicating that much of the gold is inaccessible to cyanide solutions or is inhibited from entering the solution by some component of the samples. Although CN-AAS values are lower than the FA-AAS values, results of cyanidation reflect the relative levels of gold in the samples. Furthermore, results of cyanidation adequately distinguish background samples from anomalous samples.

Cyanidation generally recovered more than 80% of the gold in the light mineral fractions of C-horizons (Delaney and Fletcher, 1994). Unlike the C-horizons, A and B-horizons were not separated into density fractions. One would expect, therefore, that because free gold is generally associated with heavy minerals, gold recovery by cyanide would be higher in the A and B-horizons than in the light mineral fractions of C-horizons. In fact, gold recovery was *lower* in the upper horizons. Possible explanations for the lower gold recovery include: inhibition of cyanide resulting from the presence of organic matter; encapsulation of gold in secondary minerals such as iron oxides; or encapsulation of gold in primary minerals that have a source other than the C-horizons, such as eolian deposits. However, lower gold recovery in the A and B-horizons was found in a variety of soil types developed over gold deposits, in climates varying from the deserts of Nevada to the humid lowland of southern Ontario (Delaney and Fletcher, 1993). The most likely explanation, therefore, is that gold is encapsulated in heavy minerals. This interpretation is the reverse of the common assumption that most gold associated with heavy minerals exists as free particles.

CONCLUSIONS

At Fish Lake, although anomalous gold values were detected by FA-AAS in all size fractions using 30-gram subsamples, estimates of the number of gold particles in the subsamples suggest that they are too small to be representative and would suffer from the nugget effect. To achieve representativity, samples larger than 100 grams would be required. Such samples are too large to be analyzed efficiently by standard FA-AAS but could be processed using cyanidation. Although results of CN-AAS analysis are generally lower than the corresponding results of FA-AAS, values show the same concentration trends.

ACKNOWLEDGMENTS

This project was funded by Chemex Labs, Cominco Ltd, Noranda Exploration Company Limited, Teck Corporation and the Natural Sciences and Engineering Research Council of Canada. Samples were prepared by Joni D. Borges, Sarapi Paopongsawan and Troy Priest.

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RESIDENCE SITES OF TRACE ELEMENTS IN OXIDIZED TILL

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(Geological Survey of Canada Contribution No. 36893)

INTRODUCTION

A common problem in the geochemical analysis of till, and soils developed on till is the choice of a representative and geologically meaningful grain-size fraction for analysis. For each specific set of source rocks and ore minerals, enough data should be available so that one can choose an optimum size fraction for analysis. Analysis of this size fraction should detect subtle anomalies and should not be biased by sample-to-sample variations in the abundance of "inert" rock-forming minerals. The size range must include the specific size fraction to which ore minerals are glacially comminuted and may include the size fraction where trace elements accumulate during weathering; two considerations that are often neglected in routine orientation surveys.

Dreimanis and Vagners (1971), Lindén (1975) and Haldorsen (1977) investigated the glacial comminution of common rock-forming minerals, identifying the "terminal grades" for several of them. Recently, more emphasis has been placed on the comminution behaviour of ore minerals and the effects of weathering on trace metal levels *versus* grain size (Kauranne, 1967; Eriksson, 1973; Shilts, 1973, 1984; Smith and Gallagher, 1975; Ayras, 1977; Klassen and Shilts, 1977; DiLabio, 1979, 1981). The amount of published information on the residence sites of trace elements in till is still quite small, including gold, which has drawn the most attention (DiLabio, 1982a, 1985, 1988; Sopuck *et al.*, 1986; Shelp and Nichol, 1987). There are essentially no data on platinum group elements.

No samples were collected specifically for this study; they have come mainly from Geological Survey of Canada archival material collected from drift prospecting research by the author (Table 15-1). The variety of ore deposit types that is represented by the sample suite, and the amount of analytical work that could be performed, are limited by the variety and size of the remnant samples in the archives. A few samples were donated by exploration geologists who have been supporting this research.

No attempt has been made in this study to evaluate the effects of till type on residence sites. Presumably, the transport of debris in a subglacial *versus* supraglacial position may affect the process of comminution. All the till samples used in this study are assumed to have been transported subglacially.

METHODS

A wide range of grain sizes finer than 4 millimetres has been subdivided into as many as ten fractions representing the variety of components of till; from rock fragment dominated (4-1 mm), through silicate mineral dominated (1.0-0.02 mm), to phyllosilicate dominated (<0.02 mm). Each original sample of till was dry sieved to recover the -4-millimetres matrix portion. The -4-millimetres material was then dry sieved to obtain samples of fines in fractions such as -0.037 or -0.063 millimetre. The oversized sediment from this operation was wet sieved to wash away adhering fines, dried, and dry sieved at 1 phi intervals using stainless steel

TABLE 15-1
SUMMARY OF RESIDENCE SITES OF TRACE ELEMENTS

Locality	Type of source	Element/Sample Type	Distance from Source (metres)	Residence Sites of Trace Elements (Grain Size Fractions)	Comments
Waverley, N.S.	Coarse visible gold in vein	Au/oxidized till	150 to 350	<0.063 mm, varies with distance	*See* diagram
Onaman R., Ont.	Au in chalcopyrite	Au/oxidized till	<50	<0.037 mm,	Soil profile
		Cu/oxidized till	<50	all fractions	Malachite in all fractions
Owl Creek Mine, Ont.	Au in pyrite, rare visible gold	Au/unoxidized till	<5	0.125 to 0.063 mm	Au in pyrite this size
		Au/oxidized till	<5	all fractions analyzed	Au in limonite-goethite in all sizes
Darling Tp., Ont.	Au in pyrite?	Au/oxidized till	N/A	<0.063 mm	Only two samples.
Yathkyed L., N.W.T.	Au in pyrite, arsenopyrite, rare fine visible gold. Coarse visible gold in vein.	Au/oxidized till	<5	4 to 2 mm, <0.125 mm	
Ferguson L., N.W.T.	N-Cu sulphides, Au in chalcopyrite	Au/gossan	0	<0.063 mm	Au in limonite-goethite
		Ni, Cu/oxidized till	<50	<0.002 mm	Background and anomalous sites
		Pt/gossan	0	<0.063 mm	Noisy data
		Pd/gossan	0	<0.063 mm	Pd in limonite-goethite
		Pd/oxidized till	<20	<0.063 mm	
Waverley, N.S.	Coarse scheelite in vein	W/oxidized till	250	2.0 to 0.5 mm, <0.002 mm	Soil profile
Strange L., Nfld.	Peralkaline granite, several exotic minerals, mostly coarse	Sr, Nb, Th, Be, Y/oxidized till			Till from mudboils
			500 to 6500	4 to 1 mm, <0.037 mm	
		Li/oxidized till	500 to 6500	4 to 2 mm	
		Pb, U/oxidized till	500 to 6500	<0.037 mm	
Kazan Falls, N.W.T.	Vein-type U-Cu-Pb	Cu, Pb/oxidized till	50 to 100	<0.002 mm	Till from mudboils

sieves of the following sizes: 2.0, 1.0, 0.5, 0.25, 0.125, 0.063 and 0.037 millimetres. Fractions coarser than 0.063 millimetres were ground to powder prior to analysis. When the samples were adequately large, a -0.002-millimetre fractionwas recovered by centrifuging and decantation of a separate portion of each original sample.

Heavy minerals were recovered from the 0.25 to 0.063-millimetre fraction of selected samples using methylene iodide (s.g. = 3.3) as the heavy liquid. These separates were examined with a scanning electron microscope (SEM) using displays of both secondary and backscatter electron images to guide the examination and photography. Qualitative analyses of grains observed in the displays were obtained using energy dispersive X-ray spectrometry.

Gold analyses were performed on most samples by the fire assay - atomic absorption (FA-AA) technique. Ten to fifteen grams of sample were analyzed, except for the -0.002-millimetre fraction, of which only 1.0 to 2.5 grams were available for analysis. Analyzed weights were 5 to 10 grams for a few small samples. Some aberrant results may have resulted from analysis of such small samples. A number of the gold analyses and all the platinum group analyses were performed by the fire assay - inductively coupled plasma - atomic fluorescence spectroscopy method, following sample digestion in aqua regia. Tungsten analyses were performed by colorimetry after sintering. Analyses for zirconium, niobium, thorium, beryllium and yttrium were by X-ray fluorescence. Lithium, copper, nickel and lead analyses were carried out by atomic absorption after aqua regia digestion.

OBSERVATIONS

GOLD

In determining the residence sites of gold in till, consideration must be given to the original form of the gold (Table 15-1). Although base metals are held normally in sulphide and silicate minerals (Shilts, 1984), gold may have originally been native or tied up in oxide, sulphide or silicate minerals. Consideration must also be given to the possibility of remobilization and reprecipitation of gold during weathering.

At Waverley, Nova Scotia, quartz-carbonate veins in Meguma Group greywackes contain coarse-grained native gold, scheelite and arsenopyrite. Oxidized till was collected from shallow test pits (<1 m) at several distances down-ice from the deposit (Figure 15-1). Close to the deposit, most of the grain-size fractions are gold-rich. Down-ice from the deposit, the overall gold content of the till declines sharply, with some exceptions, and the finer fractions (<0.063 mm) are the most consistently auriferous grain sizes. Only in the most gold-rich sample was particulate gold evident in an SEM search of sand-sized heavy minerals. Grains of gold were not found in searches of finer fractions of this sample. Based on the SEM studies, it appears that most of the gold in these weathered samples is present in an adsorbed form on secondary iron and manganese oxides and hydroxides, and on phyllosilicates. It also appears that a fine fraction such as -0.063 millimetre (-230 mesh) would be the most suitable for analysis of samples collected in the Meguma Terrane, coupled with panning or tabling of large samples, which has been shown by MacEachern and Stea (1985) to be an effective addition to geochemical analyses in this terrane.

At Onaman River, near Beardmore, Ontario, copper-silver-gold mineralization carried its gold in chalcopyrite and pyrite. In six exploration trenches through the dispersal train derived from this deposit, gold content was found to vary with the copper and silver contents of the till (DiLabio, 1982b). Results of detailed sampling of a soil profile in the dispersal train are shown in Figure 15-2. Generally, gold levels in the six samples increase up the soil profile, and in the majority, the most auriferous fractions are the finest; however, gold is also enriched in coarser grain-size fractions, which consist predominantly of locally derived rock fragments. Regardless of the gold content or the depth of the samples in the soil profile, the fractionation curves have roughly the same shape and they all display gold enrichment in fine fractions, presumably because the gold released during weathering of the sulphides is very fine grained (native) or is absorbed on fine-grained phases. This gold enrichment in fine sizes is characteristic of the behaviour of chalcophile elements (mainly released from weathering sulphides) in oxidized till (DiLabio, 1979, 1981; Shilts, 1984), lending support to the idea that gold is remobilized in the soil profile and may behave like some base metals during weathering.

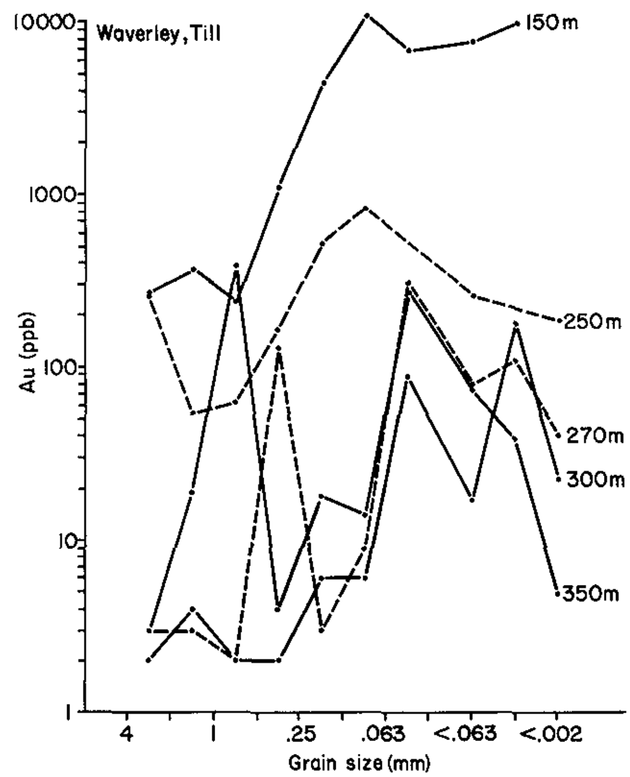

Figure 15-1. Abundance of gold *versus* grain size of analyzed fraction of oxidized till at several distances down-ice from the gold deposit at Waverley, Nova Scotia.

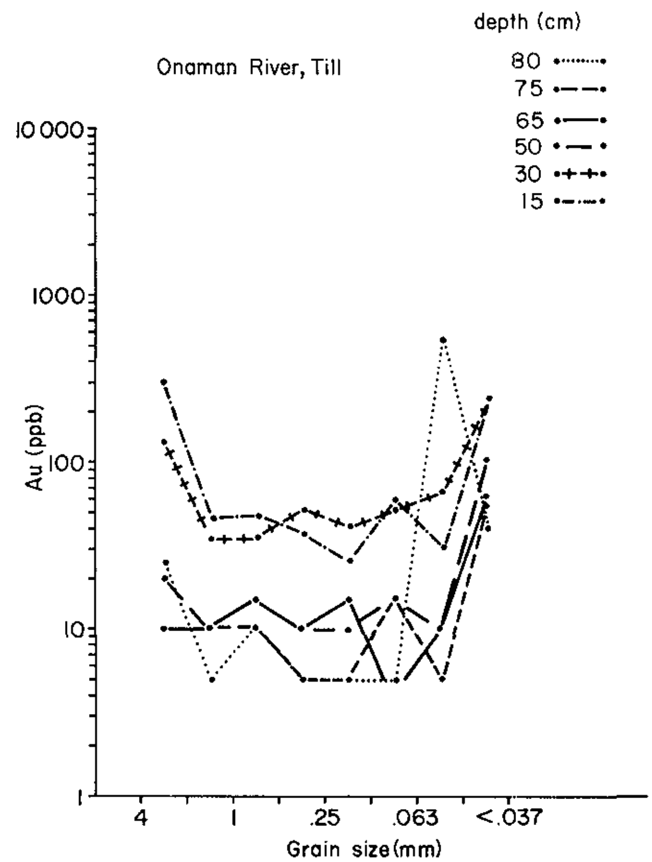

Figure 15-2. Abundance of gold *versus* grain size of analyzed fraction of oxidized till at varying depths below surface in a dispersal train at Onaman River, Ontario.

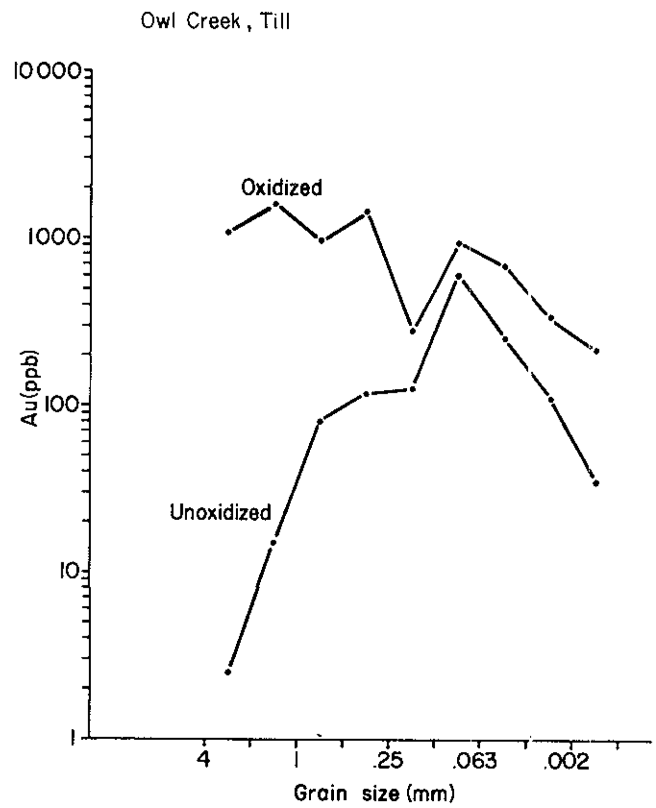

Figure 15-3. Abundance of gold *versus* grain size of analyzed fraction of a sample of unoxidized till and its oxidized equivalent at the Owl Creek mine, Timmins, Ontario.

At the base of the thick Quaternary sequence overlying the Owl Creek gold deposit near Timmins, Ontario, an unoxidized, green, muddy till is preserved. Within this till, discrete decimetre-sized cigar-shaped lenses of its oxidized equivalent are present. The unoxidized green till contains abundant fresh pyrite (the host for gold in the ore deposit) and Paleozoic carbonate pebbles and granules; pyrite and carbonate clasts within the oxidized lenses are decomposed. Fractionation curves for the two types of till (Figure 15-3) show the oxidized till is much more auriferous in all size fractions than the unoxidized till, where strong gold enrichment is present in the fine sand and silt fractions of the unoxidized till. The extra gold in the oxidized till cannot be accounted for only by the volume loss caused by the decomposition of the pyrite and carbonates. It appears that the till has been oxidized by groundwater flowing along the till-bedrock interface while at the same time gold has been added to the oxidized till. Because the oxidized till is not part of a paleosol, ancient surficial weathering is probably not the cause of the oxidation. It is not known how long this process may have operated, but it may have been a short period (since deglaciation) or a long period, because the sequence at the Owl Creek mine spans the entire duration of the last glaciation (Bird and Coker, 1987; DiLabio *et al.*, 1988).

Scanning electron microscopy indicated that the sand-sized heavy minerals in the unoxidized till at the Owl Creek mine are dominated by euhedral pyrite, which explains the peak in gold content in the fine sand fraction. Gold grains were not observed, although they may be present because the ore contains only a small amount of free gold. Heavy minerals in the oxidized till are dominated by earthy limonite-goethite grains and corroded pyrite remnants. Again, no gold grains were evident. Most likely the gold in the oxidized till is tied up in the secondary iron oxides and hydroxides. These secondary iron-rich grains were observed in all grain-size ranges, and appear to have acted as traps for gold released from oxidizing pyrite and for gold transported in groundwater through the oxidized till.

In studies in the Grenville metasedimentary belt of southeastern Ontario, Gleeson *et al.* (1989) have shown that the -0.063-millimetre fraction of the C-horizon of soil developed on till is an effective fraction for analysis in this region. Fractionation of an anomalous and a near-background sample from their study (Figure 15-4) supports their results. The enrichment of gold in the finer grain sizes relative to the coarse sizes reflects the complete decomposition of the gold-bearing pyrite in the soil in this area. It is not known in what form the gold was held in the pyrite, before weathering.

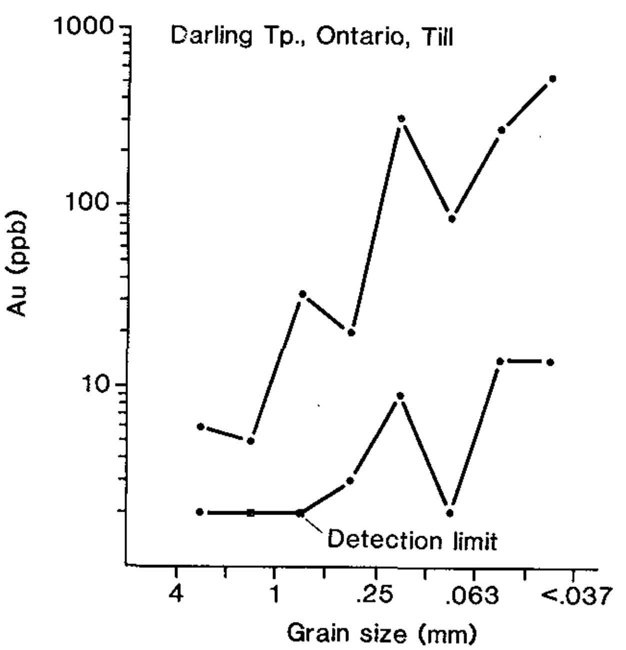

Figure 15-4. Abundance of gold *versus* grain size of analyzed fraction of oxidized anomalous (upper curve) and near-background (lower curve) till in Darling Township, Ontario.

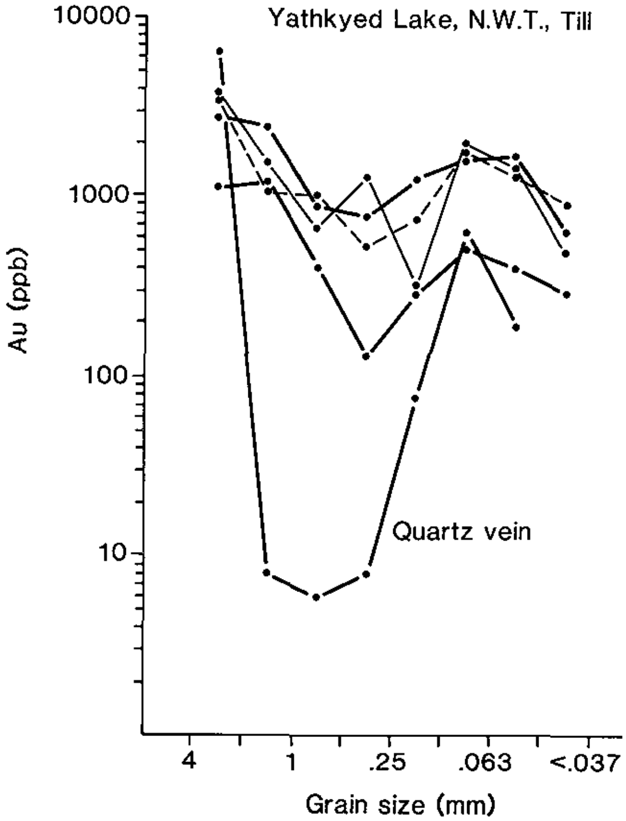

Figure 15-5. Abundance of gold versus grain size of analyzed fraction of oxidized till from near a quartz vein (one sample) and from near a stratiform deposit (four samples) near Yathkyed Lake, District of Keewatin, N.W.T. Curves were drawn with different patterns for clarity.

A small number of till samples collected near gold occurrences in periglacial terrain were also used for this study. Samples were collected from mudboils in tundra near Yathkyed Lake, District of Keewatin. Two deposits are represented on Figure 15-5. The first is a quartz vein containing abundant coarse, visible gold. One sample of till from this site shows wildly divergent gold levels ranging from over 6000 ppb in the 4 to 2-millimetre fraction down to 6 to 8 ppb in the next three finer fractions. This must result from the "nugget effect" in the coarser fraction in which the presence or absence of a few gold grains can lower reproducibility of results from subsample to subsample. Anomalous, but erratic gold levels were found in the three finest fractions analyzed. This site would require more sampling overlying and down-ice from the deposit to determine if consistent patterns exist in the fractionation curves. Larger weights (*e.g.*, 30 g) for analysis would help overcome the nugget effect.

At the second site in this district, four samples were collected overlying gold mineralization in the form of fine blebs in arsenopyrite and as free gold along grain boundaries. Consistently, fractionation curves for these samples (Figure 15-5) show gold enrichment in all grain size ranges. The highest values occur mainly in the coarser sizes (>0.5 mm) and in the finer sizes (<0.125 mm), with lowest values in the medium sand range. The coarse peak for gold probably represents gold-rich rock fragments and surviving arsenopyrite fragments and the fine peak represents gold released during the weathering of the arsenopyrite as well as silt-sized free gold grains.

It has previously been shown that the gossan developed on the nickel-copper massive sulphide occurrence at Ferguson Lake, District of Keewatin, is depleted in nickel and copper (DiLabio, 1979). Analysis of mineralized samples showed that small concentrations of gold (20 to 200 ppb) are contained in the primary sulphide minerals. Reanalysis of the gossan samples shows that significant amounts of gold (Figure 15-6) have remained in the gossan during postglacial weathering (about 7000 years in this area). During this time, the sulphide-rich rock has decomposed to a depth of at least 2 metres and the resultant gossan is an iron-rich mud retaining little of its original textures. Gold levels in the samples increase in the finer grain sizes and four out of five samples have their maximum gold content in the finest fraction. This probably reflects adsorption of the gold on or within the fine-grained secondary iron phases.

Table 15-1 summarizes the data on gold residence sites discussed in this study. Only one sample of unoxidized till was available (Owl Creek). In that sample, gold is most abundant in the grain-size range that contains abundant auriferous pyrite, 0.125 to 0.063 millimetre. More work is required on unweathered till from a variety of sources before generalizations can be made about residence sites. In oxidized till, gold seems to be most abundant in fine size ranges, usually the ≤0.063-millimetre fraction. This agrees with the findings of Averill (1988) in a Canada-wide study, with

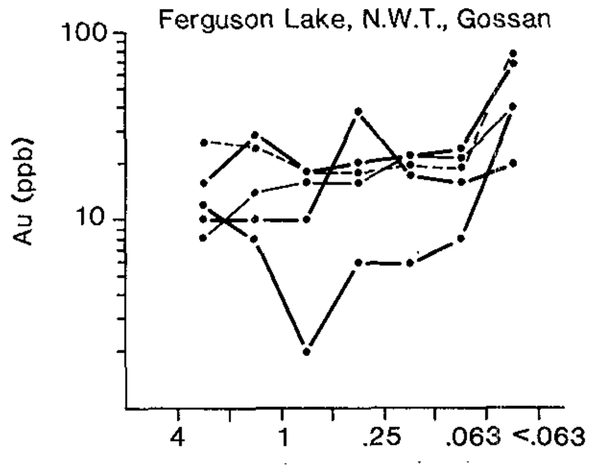

Figure 15-6. Abundance of gold *versus* grain size of analyzed fraction of five samples of gossanous sediment from the Ferguson Lake nickel-copper occurrence, District of Keewatin, N.W.T.

Shelp and Nichol (1987) for till associated with the Owl Creek mine and the Hemlo, Ontario deposits, and with the findings of Sopuck *et al.* (1986) for till derived from gold deposits in the La Ronge area of northern Saskatchewan. At most sites in the present study, free gold was originally fine-grained, gold liberated from sulphides during weathering was probably fine grained, and gold adsorbers such as secondary iron oxides were also fine grained. At every site, analysis of the -80 mesh (-0.177 mm) fraction used traditionally in geochemical surveys would have resulted in lower gold values than analysis of a finer fraction, because of the presence of a high proportion of geochemically "inert" minerals (*e.g*, quartz and feldspar, in the fine sand fraction; Dreimanis and Vagners, 1971). Because an adequate volume of sample in the -0.063-millimetre or -0.037 millimetre-range can be recovered simply and inexpensively by dry sieving, it is recommended that either of these fractions be used for geochemical analysis of oxidized till. Table 15-1 shows that most samples were collected close to the mineralized source. Further work is planned to fractionate samples at increasing distances down-ice from their sources to test the persistence of the residence sites as well as sampling additional sites. Sequential leaching could be used to determine which phases are hosting the gold.

PLATINUM GROUP ELEMENTS

The only available set of data on the residence sites of platinum group elements (PGE) comes from the gossan samples from Ferguson Lake described previously with respect to gold content. In addition, one till sample was also found to contain significant palladium levels. In this area, sulphide-rich rock was found to contain up to 650 ppb platinum and 2600 ppb palladium (author's data and those of Jonasson *et al.*, 1987). In the gossan samples, there is a striking difference between the distributions of platinum and palladium (Figure 15-7). Platinum levels are wildly divergent, ranging from less than 10 ppb to 100 to 1000 ppb in adjacent fractions of the same samples. In contrast, palladium levels in the gossan are more uniform, with several sample levels near 1000 ppb in most fractions. The maximum palladium content of all samples occurs in the finest fraction (-0.063 mm). Because of the highly decomposed nature of the gossanous mud, the palladium pattern is interpreted to reflect palladium residence in fine-grained secondary iron oxide and hydroxide phases which coat grains of all sizes, occur as earthy grains, or as free powder in the finest grain sizes. The platinum pattern, on the other hand, may indicate that platinum occurs as randomly distributed micronuggets hosted in coarser grains and present as fine free grains. The till sample shows maximum palladium levels in the finest fraction. Together with the data on the gossan samples, this implies that a fine fraction (*i.e.*,<0.063 mm) is the most suitable for palladium analysis in geochemical exploration. Analysis of this fraction for platinum is also indicated (Figure 15-7). A number of new sample suites will be tested to widen the PGE database. Scanning electron microscope examination of the samples will be carried out to attempt to isolate a platinum-bearing phase.

LITHOPHILE ELEMENTS

The distribution of tungsten in till samples collected from a section at Waverley, Nova Scotia, follows a similar pattern from sample to sample (Figure 15-8). Tungsten is most abundant in the 2 to 0.25-millimetre and -0.002-millimetre size ranges. Originally, this bimodal distribution of residence sites was thought to represent the presence of sand-sized scheelite grains and scheelite powder from glacial abrasion of this relatively soft, cleavable mineral, to produce the second mode in the -0.002-millimetre fraction (DiLabio, 1982a). Recently, however, Johansson *et al.* (1986) have described a site in Finland where scheelite is broken down by acidic soil water, a process that may also have taken place at Waverley, where the soil is strongly acidic. Very large volumes of arsenopyrite are decomposing and acidifying the soil, as indicated by arsenic contents of 1000 to 10 000 ppm, in the -0.063-millimetre fraction. No scheelite grains are present in samples collected within 135 centimetres of the surface, although small amounts of tungsten are detected in the -0.002-millimetre fraction. Dissolution of the scheelite is supported by the heavily corroded appearance of scheelite observed in SEM imagery on the deeper samples. The tungsten released during the weathering process has apparently been translocated downwards in the section and adsorbed onto the fines in the lower part of the section, probably as iron-rich phases in grain coatings and in very fine mud.

Because the -0.002-millimetre fraction is usually enriched in tungsten, this fraction should be considered the most suitable for geochemical analysis. If the sample preparation laboratory is not equipped to recover very fine grained fractions by centrifugation and decantation, a coarse fraction that can be recovered by simple sieving methods could be substituted (*e.g.* , 0.05 mm at Waverley). However, coarse fractions are prone to the nugget effect because of the small number of grains they contain per sample. Therefore, the 0.05 to 0.25-millimetre fraction is recommended for

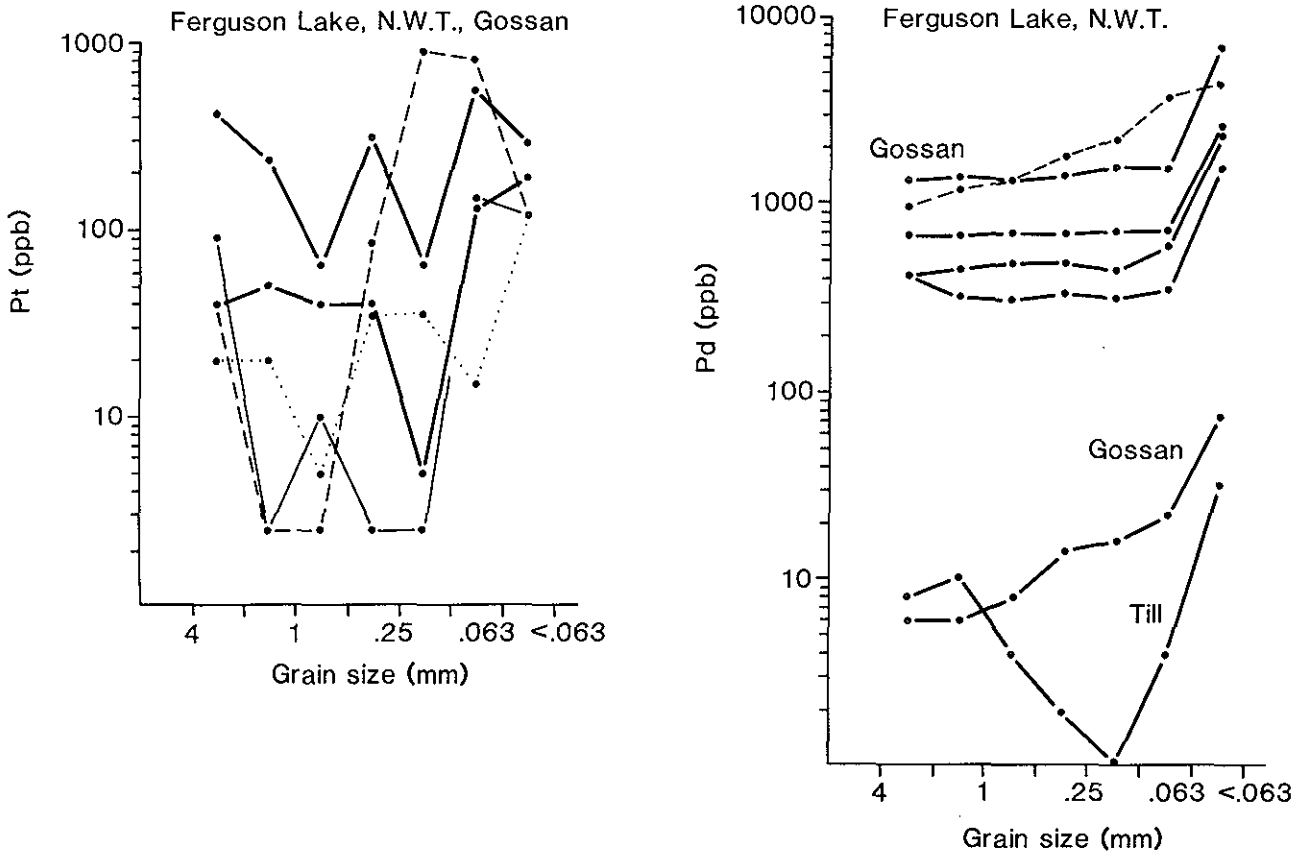

Figure 15-7 . Abundance of platinum (in 5 samples) and palladium (in 7 samples) *versus* grain size of analyzed fraction of gossanous sediment and of till (one sample, Pd only) from the Ferguson Lake nickel-copper occurrence, District of Keewatin. Curves are dashed and dotted for clarity.

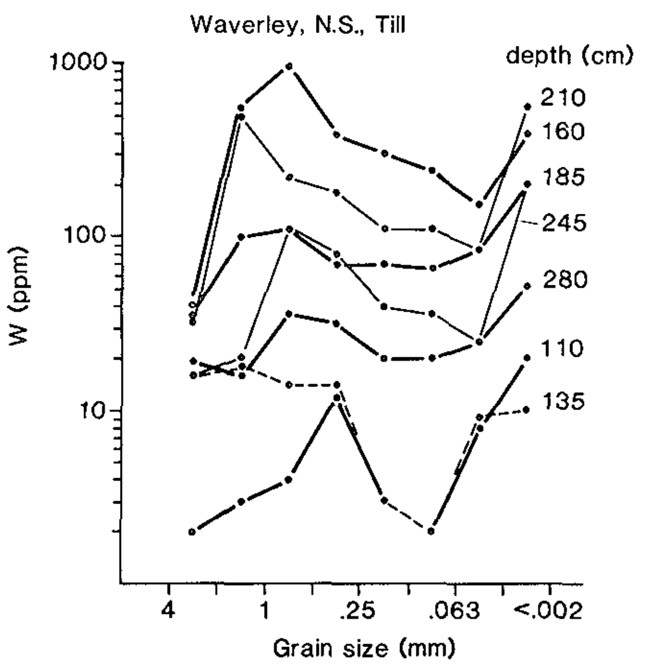

Figure 15-8 . Abundance of tungsten *versus* grain size of analyzed fraction of oxidized till at varying depths below surface at Waverley, Nova Scotia.

analysis (Figure 15-8). Coker *et al.* (1988) have shown that most fractions of till at the Great Gull scheelite prospect in Newfoundland are adequate for analysis. Snow and Coker (1987) also found that all fractions of till were equally anomalous in tungsten levels at the Sisson Brook deposit, New Brunswick. Clearly, more work is required on defining the residence sites of scheelite in till.

At the Strange Lake alkalic complex, Labrador, the lithophile elements niobium, yttrium, beryllium, zirconium, thorium and lithium are present as coarse-grained exotic minerals such as gittinsite, pyrochlore, zircon, thorite, elpidite and armstrongite in a late-stage differentiate at the top of the pluton (Miller, 1986). Glaciation of the mineralized part of this pluton has given rise to a classic dispersal train over 40 kilometres long (Batterson *et. al.*, 1985; Batterson, 1989). Because the area is in the tundra, relatively fresh oxidized till samples were collected from the active centres of mudboils, which consist of periglacially churned till. Samples from background and anomalous sites were chosen for this study (Figure 15-9). All of the elements with the exception of lithium, lead and uranium show similarly shaped curves of metal abundance *versus* the analyzed grain-size range.

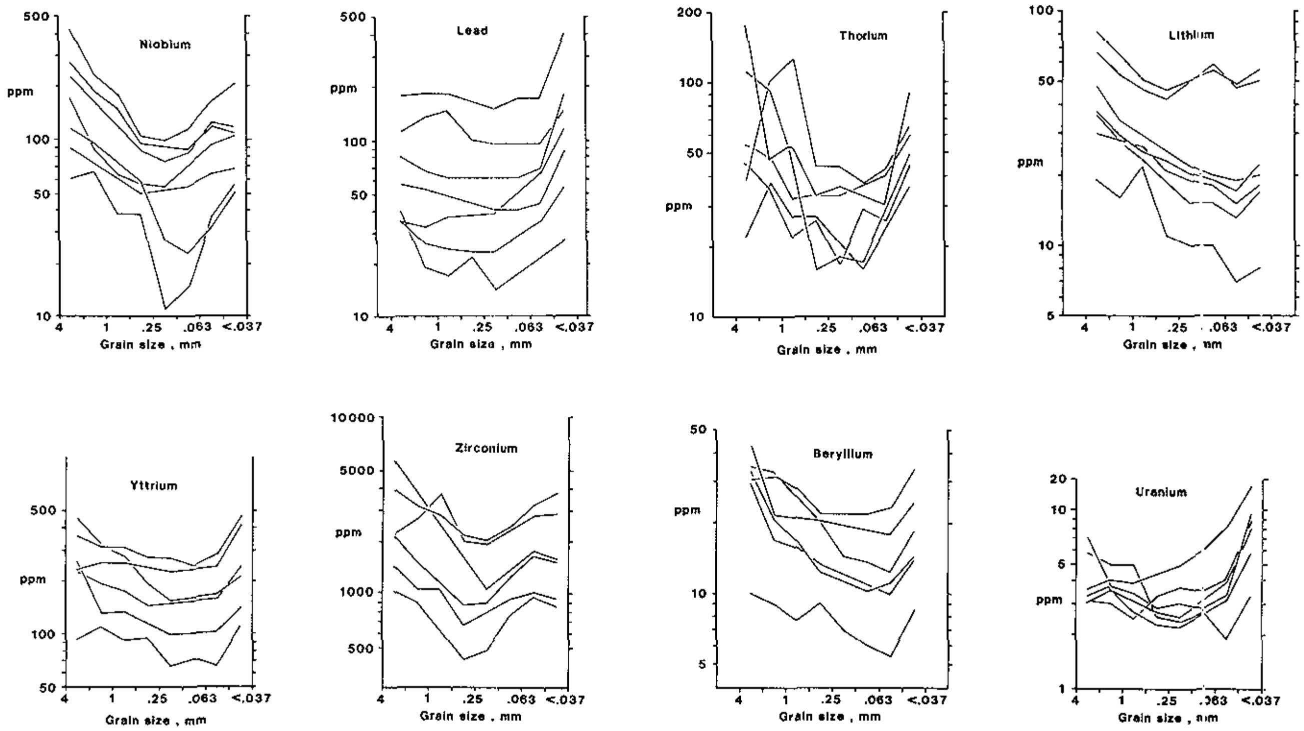

Figure 15-9. Abundance of Nb, Y, Be, Zr, Th, Li, Pb and U *versus* grain size of analyzed fraction of seven samples of oxidized till in the Strange Lake dispersal train, Labrador.

Curves of abundance for niobium, yttrium, beryllium, zirconium and thorium (Figure 15-9) show peaks in the coarsest (rock fragments) and finest sizes (mainly silt-sized mineral grains), and all show lower metal levels in the intervening sizes. The fact that the exotic minerals are chemically stable is evident from SEM observations which show a lack of corrosion on pyrochlore and zircon grains despite the fact that they have been exposed to weathering for about 7000 years. It is possible that glacial comminution ground some of the coarse minerals directly to fine sizes without leaving much in the intervening sizes. It is also possible that there are coarse and fine primary grain size ranges of the exotic minerals in the alkalic complex.

Curves for lithium abundance are highest in the coarsest sizes and decline into the fine sizes. It is not known which minerals contain the lithium and why its pattern deviates from the other elements. In contrast to the other elements, lead and uranium show patterns of preferential metal residence in the finest grain sizes (Figure 15-9), regardless of whether the sample had an overall high or low metal content. This pattern is similar to that observed for base and ferrous metals and uranium in other regions (DiLabio, 1979; Shilts, 1984). The trace elements were originally contained in unstable minerals, such as sulphides or uraninite, which broke down in the solum, as a result of postglacial weathering, to produce secondary phases that are fine grained and/or release the trace elements for adsorption on other fine-grained phases.

Based on the Strange Lake example, analysis of the finest fraction that can be recovered in sufficient quantity is recommended for the lithophile elements. No tests have been performed on the clay (-0.002 mm) fraction of these samples because of the large sample weights (15 g) that were required for analysis. However, testing of the clay fraction could be useful because it is known to be applicable in geochemical surveys for base metals and uranium. As the analysis of the -0.037-millimetre or -0.063-millimetre fraction would be adequate to map the dispersal train, the extra expense of recovering clays from till is not warranted in this particular case.

BASE METALS

The six till samples from Onaman River, discussed above in terms of their gold content (Figure 15-2), were also analyzed for copper (Figure 15-10). Although no chalcopyrite survives in the till, all fractions of the six samples are copper rich because of secondary malachite grains and coatings evident in every size range. The gentle methods used in wet sieving the samples did not destroy the malachite. There is no preferential enrichment or depletion in the finest fraction (-0.037 mm). This example illustrates how the presence of secondary minerals can distort primary (detrital) distributions of trace elements in till.

At the Ferguson Lake occurrence, four till samples were analyzed, representing sites both inside and outside the dispersal train. The residence site of copper and nickel (Figure 15-11) is clearly in the finest size range analyzed (-0.002 mm). Metal levels in this fraction are orders of magnitude higher than in all the coarser fractions. Because sulphide grains in till are broken down by weathering processes, the

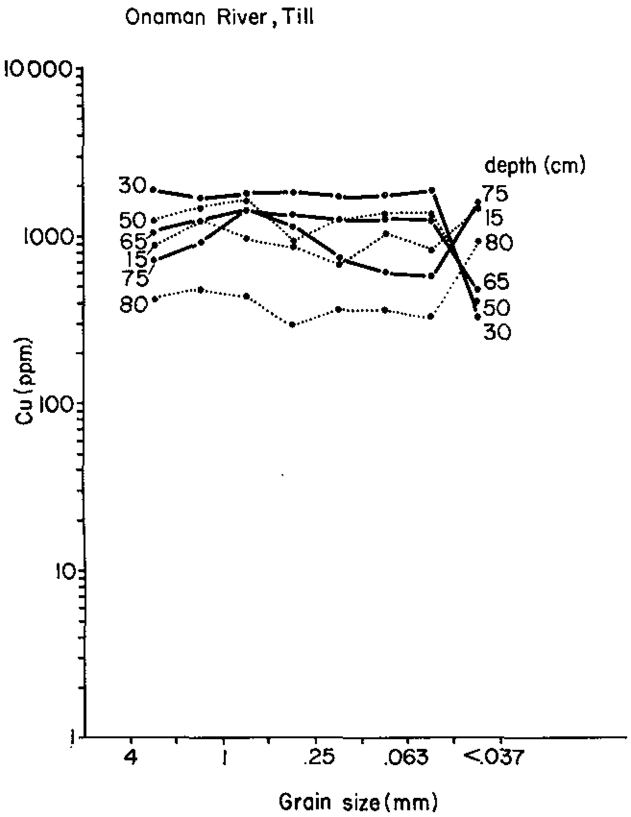

Figure 15-10. Abundance of copper *versus* grain size of analyzed fraction of oxidized till at varying depths below surface in a dispersal train at Onaman River, Ontario.

trace metals are most likely adsorbed on the phyllosilicate minerals present in the fine fraction.

Accessory base metal sulphides are present in vein-type uranium mineralization at Kazan Falls, on the Kazan River, Northwest Territories. Copper and lead contents of the mineralized rock samples reach 0.12% copper and 0.64% lead (DiLabio, 1979). Results from four till samples from within the dispersal train show that copper and lead (Figure 15-12) are at their highest levels in the finest fraction (-0.002 mm). This pattern is also interpreted as a reflection of metal adsorption on phyllosilicates in the finest fraction.

CONCLUSIONS

Fractionation experiments of this type are relatively easy to perform and can provide valuable information in the initial stage of a geochemical exploration program. The choice of optimum grain-size fractions for analyses of till in a given area should be made on the basis of such experiments, conducted as part of an orientation survey. The results have the additional value of indicating the original residence sites of trace elements prior to recycling of the till itself and the adsorbed trace elements it holds into modern stream or lake sediments.

Research is now in progress to identify some of the primary and secondary mineral phases that are the preferential

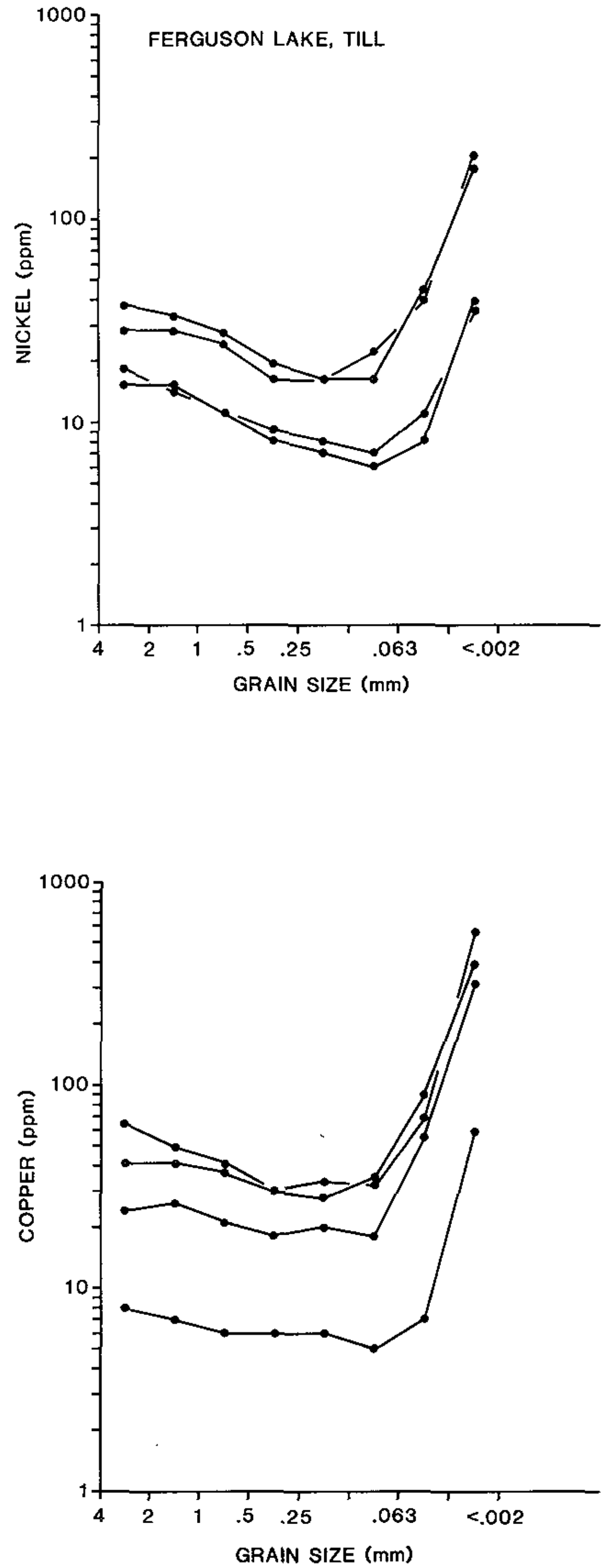

Figure 15-11. Abundance of nickel and copper *versus* grain size of analyzed fraction of oxidized till at Ferguson Lake, N.W.T.

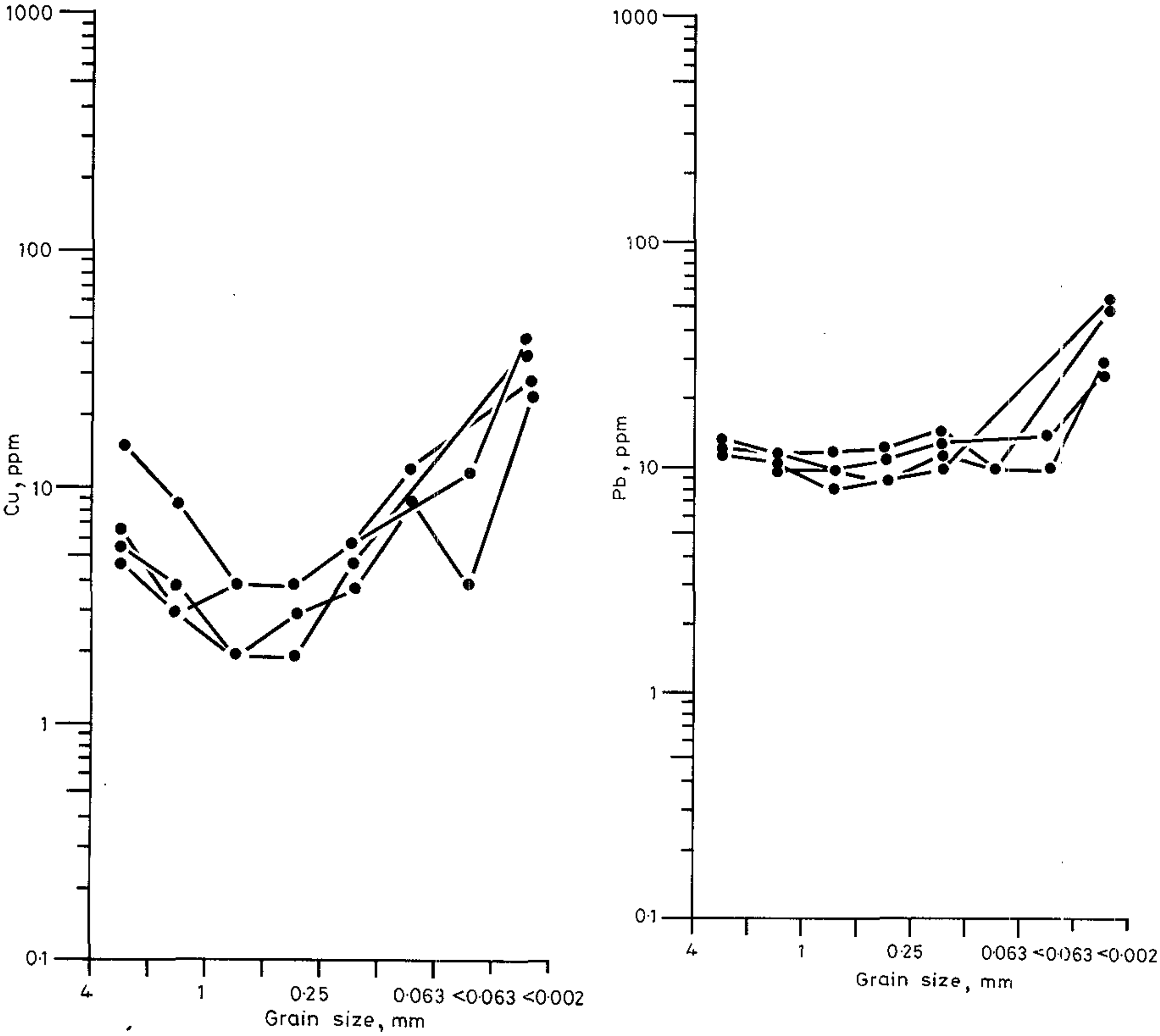

Figure 15-12. Abundance of copper and lead *versus* grain size of analyzed fraction of oxidized till at the Kazan Falls uranium occurrence, Kazan River, N.W.T.

residence sites of the trace elements, particularly in weathered samples. Future work should also recalculate trace element data to take into account variations in grain size distribution of the till samples, as was done by Dreimanis and Vagners (1971), DiLabio (1981), Sopuck *et al.* (1986) and Shelp and Nichol (1987). This approach permits the identification of fractions that may hold the bulk of the metal or mineral in a sample, but because the fractions contain much inert sediment they may be overlooked. This becomes important when one attempts to recover a particular mineral using sluice, shaking table or heavy liquid separation methods.

ACKNOWLEDGMENTS

I thank W.B. Coker for critically reading an early draft of the manuscript and P.J. Henderson for valuable comments on the final version. Samples were donated to this study by: V.N. Rampton, Terrain Analysis and Mapping Services, Stittsville, Ontario; Falconbridge Ltd., Timmins, Ontario; and K. Reading, Thornhill, Ontario.

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GEOCHEMICAL PARTITIONING IN TILL

W.W. Shilts, Geological Survey of Canada

INTRODUCTION

It has long been known that the various processes associated with glacial crushing and abrasion of bedrock, and of clasts undergoing glacial transport, reduce minerals to characteristic sizes, determined largely by their original grain size, hardness, cleavage, and the cementation or metamorphic and igneous history of their source rocks. Dreimanis and Vagners (1971, 1972) expressed this phenomenon elegantly by introducing the concept of "terminal mode" for the optimum grain size to which a mineral can be reduced, given the force and energy typically available in the glacial environment. Thus, hard, uncleaved or poorly cleaved minerals such as quartz, feldspar, garnet, pyrite and magnetite dominate either the medium or the fine sand fraction of glacial sediments, depending on their grain size in the source rocks; calcite, dolomite and gypsum have their terminal modes in the silt sizes because of their softness or good cleavage; clay minerals, micas and other phyllosilicates, serpentine, and hematite, because of their excellent cleavage, fine original grain size, and extreme softness, dominate the sub-10-micron sizes, particularly the clay-sized fraction below 4 microns. Quartz, because of its ubiquity and its high concentration in crustal bedrock and glacial sediments derived from it, is found as discrete, monomineralic particles in all grain sizes from decimetres to microns. Nevertheless, quartz is, as the terminal mode theory would predict, most common in the fine sand fraction where it comprises, with feldspar, typically more than 95% of all grains.

Because different minerals are characteristic of different size fractions of till, it follows that minerals' individually differing chemistry will be reflected by a typical geochemical signature for each grain size, depending on the dominant mineral(s) in that grain size. In analyzing tills, because of their typically wide range of grain sizes, samples are necessarily truncated at some upper size limit, and, unless special sieving, centrifuging, filtering, or heavy liquid techniques are employed, the sample analyzed comprises a wide range of grain sizes. If a wide range of grain sizes is used, then one or another size may dominate the chemistry of the fraction chosen for analysis. If the proportion by weight of a particular size fraction varies for sedimentological reasons, that is varying processes of deposition, post-depositional reworking etc., it is possible that compositional variations, and therefore geochemical variations, may not represent the provenance of the samples. In the case of varying grain-size distributions related to varying sedimentary processes, the geochemical analyses may actually represent nothing more than textural variations (Figure 16-1; Shilts, 1971). As the objective of geochemical sampling programs, whatever their ultimate goal (exploration, environmental), is to reflect provenance of glacial sediments, this uncontrolled facies and process-related variation is not always desirable. The

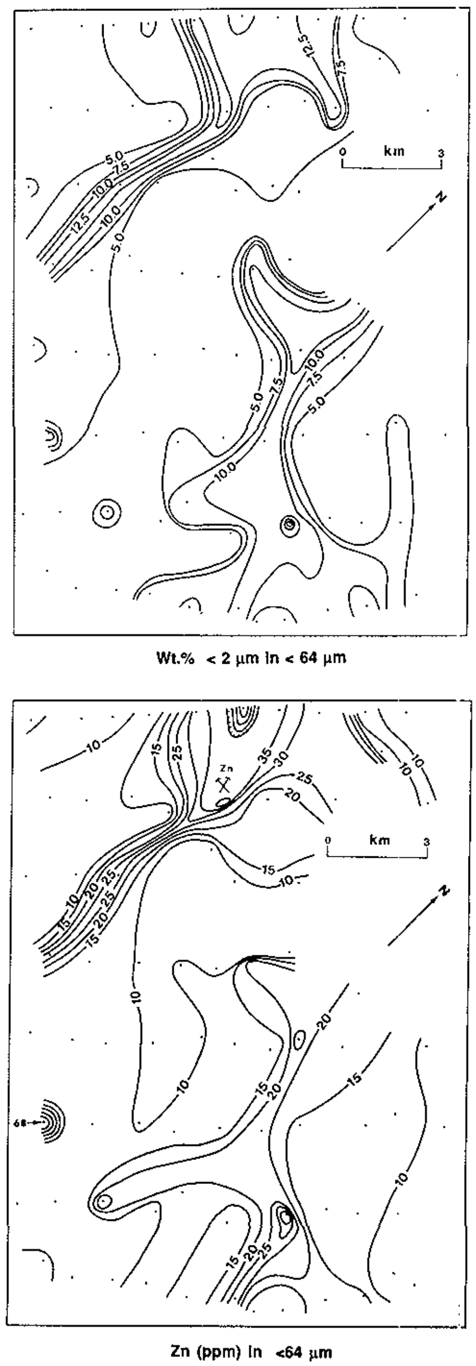

Figure 16-1. Maps comparing patterns of areal variation of Zn in silt + clay fractions with weight percentage of clay-sized particles in silt + clay fractions of till from Carr Lake area, District of Keewatin. Note how partitioning of Zn into clay fractions overwhelms provenance signal from zinc mineralization shown by crossed picks (modified from Shilts, 1971).

author and colleagues have pointed this out in a series of papers written in response to difficulty in interpreting texture-generated geochemical anomalies in regional drift geochemical sampling programs on the Canadian Shield and in the Appalachian Mountains of Québec (Shilts, 1971, 1973, 1975, 1984, 1991, 1993; DiLabio, 1982: Ridler and Shilts 1974; Klassen and Shilts, 1977).

Among the most difficult minerals to accommodate in an analytical and sample processing scheme are those that dominate the fraction of till finer than about 10 microns. These minerals are dominated by phyllosilicates by virtue of the originally fine crystallite size and their excellent cleavage. Because of the distinctive physico-chemical characteristics of phyllosilicates, that is large internal surface or reaction area, high exchange capacity, and 'loose' lattice structure that may accommodate cations with a wide range of ionic radii, they can dominate the chemistry of a sample that has been artificially truncated at coarser grain sizes by sieving or other physical separation techniques. In fact, it has been my experience that most metal derived from till samples containing a wide range of grain sizes usually resides predominantly in the sub-4-micron fraction. As it is possible to trace geochemical signatures of orebodies in dispersal trains by analyzing separates that include this chemically dominant fraction, there must be some signal in the fraction that is related to provenance.

Even though exploration targets may be composed of sulphide minerals, fragments of which are almost never found in the sub-4-micron fraction, the phyllosilicate fraction is commonly a useful source of geochemical information of sufficient coherence to generate recognizable dispersal patterns (Shilts, 1975, 1984). If high metal levels associated with the finest fractions of oxidized till in dispersal trains were due solely to destruction of transported sulphide minerals (or other labile minerals) by post-depositional weathering processes and subsequent adsorption of their cations onto clay particles or into finely divided secondary iron and manganese oxyhydroxides (Shilts and Kettles, 1990), the "mystery" of high metal concentrations in the clay fraction would be solved. However, high metal levels also are observed in unweathered tills, either permanently frozen or permanently below the groundwater table (Shilts, 1980). Also, many weathered, sulphide-free samples of till that was rich in sulphide minerals in its unweathered state, show no secondary enrichment of metal in clay-sized fractions (Shilts and Kettles, 1990). Furthermore, cations occurring in mineral phases that are relatively stable in the weathering environment (Sn, W, some Zn) are enriched in the clay fraction (Tables 16-1, 2, 3, 4, 5, 6, 7).

A striking example of the dominant influence of the chemistry of the clay (<2 μm) fraction over that of the coarse

TABLE 16-1
ANALYSES OF TILLS RICH IN ULTRAMAFIC DEBRIS

	Cr (ppm)			Ni (ppm)			As (ppm)		
Size fraction/element	A	B	C	A	B	C	A	B	C
Bulk Sample	--	284	1744	--	500	1600	--	8	4
2.0-6.0 mm	3320	400	1780	1050	880	1600	160	5	2
0.25-2.0 mm	3220	294	1852	970	556	1500	157	13	2
0.044-0.25 mm	2520	200	1980	745	267	970	162	4	3
0.004-0.044 mm	1856	236	1424	910	403	1020	245	16	5
0.001-0.004 mm	3560	274	1148	1200	743	2300	553	10	11
≤ 0.001 mm	--	256	1468	--	913	4100	770	13	12

(A) Basal till near an Archaean komatiite, central District of Keewatin
(B) Basal till near Paleozoic ophiolite complex, Québec Appalachian Mountains
(C) Flow till forming lateral moraine of modern glacier, on Mesozoic ophiolite complex, Swiss Alps near Zermatt.

Explanation for Table 16-1

Bulk Sample:	total sample finer than 6 mm.
2.0-6.0 mm	fraction almost wholly composed of rock fragments.
0.25-2.0 mm	fraction composed of mixture of rock fragments and mineral grains.
0.044-0.25 mm	sand and coarse silt; fraction composed almost wholly of mineral grains, dominated by quartz and feldspar (usually >90%).
0.004-0.044 mm	Silt; mineral grains dominated by quartz and feldspar.
0.001-0.004 mm	Clay; mineral grains dominated by phyllosilicates and other soft minerals.
< 0.001 mm	Clay and colloidal particles.

Note: multiply mm by 1000 to obtain μm as in text and in other tables and figures.

TABLE 16-2
SAMPLE 85SK 22265; OXIDIZED, SANDY, GRANITE-RICH TILL, NEAR TANGIER LAKE, NOVA SCOTIA

* Size fraction/ element	W (ppm)	Cu (ppm)	As (ppm)
Bulk Sample	500	106	8
2.0-6.0 mm	60	31	2
0.25-2.0 mm	360	53	3
0.044-0.25 mm	500	90	6
0.004-0.044 mm	550	167	13
0.001-0.004 mm	1800	500	45
< 0.001 mm	> 2000	609	80

TABLE 16-3
SAMPLE 90KAL-001: OXIDIZED, SLATE-RICH BASAL TILL OVERLYING GOLD-BEARING QUARTZ VEIN IN GABBRO, NEAR ST-MAGLOIRE, QUÉBEC APPALACHIANS

* Size fraction/ element	Au (ppb)	As (ppm)	Sb (ppm)
< 0.064 mm	624	207	0.6
0.064-2.0 mm	399	120	0.5
0.002-0.064 mm	838	215	0.7
< 0.002 mm	83	341	1.6

TABLE 16-4
SAMPLE 80AR-0772: SANDY, CLAY-POOR, PEBBLY TILL, GRENVILLE OF EAST ONTARIO

* Size fraction/ element	As (ppm)	Zn (ppm)	Cu (ppm)
Bulk Sample	42	56	15
2.0-6.0 mm	2	40	7
0.25-2.0 mm	21	38	8
0.044-0.25 mm	12	42	8
0.004-0.44 mm	189	65	16
0.001-0.004 mm	630	385	165
< 0.001 mm	--	830	440

TABLE 16-5
SAMPLE 85TR-041: TILL, COMPOSED MOSTLY OF WEATHERED, TIN-BEARING GRANITE, NEAR ROCKY BROOK, NEW BRUNSWICK

* Size fraction/ element	Sn (ppm)	U (ppm)	Mn (ppm)	Fe (%)	As (ppm)
Bulk Sample	20	5.2	175	1.0	<2
2.0-6.0 mm	21	1.9	83	0.3	<2
0.25-2.0 mm	20	3.5	169	1.0	<2
0.044-0.25 mm	41	4.3	400	1.4	2
0.004-0.044 mm	--	13.3	893	2.8	10
0.001-0.004 mm	82	11.8	1255	3.4	25
< 0.001 mm	--	11.3	1528	3.2	30

TABLE 16-6
SAMPLE 80SMA-192: NEAR-SURFACE BASAL TILL, CENTRAL DISTRICT OF KEEWATIN

* Size fraction/ element	Pb (ppm)	U (ppm)	Mo (ppm)	As (ppm)
Bulk Sample	136	1.7	8	23
2.0-6.0 mm	168	0.9	8	5
0.25-2.0 mm	74	1.1	4	7
0.044-0.25 mm	44	1.2	6	8
0.004-0.044 mm	102	5.5	6	25
0.001-0.004 mm	570	8.0	15	76
< 0.001 mm	1300	2.6	26	112

TABLE 16-7
SAMPLE 8-AR-0109: OXIDIZED, ICE-CONTACT, GRAVEL, POORLY SORTED, GRENVILLE OF EAST ONTARIO

* Size fraction/ element	Cu (ppm)	Ni (ppm)	Cr (ppm)
Bulk Sample	56	326	935
2.0-6.0 mm	36	387	1116
0.25-2.0 mm	27	213	690
0.044-0.25 mm	27	221	1093
0.004-0.44 mm	152	661	1284
0.001-0.004 mm	267	982	1212
< 0.001 mm	484	1228	1111

*See Table 16-1 for explanation.

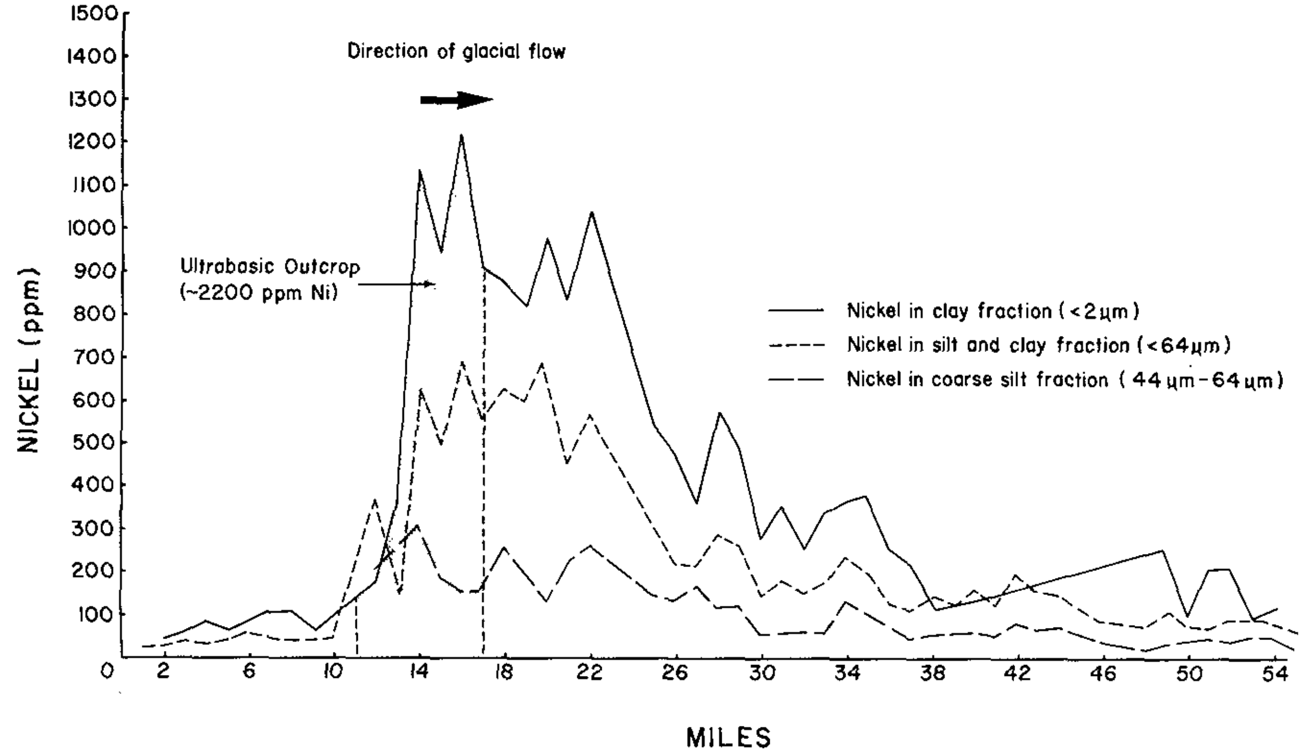

Figure 16-2. Profile of nickel concentrations in three size fractions of till along the axis of a dispersal train extending southeastward from ultramafic source outcrops near Thetford Mines, Quebec (modified from Shilts, 1991).

silt sizes is illustrated by Figure 16-2, which depicts the actual long profile (dispersal curve) of a nickel dispersal train from the ultramafic outcrops (serpentinized peridotite, pyroxenite) near Thetford Mines, Québec. In this example, nickel-bearing serpentine group minerals were preferentially concentrated in the clay fraction because of their softness. The coarse silt sizes (44-64µm) also contain serpentine, but its nickel signal is mostly obscured by the high concentrations of quartz and feldspar in this fraction, so that its geochemical dispersal signature is detectable only near the source outcrops. The signature of the -64-micron fraction falls between the clay and silt curves and reflects clearly the influence of the nickel concentration in its -2-micron component. The coarse silt accounts for only 17% of the nickel signal in the most nickel-rich samples. Though not depicted here, some clay separates from till down-ice from the ultramafic outcrops contained as much as 2800 ppm nickel, a concentration higher than that in the bulk analyses of the source rocks. In the source rocks, nickel-bearing phases are presumably diluted by other silicates.

PROCEDURE

Once the importance of understanding the relationship of the chemistry of the "clay" fraction (henceforth taken to mean <4µm or <2µm fraction) to till provenance was recognized, a program to study geochemical partitioning of till samples was undertaken in 1980, based on the analysis of a large number of clay separates from tills from diverse geological settings throughout Canada completed in the 1970s (Lindsay and Shilts, 1995, this volume). At about the same time, a group in Finland, recognizing the same phenomenon, undertook a similar partitioning study. The preliminary results of both of these studies were coincidentally published in a special issue of the Journal of Geochemical Exploration in 1984 (Shilts, 1984; Nikkarinen *et al.*, 1984). The present paper expands on those results and on a further discussion of them published in 1991 (Shilts, 1991).

In 1980, a suite of 30 glacial sediment samples and one gossan sample that had been processed in the Drift Sedimentology Laboratory of the Geological Survey of Canada was selected for partitioning studies on the basis of chemical compositions. Samples were chosen to represent anomalously high concentrations of most of the elements that were commonly determined at that time (Cu, Pb, Zn, Ni, Co, As, Ag, Cd, U, Hg); a number of samples with "normal" or background metal concentrations of these elements were also selected. The sediment samples came from a variety of geological terranes, Archean greenstone belts of central and northern Keewatin, Precambrian Grenville metasedimentary belts of eastern Ontario, the ophiolite belt of the Appalachian Mountains of southeastern Québec, and from modern till in the lateral moraine of Findeln Glacier in the ophiolite belt of the high Swiss Alps, near Zermatt. Over the years these samples were supplemented by flow till from near the zinc mines at Franklin Furnace, New Jersey, till overlying platinum group and nickel mineralization in northern Ungava and till overlying tin and tungsten prospects in New Brunswick and Nova Scotia, respectively. The samples as a whole included a few ice-contact gravel samples and a gossan, but were primarily of tills with a variety of textures. The tills and gravels included both obviously weathered and unaltered examples. The alteration status and facies of the samples are indicated on Figures 16-3 and 4.

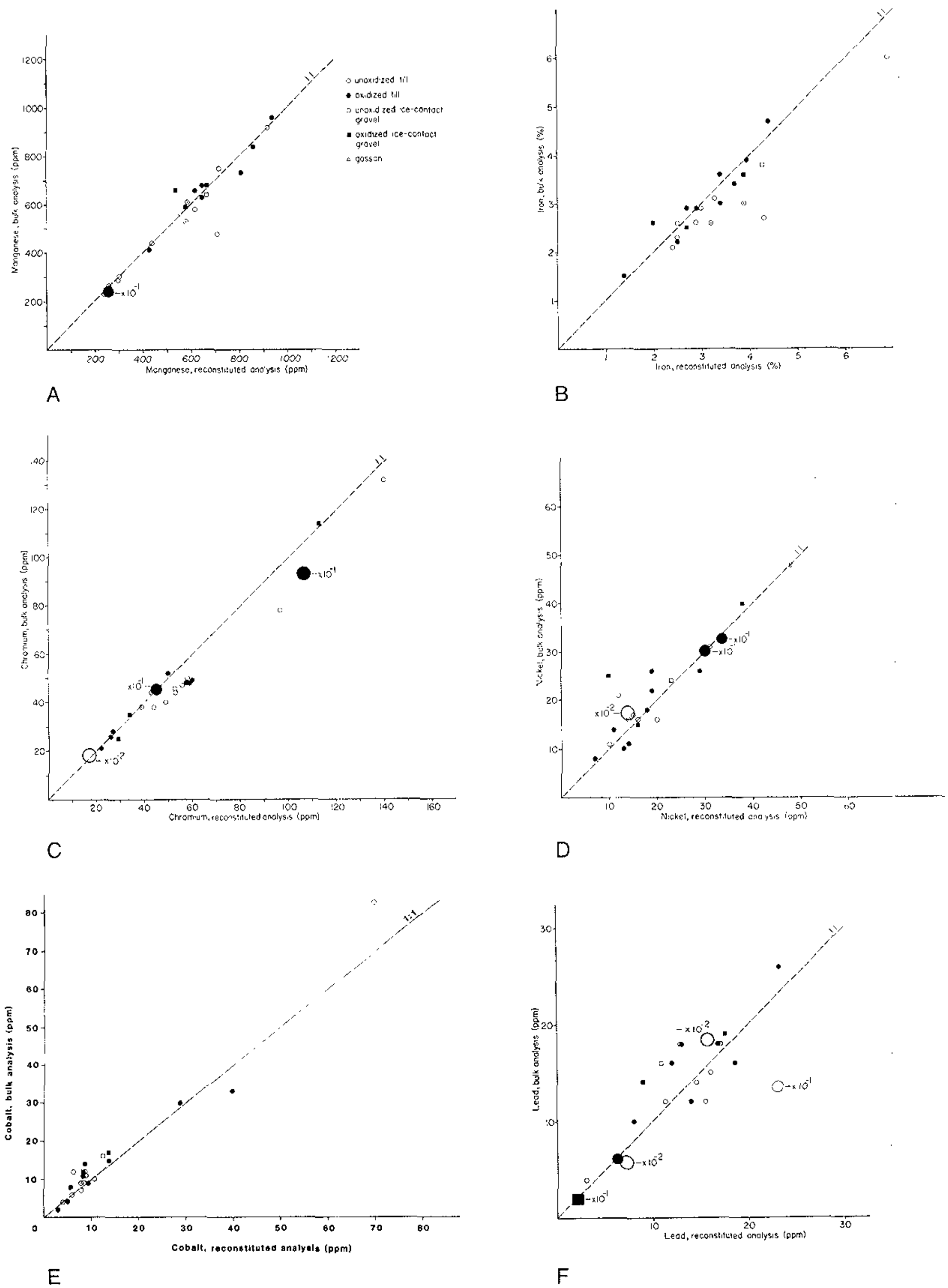

Figure 16-3. Bulk analyses of <6000 micron fraction plotted against reconstituted analyses obtained by summing metal contributions of each grain-size fraction (also *see* Table 16-1) for till and related sediments. (Figure continued on next page.)

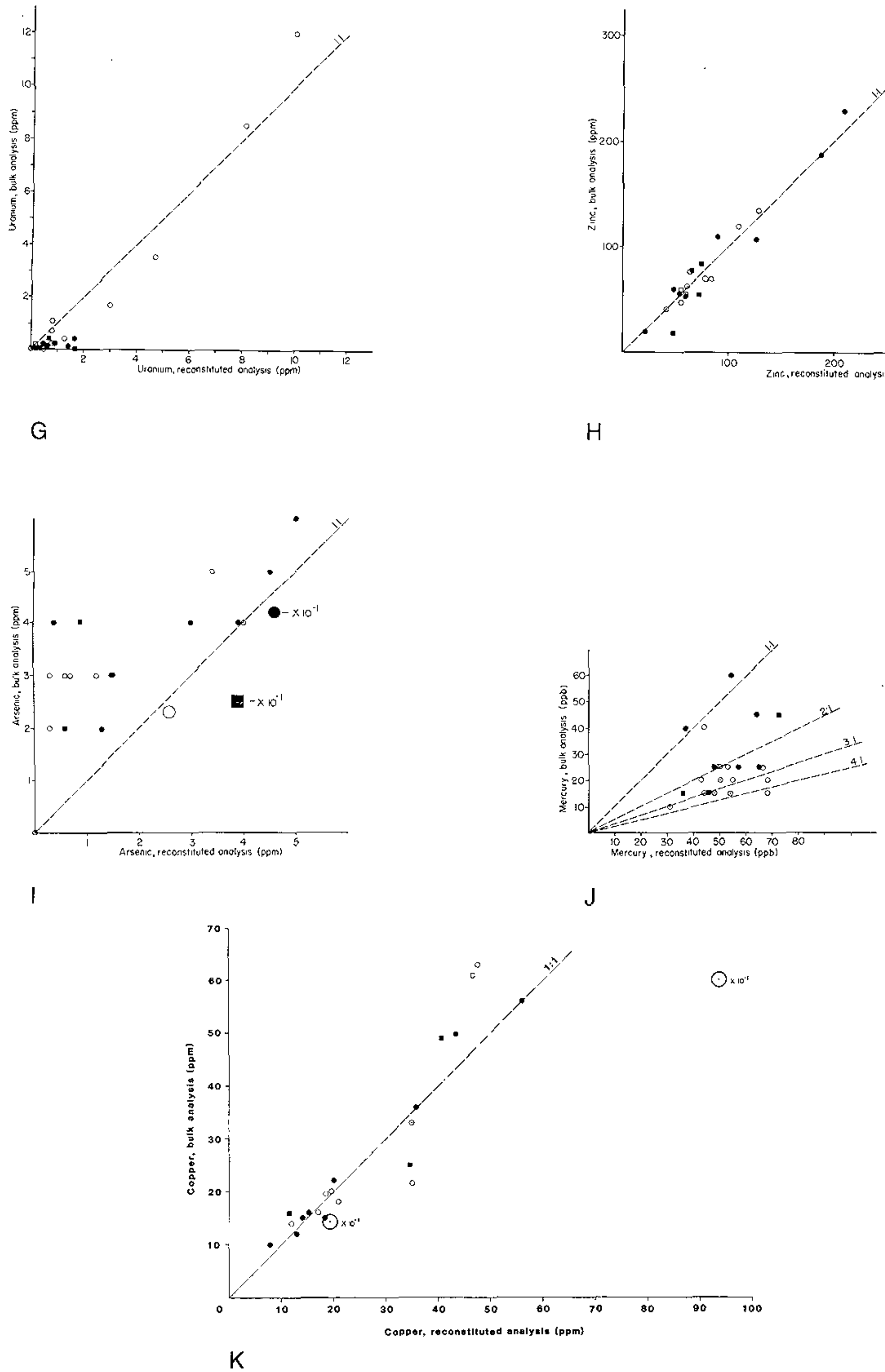

Figure 16-3. Continued.

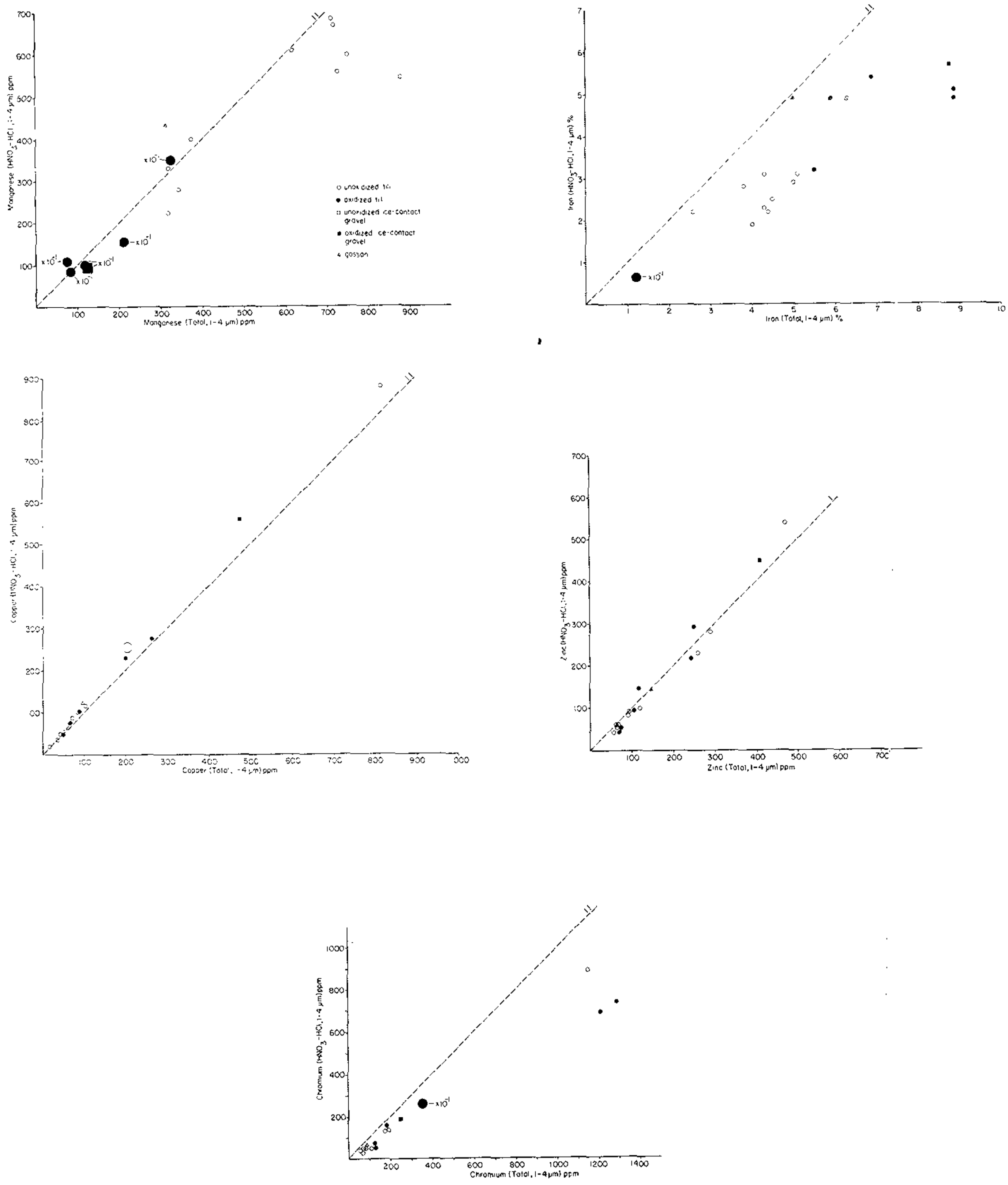

Figure 16-4. Relationship of metal extracted from 1 to 4-micron fraction of glacial sediments by total extraction processes to metal leached by aqua regia.

Each sample was suspended in a weak sodium hexametaphosphate solution and disaggregated in a stainless steel milkshake mixer with a Nalgene blade. The sediment left in suspension after a few seconds of settling following this vigorous agitation was decanted into a 1000-millilitre vessel in a centrifuge. Through a series of centrifugations, the material finer than 4 microns was separated from coarser particles, and the -4-micron sediment was further split into a 1 to 4-micron fraction and a -1-micron fraction.

The particles coarser than 4 microns were dried and sieved through a 44-micron screen, producing a 4 to 44-micron fraction. Because it is virtually impossible to remove all clay-sized particles from suspension of silt and clay (Jackson, 1956, p. 139), some are inevitably trapped with the fine silt. Although it is estimated that over 90% of the clay in the sample was removed by three resuspensions of the silt-clay mixture, the lack of control on the amount of clay remaining in the silt separate may be a source of some error in estimating the silt's true geochemical composition. Moreover, this error is likely to be more serious in samples with higher original clay contents; this must be borne in mind when evaluating the results presented below.

The coarse material remaining after decantation of suspended silt and clay was dried and was split further into several grain-size fractions using stainless steel sieves. The fine sand - coarse silt fraction (250-44μm) was added to coarser particles that failed to pass the 44-micron sieve during silt separation. Finally, a bulk sample was split from the original sample and dried, disaggregated, and passed through a 6-millimetre sieve.

After these procedures, the following seven fractions were available for analysis: a bulk sample, with less than 6 millimetre (6000μm) maximum particle size; a 6000 to 2000 micron fraction; a 2000 to 250 micron fraction; a 250 to 44 micron fraction; a 44 to 4 micron fraction; a 4 to 1 micron fraction; and a less than 1 micron fraction were available for analysis.

After drying, each fraction was crushed to a fine (<63μm) powder using a ceramic rather than a tungsten carbide ball mill to minimize the potential for tungsten and cobalt contamination. Throughout the sample preparation procedure, each step was carefully monitored to ensure that fractionation was complete and that each fraction was uncontaminated by coarser or finer particles. Only distilled, deionized water and reagent-grade sodium hexametaphosphate were used for washing and centrifugation. Chemical analyses of the metaphosphate indicated that all metals discussed here were present in amounts below detection limits of the analytical procedures applied to the fractions.

Each of the fractions was subjected to a variety of analytical techniques (*see* Table 16-8). Selected 1 to 4-micron fractions were also leached with hot aqua regia (HNO_3/HCl), and ammonium citrate and sodium dithionate leaches were used to remove loosely held metal from the clay and oxide phases, respectively. The latter data are not presented here, but are pertinent to later discussions and were discussed briefly by Shilts (1984).

TABLE 16-8
ANALYTICAL TECHNIQUES

Analytical Lab	Element	Detection Limit	Extraction Multiple Acid, Total Digestion	Method
BC	Pb	2 ppm	$HF-HClO_4-HNO_3-HCl$	AAS
BC	Zn	1 ppm	"	"
BC	Co	1 ppm	"	"
BC	Ni	2 ppm	"	"
BC	Cr	2 ppm	"	"
BC	Mo	1 ppm	"	"
BC	Mn	1 ppm	"	"
BC	Fe	0.1%	"	"
BC	Cd	0.2 ppm	"	"
BC	As	2 ppm	HNO_3-HClO_4	colorimetric
BC	Hg	5 ppb	$HNO_3-H_2SO_4-HCl-HClO_4$	Cold vapour AAS
BC	*U*	*0.1 ppm*	*HNO_3*	*fluorometry*
BC	W	2 ppm	Carbonate sinter	colorimetric
BC	Sn	1 ppm	---	XRF
BC	Sb*	0.05 ppm	---	INAA
BC	Au*	0.5 ppb	---	"
BC	As*	0.2 ppm	---	"
C	Pd**	2 ppb	Total ICP digestion	FA-ICP-AFS
C	Au**	2 ppb	"	"
C	Pt**	5 ppb	"	"
C	Ni**	1 ppm	"	ICP-AES
C	Co**	1 ppm	"	"
C	Cr**	1 ppm	"	"
C	Cu**	1 ppm	"	"

* Samples from St.Magloire (*see* Table 3)
** Samples from Ungava (*see* Table 16-10)

Abbreviations:

BC	Bondar-Clegg and Company, Ltd.
C	Chemex Labs, Ltd.
AAS	atomic absorption spectrometry
FA	fire assay
ICP	inductively coupled plasma
AFS	atomic fluorescence spectrometry
AES	atomic emission spectrometry
INAA	instrumental neutron activation analysis
XRF	X-ray fluorescence

RESULTS AND DISCUSSION

Because some of the separations (44μm particles) required suspension in distilled water and centrifugation, there was some concern that loosely held metal could be lost from the phyllosilicate phases, particularly for weathered samples. To evaluate this phenomenon, a method of comparing the cation contribution of each size fraction to the bulk composition of a sample was devised. By determining the size distribution of each sample using standard sieve and pipette techniques, it was possible to calculate or estimate the weight percent of each geochemically analyzed size fraction, assuming that the total sample would pass a 6-millimetre sieve. Multiplying the weight percent in grade by the trace element concentration in grade permitted derivation of a contribution of metal from each fraction, assuming 100% efficiency of the extractions. Summing these contributions yielded a concentration that could be compared directly to the "total" metal derived from analysis of the pulverized bulk sample (Table 16-9). In most cases the reconstituted analyses match the bulk analyses fairly closely (Figure 16-3), indicating that, for these samples, the physical partitioning procedure is giving an adequate picture of the true trace element distribution by size.

Only mercury and arsenic show significant variability, with few reconstituted samples approximating the original bulk analysis (Figure 16-3). This probably reflects a number of analytical and sample processing problems unique to

TABLE 16-9
CALCULATIONS FOR COMPARING
RECONSTITUTED TILL TO BULK ANALYSES

Sample 80SAR009: oxidized till, Grenville Terrane, E. Ontario

* Grain Size	Wt % in Grade	Cu (ppm)	Cu x % in Grade	Pb (ppm)	Pb in grade	Zn (ppm)	Zn x % in grade	Co (ppm)	Co x % in grade
Bulk Sample	100	36	36	18	18	230	230	15	15
2.0-6.0 mm	0.48	6	0.0	2	0.0	26	0.1	3	0.0
0.25-2.0 mm	23.5	23	5.4	14	3.3	145	34.1	15	3.5
0.044-0.25 mm	31.6	19	6.0	12	3.8	125	39.5	8	2.5
0.004-0.044 mm	35.1	35	12.3	18	6.3	196	68.8	12	4.2
0.001-0.004 mm	4.6	110	5.1	32	1.5	540	25.1	31	1.4
< 0.001 mm	4.6	156	7.2	44	2.0	910	42.2	45	2.1
Total Reconstituted			**36**		**17**		**210**		**14**

* Grain Size	Wt% in Grade	Ni (ppm)	Ni x % in grade	Cr (ppm)	Cr x % in grade	Mo (ppm)	Mo x % in grade	Mn (ppm)	Mn x % in grade	Fe (%)	Fe x % in grade
Bulk Sample	100	26	26	54	54	5	5	680	680	3.6	3.6
2.0-6.0 mm	0.48	4	0.0	18	0.1	4	0.0	172	0.8	0.5	0.00
0.25-2.0 mm	23.5	20	4.7	38	8.9	5	1.2	700	164.7	2.5	0.6
0.044-0.25 mm	31.6	14	4.4	48	15.2	2	1.0	550	173.7	2.6	0.8
0.004-0.044 mm	35.1	30	10.5	70	24.6	6	2.1	595	209	4.0	1.4
0.001-0.004 mm	4.6	76	3.5	110	5.1	8	0.4	860	39.9	5.5	0.3
< 0.001 mm	4.6	134	6.2	110	5.1	12	0.6	1420	65.9	6.4	0.3
Total Reconstituted			**29**		**59**		**5**		**654**		**3.4**

Sample 80LAAMK-025: unoxidized till, Archean volcanic terrain, central District of Keewatin

* Grain Size	% in Grade	Cu (ppm)	Cu x % in Grade	Pb (ppm)	Pb x % in Grade	Zn (ppm)	Zn x % in Grade	Co (ppm)	Co x % in Grade
Bulk Sample	100	145	145	665	665	54	54	7	7
2.0-6.0 mm	10.04	74	7.4	450	45.2	70	7	18	1.8
0.25-2.0 mm	24.47	50	12.2	330	80.8	46	11.3	10	2.5
0.044-0.25 mm	27.6	43	11.9	250	69	37	10.2	3	0.8
0.004-0.044 mm	25.87	124	32.1	490	126.8	50	12.9	4	1.0
0.001-0.004 mm	6.01	816	49	2600	156.3	120	7.2	13	0.8
< 0.001 mm	6.01	1390	83.5	4000	240.4	192	11.5	16	1.0
Total Reconstituted			**196**		**718**		**60**		**7.9**

* Grain Size	% in Grade	Ni (ppm)	Ni x % in Grade	Cr (ppm)	Cr x % in Grade	U (ppm)	U x % in Grade	Mn (ppm)	Mn x % in Grade	Fe %	Fe x % in Grade
Bulk Sample	100	31	31	78	78	8.5	8.5	260	260	2.1	2.1
2.0-6.0 mm	10.04	72	7.2	200	20.1	8	0.8	450	45.2	3.4	0.34
0.25-2.0 mm	24.47	25	6.1	70	17	3.9	1.0	278	68.0	2.2	0.54
0.044-0.25 mm	27.6	18	5.0	56	15.5	3.7	1.0	180	49.7	1.4	0.39
0.004-0.044 mm	25.87	20	5.2	78	20.2	8	21	190	49.2	2.0	0.52
0.001-0.004 mm	6.01	52	3.1	175	10.5	44	2.6	344	20.7	4.3	0.26
< 0.001 mm	6.01	72	4.3	228	13.7	11	0.7	400	24.0	5.5	0.33
Total Reconstituted			**31**		**97**		**8.2**		**257**		**2.4**

**See* Table 16-1 for explanation

these two elements: analytically, the cold vapour AAS technique for mercury and the colorimetric technique for arsenic are notoriously prone to operator and other errors, leading to lack of precision and accuracy; the volatile nature of mercury probably magnifies errors associated both with various lengths of time that samples were stored, and with physical processes associated with disaggregation of a sample in water.

For some exceptionally anomalous samples, the reconstituted analysis is significantly lower than the bulk analysis (*see* Cu and Pb, for example), probably because a significant amount of metal stays in the solution that is decanted after the finest clay (<1µm) is sedimented by centrifuging (see Lindsay and Shilts, 1995, this volume). Colloids and particles finer than about 0.3 microns are virtually impossible to remove by centrifuging, and were discarded (*see* Lindsay and Shilts, 1995, this volume), indicating that the fraction identified as " micron" actually has a size range of 0.3 to 1 micron. In fact, all clay separations carried out on samples prepared in the Drift Sedimentology Laboratory have a lower size limit at about 0.3 micron.

In addition to the test of accuracy in partitioning analyses of the various grain-size fractions, experiments with selective or partial leaches were carried out (Shilts, 1984). Among these, concentrations derived from "total" extractions from the 1 to 4-micron (clay) fractions were compared to the hot, aqua regia extraction commonly employed for drift geochemical analysis. It can be seen (Figure 16-4) that in this phyllosilicate-dominated size fraction, copper, zinc and, to a lesser extent, manganese are essentially totally removed from the clay fraction by either leach, indicating that the routinely used aqua regia leaches are essentially total extractions for these three metals. More iron and chromium, however, are extracted by the total leach than by aqua regia, a gossanous sample being the sole exception. Aqua regia appears to be leaving 25 to 50% of the iron and a lesser amount of chromium in the clay, an empirical observation that cannot be adequately explained at this time. Perhaps the clay fraction of tills and derived sediments contains "background" concentrations of crystalline iron oxides (Hall *et al.*, 1993) such as hematite, which is known to concentrate in sub-4-micron sizes because of its soft nature, and can only be broken down by submitting samples to a strongly reducing attack. Possibly chromium may be held in magnetite or other micro-inclusions in clay-sized grains, but no such inclusions were seen in scans with an electron microscope. Limonitic iron oxides that reside in the clay fraction of weathered sediments because of their fine crystalline size also may be resistant to aqua regia attack.

The results of the partitioning analyses are represented by the arithmetic and logarithmic plots of grade size against concentration for the initial 30 samples culled from our 1980 programs (Figures 16-5 and 6). Although there is considerable vertical scatter of concentrations within each grade size cell, it can be seen that for most of the elements, concentrations increase in the finest, phyllosilicate-dominated sizes. The concentrations in the most anomalous samples exceed those derived from bulk analyses by a factor of 10 or more for seven of the eleven elements analysed.

The significance of this enrichment is apparent on the arithmetic plots of copper, arsenic and uranium (Figure 16-5), which have been broken down into background and anomalous groups. Tables 16-1 to 7 and 10 demonstrate, by listing actual concentrations, just how significant geochemical partitioning can be by grain size for some of the elements shown graphically by Figures 16-5 and 6 and for other ele-

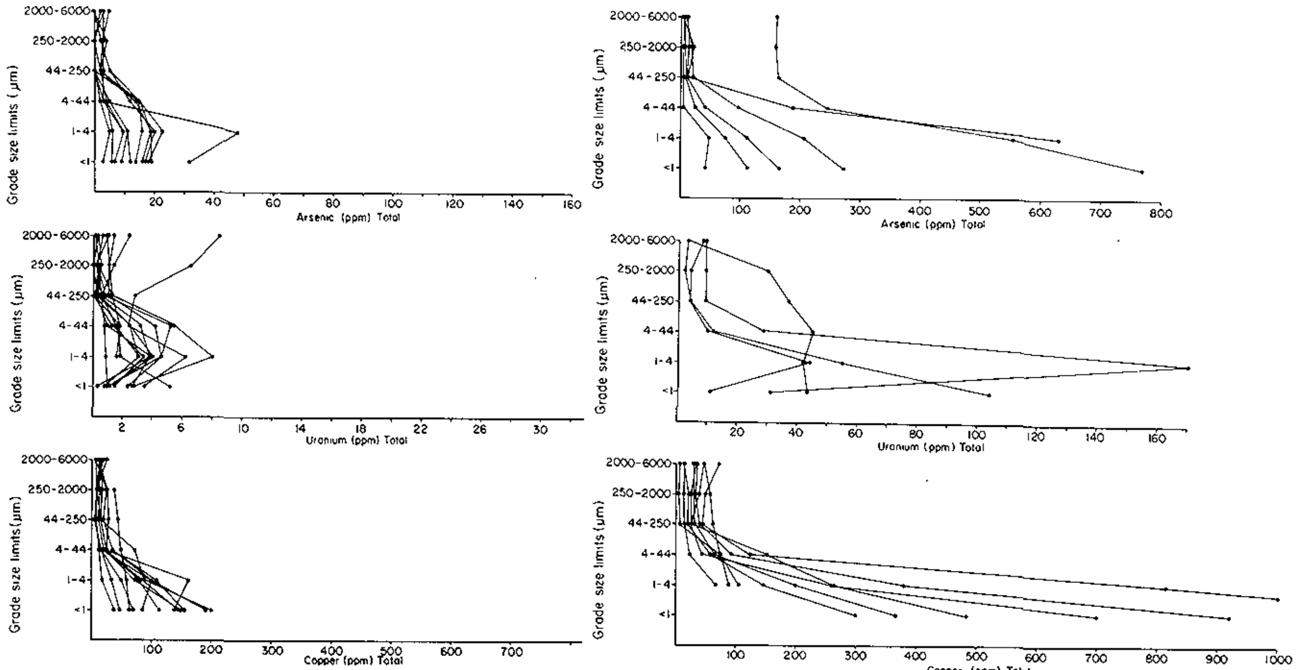

Figure 16-5. Arithmetic plot of arsenic, uranium, and copper in various grain sizes of glacial sediments with background (left side figures) and anomalous (right side figures) concentrations (modified from Shilts, 1984).

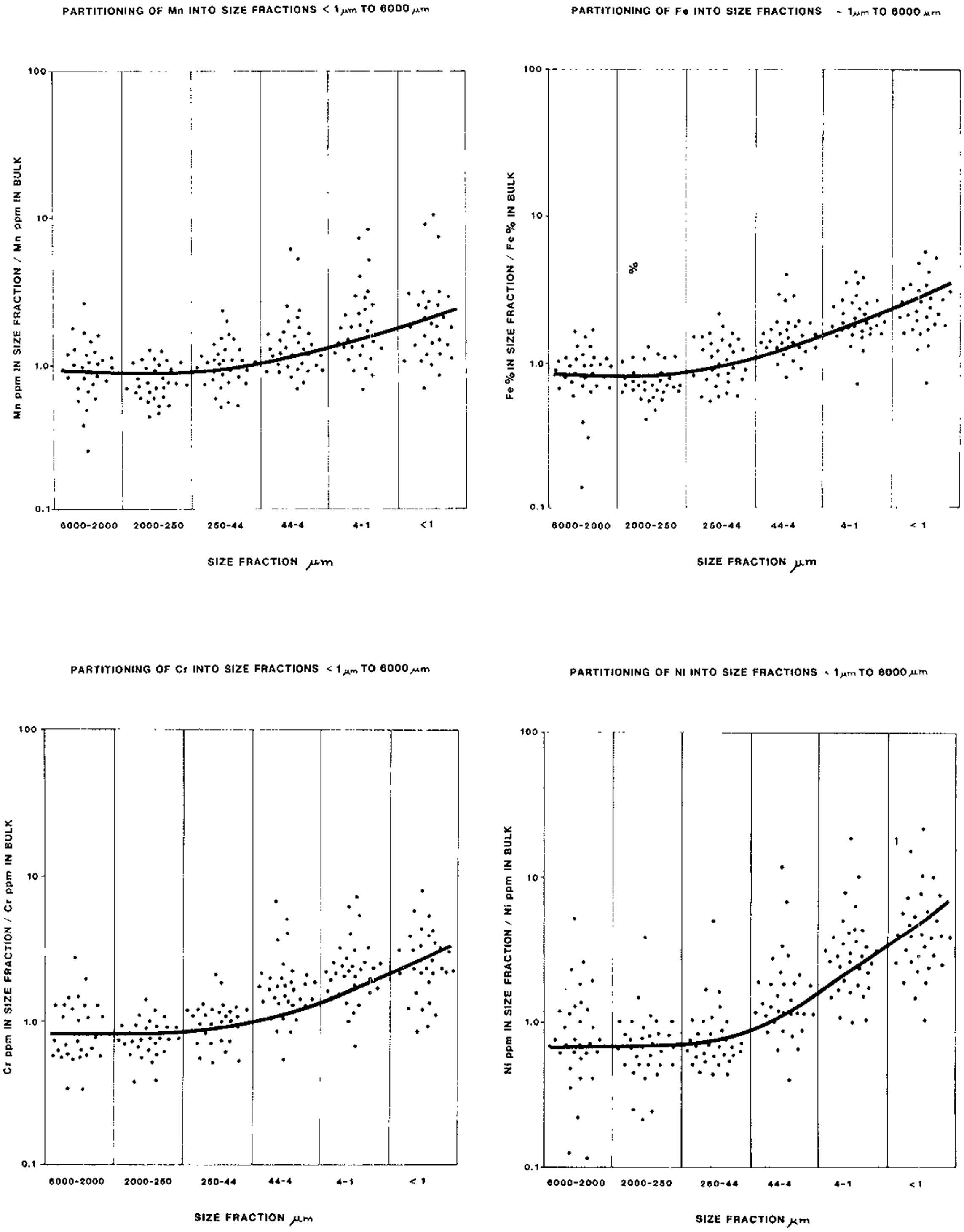

Figure 16-6. Logarithmic plots of the ratio of trace metal concentrations in selected size fractions <6000 micron to concentrations in bulk (<6000µm) fractions. Lateral spread of dots in size fraction cells is for convenience of plotting. Heavy lines are estimated trends drawn by hand approximately through median values.

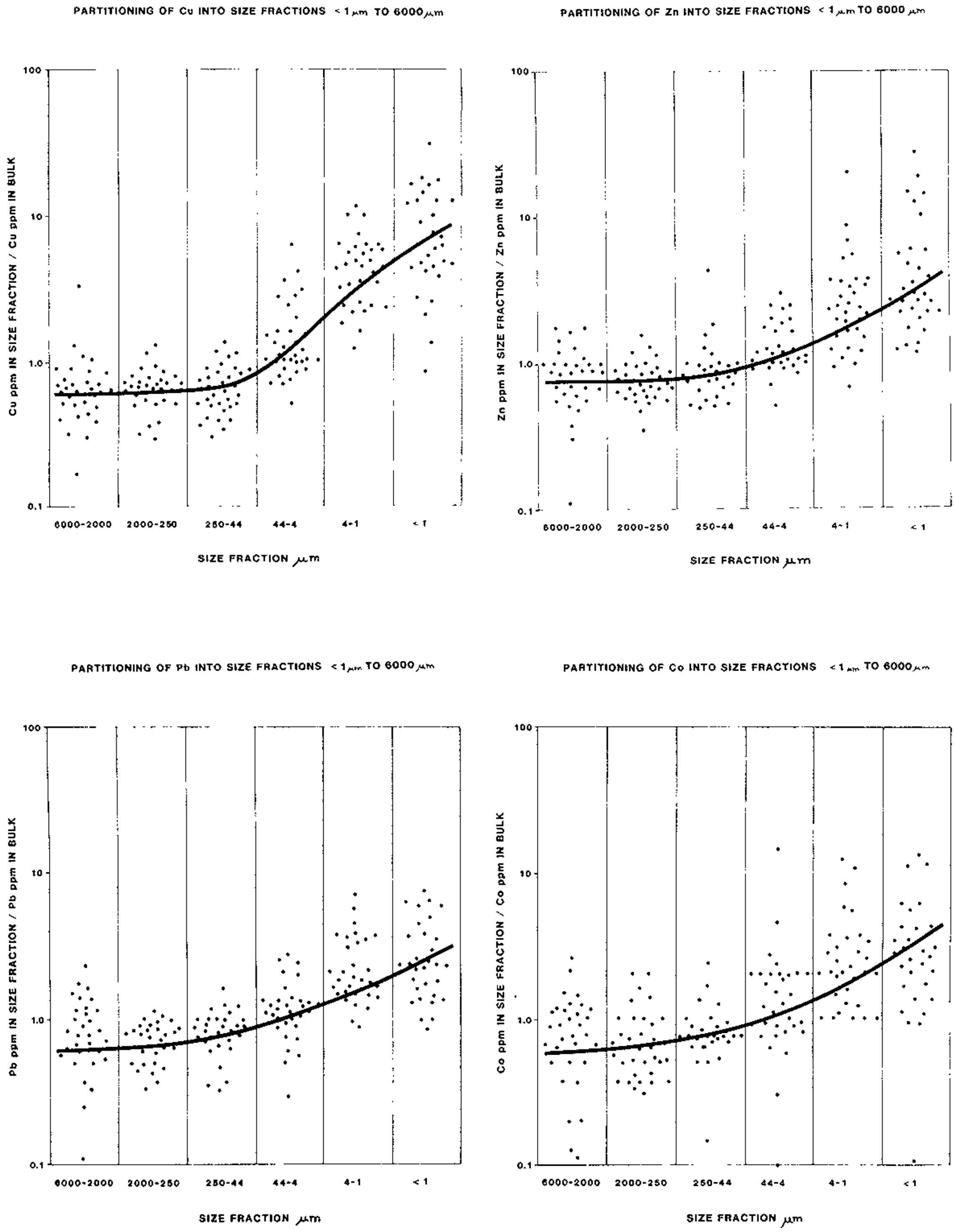

Figure 16-6. Continued.

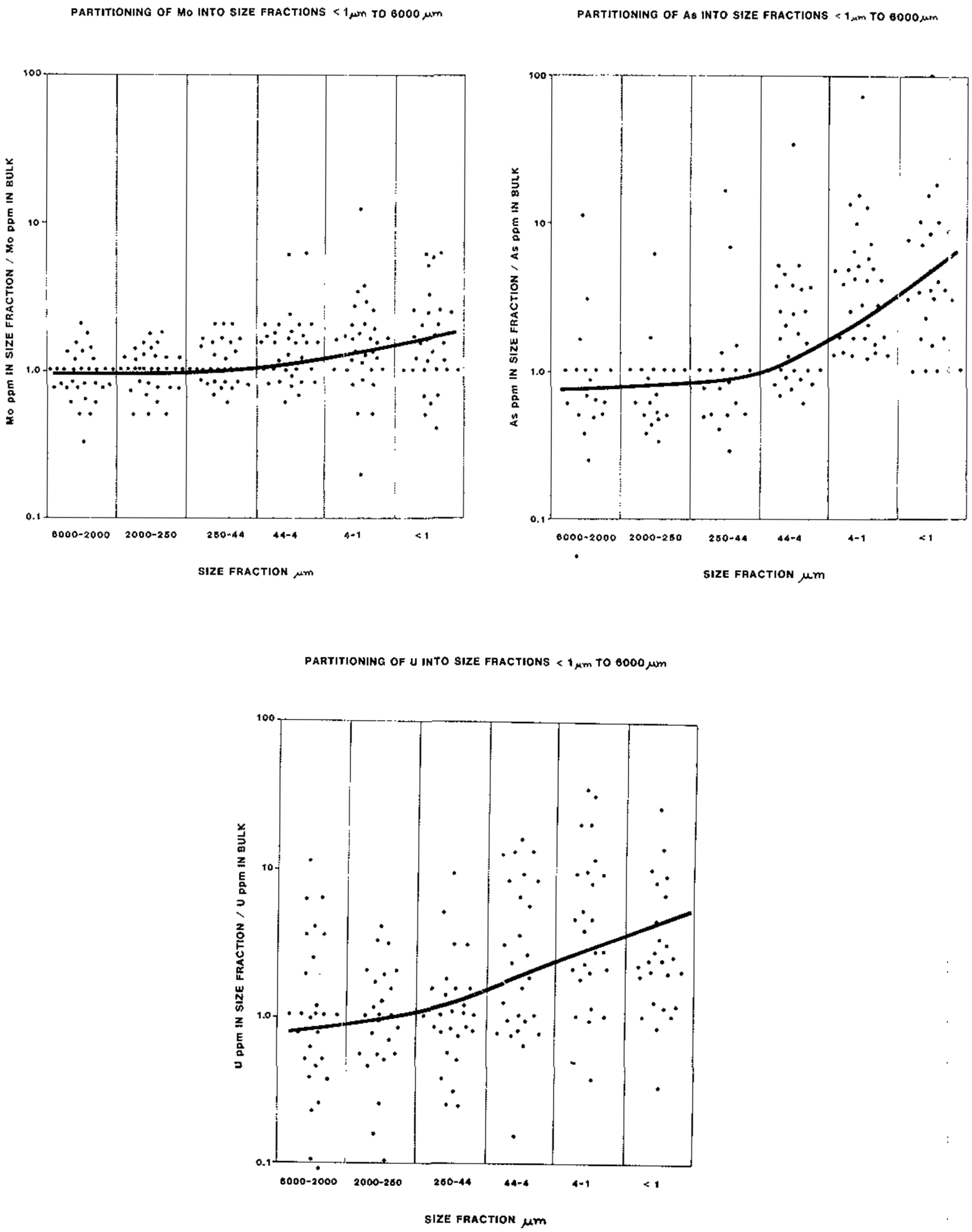

Figure 16-6. Continued

TABLE 16-10
PARTITIONING IN TILL OVER ULTRAMAFIC BEDROCK,
NORTHERN UNGAVA, QUEBEC

Raglan 3**	Pd (ppb)	Pt (ppb)	Ni (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Au (ppb)
Bulk Sample (< 6.0 mm)	1100	330	2966	91	1305	4460	120
< 0.063 mm (silt + clay)	980	210	3466	84	669	5400	160
2.0- 6.0 mm	2100	500	2579	91	2360	4230	620
0.25-2.0 mm	1400	490	3249	117	1760	4430	230
0.063-0.025 mm	1100	220	2306	79	904	3380	130
0.045-0.063 mm	900	180	2164	62	913	3300	160
0.002-0.045 mm	720	300	2418	72	629	3620	210
< 0.002 mm	2300	110	6355	118	882	>10 000	60

Raglan 5***	Pd (ppb)	Pt (ppb)	Ni (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Au (ppb)
Bulk Sample (< 6.0 mm)	130	60	679	53	845	477	20
< 0.063 mm (silt + clay)	100	96	592	41	407	433	44
2.0-6.0 mm	130	85	727	60	1440	411	4
0.25-2.0 mm	140	75	674	64	1010	436	6
0.063-0.025 mm	110	50	446	40	538	346	8
0.045-0.063 mm	68	100	406	34	469	291	34
0.002-0.045 mm	78	70	490	37	445	344	26
< 0.002 mm	390	70	1601	104	1045	1405	10

- Samples collected and donated by Michel Bouchard, Université de Montréal

** Sample of strongly altered till collected from a mudboil 8 m down-ice from PGE/sulphide mineralization

*** Sample of apparently unaltered till collected from till plain 170 m down-ice and downslope from gossan near Raglan 3

ments not included in the original analysis (W, Cd, Au, Sb, Sn, Pd and Pt). Each element appears to have a particular "fingerprint" of concentration ranges through various grain sizes, a further confirmation that the terminal modes of minerals hosting these elements vary. Furthermore, the tables indicate the significant influence that the finest fractions of glacial sediments have on their overall chemistry.

CONCLUSIONS

The conclusions drawn from this study of the geochemical ramifications of physical partitioning of mineral phases into various grain sizes by glacial abrasion and crushing are empirically straightforward, but conceptually in need of further study and explanation:

(1)It is obvious that for most trace elements, concentrations are lowest in the quartz-dominated medium sand to fine silt ranges and significantly elevated in the fine silt and clay fractions. Because the samples analyzed were a mix of depositional facies and ranged from samples strongly altered by weathering to samples that are virtually unaltered, the consistency of trends must be related largely to primary mineralogical characteristics of the original glacial sediment. Though most of the cation exchange capacity (CEC) of glacial sediments resides in their clay-sized fraction because of the dominance of phyllosilicate minerals, secondary adsorption does not affect samples from the near-surface weathering environment noticeably more than those that are virtually unaltered (Shilts, 1984; Shilts and Kettles, 1990). Thus, increased concentration of metals in phyllosilicates probably reflects the ability of their lattices to accept stray cations into their structure at some phase of their evolution, evidently before they were ripped from their hostrocks by glacial grinding. Further selective leaching of these fractions, described by Shilts (1984), and extensive searching through anomalously metal-rich 0.3 to 2-micron separates with a scanning electron microscope with backscattering capabilities, failed to show either any evidence of loosely held cations on clay particles or of micro-inclusions or of other finely divided primary mineral phases, such as sulphides. Evidently, in the samples examined here, metal enrichment in the clay fraction can be a primary phenomenon related to syngenetic geochemical processes, such as the enrichment of metals in clays around sea-bottom volcanic vents or ion migration by a variety of processes during hydrothermal activity or metamorphism. This problem will be solved only by carrying out similar partitioning studies that focus on minerals that physically reduce easily to clay sizes, in source rocks in the vicinity of various types of mineral deposits.

(2)Geochemical samples containing significant amounts of high exchange capacity components (organic compounds, iron and manganese oxyhydroxides, *etc.*) are chemically rationalized to remove uneven adsorption effects. Likewise, because fine fractions commonly contain metal-poor and metal-rich phases in varying proportions, conventional sieve-separation of these fractions must also be rationalized in some way. This can be done by simple grain-size analysis of the fraction analyzed (Shilts, 1971) or by analyzing for aluminum, which occurs preferentially, but not exclusively, in the phyllosilicate phases of the clay fraction. An alternative technique is to separate the clay fractions by centrifugation and analyze them directly (Shilts, 1975). This latter method has been widely and routinely used by the Geological Survey of Canada and its contract clients since 1973 (*see* Lindsay and Shilts, 1995, this volume), but it is expensive, requires careful quality control, and is not appropriate for exploration for metals that tend to occur in phases that have their terminal modes in coarser grain-size fractions, such as chromium (chromite) or gold. For environmental studies, direct analyses of the clay fraction are particularly useful, because this fraction not only preferentially adsorbs pollutants due to its high exchange capacity, but it is the first to yield anthropogenically derived or naturally occurring trace elements as a result of soil or sediment disturbance by natural or anthropogenic physical (erosion, excavation, dredging) or chemical (acid rain, reservoir-filling, chemical disposal) processes.

(3)Further research combining physical partitioning techniques similar to those described here with chemical partitioning techniques, such as sequential leaching (Hall *et al.*, 1993), should help explain many of the compositional phenomena revealed by this and similar studies. It is particularly important to understand processes controlling partitioning when evaluating the significance of the magnitude of anomalies generated by exploration geochemical sampling or in setting permissible metal levels for remediation of contaminated glacial soils in environmentally degraded terrains in urban areas and around various types of mines.

ACKNOWLEDGMENTS

A number of colleagues contributed many of the samples that were used in this study, either directly or by providing me with the opportunity to collect samples personally. I thank M. Bouchard, W. Coker, A. Dyke, E. Evenson, I. Kettles, A. LeCheminant, A. Miller, C. Schlüchter, and F. Taylor for their samples or assistance in sampling. The clay separation technique was developed originally in collaboration with Dianna Campbell. The manuscript benefitted significantly from comments on early versions by I. McMartin and A. Plouffe. I particularly thank R. Garrett and G. Hall for their constructive criticism of later versions. The author assumes, however, all responsibility for data presented and conclusions drawn.

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A STANDARD LABORATORY PROCEDURE FOR SEPARATING CLAY-SIZED DETRITUS FROM UNCONSOLIDATED GLACIAL SEDIMENTS AND THEIR DERIVATIVES

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INTRODUCTION

The following procedure for separating clay-sized particles from glacial sediments has been employed in the Drift Prospecting Laboratory of the Terrain Sciences Division of the Geological Survey of Canada since 1973. It is important to recognize, when interpreting geochemical results from projects carried out by members or associates of this division, that the clay analyses yield significantly different results from those obtained from dry-sieved silt and clay (<250 mesh or <64µm) samples. Using this method sufficient clay-sized material for geochemical and X-ray diffraction analyses has been obtained from esker gravels (Shilts and Wyatt, 1989), till, glaciolacustrine sediments and glaciomarine sediments.

Equipment

- Centrifuge; International Centrifuge (IEC), Model DPR-6000, 6-place head with 1000-millilitre capacity and Nalgene bottles.
- Milkshake mixer; modified by replacing steel blade with Nalgene blades cut from heavy gauge labware.
- Stainless steel mixer buckets; baffles removed.
- Sodium hexametaphosphate; 5 grams per litre in distilled, deionized water.
- Nalgene cups; 100 millilitres (for drying clay).
- Stainless steel, long-handled spatula.
- Drying oven, low temperature.
- Beakers; 250-millilitre (for washing and drying sand and granule oversize).
- Agate pestle or mortar and pestle for disaggregating dried clay.

PROCEDURE

Three hundred to five hundred-gram samples are removed from plastic bags, preferably in fragments or chunks representing the sample as it occurred in outcrop, and placed in a stainless steel milkshake mixer vessel, wet. It is neither necessary nor desirable to dry the sample. Pebbles larger than 1 centimetre in diameter are removed if possible, and before adding about 200 millilitres of distilled, deionized water to which a small amount of dispersant has been added (5 g/l of reagent grade sodium hexametaphosphate is good unless phosphorus is a metal of interest; trace element "purity" of whatever dispersant is used must be confirmed). More dispersant can be added if problems with flocculation persist, but a minimum and constant amount is desirable as some dispersant is inevitably precipitated with the clay during the final drying step.

The normal stainless steel blade that is screwed on to the end of the milkshake mixing rod is replaced by a blade cut from discarded Nalgene labware. After considerable testing, it was found that no metal blade survived long when disaggregating till, with the result that considerable metal contamination could be found in sand-sized heavy minerals derived from the disaggregation process. The Nalgene blades wear rapidly, but are very cheap, and the easily recognized Nalgene residue is rarely found in the materials separated for analysis.

The sample and water slurry is mixed on the milkshake mixer machine for approximately 30 seconds and the slurry is allowed to sit for 5 to 10 seconds to allow sand and coarser grains and aggregates to settle. The slurry is then decanted into a 1000-millilitre centrifuge vessel. Another 200 millilitres of metaphosphate solution is added and the process repeated. After the second decantation, the process is repeated once more and the decanted, supernatant solution is, by this time, fairly clean. The granule-sand residue remaining in the milkshake mixer is removed and set aside to dry for further examination of pebble lithology (2 to 6 mm sizes), heavy and light mineral analysis of the sand fraction by petrographic, scanning electron microscope or geochemical techniques, and bulk magnetic susceptibility measurements of the sand fraction.

The slurry from the three decantations is now in the 1000-millilitre centrifuge vessel which is "topped up" with metaphosphate solution to 750 to 800 millilitres, depending on sediment concentration. Once six samples have been prepared this way, the vessels that are inserted on opposite sides of the centrifuge head are weighed, and metaphosphate solution is added until their weights are within 1 gram of each other, so that the six-place centrifuge will be balanced.

The next procedure is critical for adequate clay-silt separation, and lab staff should be trained to carry it out in a consistent and careful manner. The six vessels, each of which is closed with a screwtop, must be shaken briefly and vigourously so that all sediment is suspended. Then, as quickly as possible, the vessels should be placed in the centrifuge and the centrifugation process begun. To cause the silt (particles 2 to 64µm in diameter) to settle, the DPR-6000 centrifuge must be accelerated to 750 rpm as rapidly and smoothly as possible and must be held at 750 rpm for 3 minutes, after which it is decelerated rapidly and smoothly to a stop. The supernatant suspensions are poured carefully into six more 1000-millilitre centrifuge vessels, being careful not to resuspend the silt sedimented by the first centrifugation. Jackson (1956) estimates that about 75% of the -2-micron fraction is removed from the silt/clay suspension by this first centrifugation. If the original sample is clay-poor or too small to recover adequate clay, the settled silt and clay may be resuspended and the centrifugation separation repeated. In most cases this is not necessary, and in any case, after the second or third centrifugation, very little of the remaining approximately 10% of clay can be recovered. The silt with its included clay component is discarded in our procedure.

After the clay suspensions in the second set of vessels are topped up and the vessels *carefully* balanced, the suspensions are centrifuged at 2800 rpm for a further 14 minutes. After this time, some clay and colloids remain in suspension, but further centrifuging will cause little of this very fine sediment to settle. Electron microscope scans of clay particles separated using this procedure show that more than 99% of the particles range from 0.3 to 2 microns in true maximum dimension and, furthermore, that they consist predominantly of plate or disc-shaped aluminosilicates.

The final supernatant solution is discarded, again being careful not to resuspend any of the sedimented material on the bottom of the vessel during decantation. At this point the colour of the sediment surface and colours of any banding in the centrifuged sediment should be noted. These colours and bandings may have mineralogical and geochemical significance (Shilts, 1978). The sedimented clay is removed using a long-handled stainless steel spatula. Removal of the sticky, sedimented clay 'cake' may be facilitated by adding a very small amount of distilled, deionized water to the centrifuge vessel while it is vibrated at high frequency on the rubber pad of a vortex mixer. At this point, if clay mineralogical analysis is to be carried out in addition to geochemical analysis, the wet sample can be subsampled, and smear or other suitable mount(s) can be prepared for further chemical treatment and X-ray diffraction analysis. The portion of the sample to be used for geochemical analysis is placed in a small, disposable weigh boat and dried at less than 75°C (<40°C if Hg analyses are to be done). The dried sample is then disaggregated using an agate mortar and pestle or any convenient, noncontaminating technique (the dried clay can be quite hard and difficult to pulverize). The powdered sample is submitted for geochemical analysis.

The procedure described above is used routinely at the Geological Survey of Canada to process till samples. It has been transferred to the private sector where a variety of centrifuge types are used. The centrifuge speeds and concentrating procedures have to be modified to obtain the appropriate size distribution, and this should be carefully monitored among laboratories. Also, if smaller centrifuges are used, the clay-silt fraction can be preconcentrated by dry sieving, a procedure we followed in our early application of this method. Tests of the wet and dry methods of precentrifuge disaggregation showed, however, that considerable disparity in trace element concentrations was evident in the same sample (*e.g.* for uranium; Klassen and Shilts, 1977). Thus, it is not recommended that preconcentration techniques involving drying be employed. Finally, although centrifuges have been used to increase the value of g and, therefore, decrease the time to settle a set distance from Stoke's Law of settling, similar results could be obtained in settling columns or calibrated beakers, but the time required for each sample is greater. In other words, the separations can be done: using various types of centrifuge to increase g (centrifuge heads capable of accepting 1000-millilitre vessels are the best); by a combination of settling (to remove silt) and centrifugation (to remove clay); or totally by settling, processing many samples in sequence, so that eventually those for which the clay has settled (in days) are being dried at the same rate as new samples are being suspended. This technique requires considerable space and organization.

If a procedure were followed where the large amount of liquid resulting from the high liquid/solid ratio in the clay suspensions could be evaporated in a reasonable length of time, the fine clay particles and colloids could also be added to the analyzed clay sample. However, practical and chemical problems arising from the concentration of deflocculants and adherence of colloidal materials to vessel walls probably obviate the need for the total evaporation method.

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TILL GEOCHEMISTRY OF THE MOUNT MILLIGAN AREA, NORTH-CENTRAL BRITISH COLUMBIA; RECOMMENDATIONS FOR DRIFT EXPLORATION FOR PORPHYRY COPPER-GOLD MINERALIZATION

By S.J. Sibbick, B.C. Geological Survey Branch and D.E. Kerr, Geological Survey of Canada

INTRODUCTION

The successful design and interpretation of a regional drift exploration survey requires information regarding the geochemical response of the drift to the type of mineral deposit being sought. Key factors to determine include: the elements which reliably indicate the deposit type (pathfinder elements); residence sites of the pathfinder elements; and their characteristic style(s) of dispersal and dispersion. These factors can then be assessed to develop guidelines for selecting the most appropriate size fraction, sampling density and analytical techniques. Moreover, this information is essential for interpreting existing data, including pathfinder elements, their anomalous thresholds, and characteristic spatial patterns and length of dispersal trains.

Till is the preferred sample medium for regional geochemical drift exploration surveys. As the *first derivative* of bedrock (Shilts, 1993), till represents comminuted bedrock debris or older surficial sediments entrained, transported and deposited by active glacial ice. Till, of all glacial sediments, most commonly reflects the composition of its source area. Further, although it may have undergone more than one glacial episode, its location can often be directly related to interpreted ice-flow patterns and history.

Porphyry-style mineralization is particularly suited to regional-scale till surveys, given the large size of the mineralization-alteration systems involved. The Interior Plateau of British Columbia has received considerable interest as an area of high mineral potential for porphyry-style mineralization. For instance, the Mount Milligan porphyry copper-gold deposit and surrounding region has attracted an array of geological, geochemical and geophysical studies by industry, government and university scientists. In addition to numerous industry exploration programs, these include bedrock mapping by Nelson *et al.* (1991) and Struik (1992), mineral deposit studies by DeLong *et al.* (1991), surficial geological mapping by Kerr (1991) and Plouffe (1991, 1992), geochemical studies by Gravel and Sibbick (1991) and geophysical mapping by Shives and Holman (1992). Preliminary results of a regional till geochemical survey in the adjoining Manson River and Fort Fraser map areas (NTS 93K and 93N) have recently been released by Plouffe and Ballantyne (1993). In order to improve the design and interpretation of regional till surveys for porphyry copper-gold exploration, a detailed geochemical orientation survey was conducted in the vicinity of the Mount Milligan deposit (Kerr and Sibbick, 1992).

DESCRIPTION OF THE STUDY AREA

The Mount Milligan study area, centred at latitude 55°07'N and longitude 124°00'W, is located approximately 150 kilometres northwest of Prince George in north-central British Columbia (Figure 18-1). The area is accessible by logging roads from Fort St. James and from Windy Point on Highway 97. Access within the study area is limited. Exploration roads network the western third of the area near the Mount Milligan deposit, but access to the eastern two-thirds of the area is restricted to a few roads of limited extent.

Located on the Nechako Plateau, the study area is characterised by a relatively flat to hummocky plain at 1000 metres elevation, bounded on the west and east by north-trending ridges of 1300 to 1500 metres elevation. Mount Milligan, 5 kilometres north of the Mount Milligan deposit, rises to an elevation of 1508 metres.

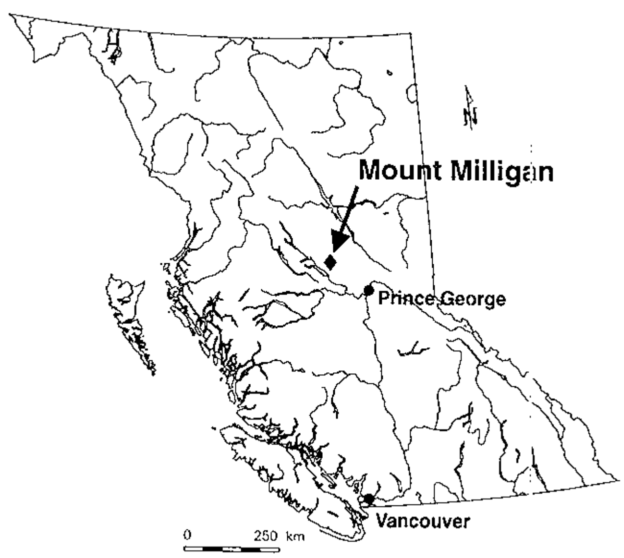

Figure 18-1. Location of the Mount Milligan study area.

REGIONAL GEOLOGY AND MINERALIZATION

Takla Group rocks of the Quesnel Terrane underlie the Mount Milligan area (Nelson *et al.*, 1991). The Quesnel Terrane is an early Mesozoic island-arc sequence bounded on the west by oceanic rocks of the Cache Creek Terrane and on the east by oceanic rocks the Slide Mountain Terrane. Metamorphic rocks of the Wolverine Complex are also in contact with the eastern boundary of the Takla Group/Quesnel Terrane (Struik, 1992). Takla Group rocks consist of Upper Triassic sediments, volcanics, pyroclastics and epiclastic sediments. Numerous coeval plutons, up to early Jurassic age, intrude the Takla Group.

The Mount Milligan deposit (Figure 18-2) is centred on Early Jurassic crowded plagioclase-porphyritic monzonite intrusions known as the MBX and Southern Star stocks (Nelson *et al.*, 1991). These, and numerous smaller stocks, intrude Upper Triassic Takla Group augite (±plagioclase) porphyry agglomerate, trachyte breccias and flows, and bedded epiclastic sediments of the Witch Lake formation. Directly east of the intrusions, the Great Eastern fault juxtaposes Takla Group rocks against Eocene continental sediments within an extensional basin (Nelson *et al.*, 1991). The eastern half of the study area is underlain by Witch Lake formation, as well as basalts and diorite of the Philip Creek succession (Struik, 1992). Quartzofeldspathic gneiss, schist and granite pegmatite of the Wolverine Metamorphic Complex outcrop in the east and northeast (Struik, 1992).

Alteration associated with the deposit comprises a crudely zoned potassic core centred on the intrusions (DeLong *et al.*, 1991) and surrounded by an east-west elongate 3.0 by 4.5 kilometre propylitic alteration halo. Mineralization consists primarily of disseminated and fracture-filling chalcopyrite and pyrite. Lesser quantities of bornite are present within the potassic alteration zone. Approximately 70% of the mineralization is hosted by the Witch Lake volcanics with the remaining 30% in the monzonite intrusions. Gold is associated with chalcopyrite, pyrite and bornite as small grains up to 100 microns in diameter along sulphide grain boundaries and microfractures in pyrite (Faulkner *et al.*, 1990). Both gold and chalcopyrite correlate directly with the potassic alteration zone (DeLong *et al.*, 1991). Reserves of the deposit are estimated at 298.4 million tonnes grading 0.45 gram per tonne gold and 0.22% copper (Schroeter, 1994).

Series of subparallel polymetallic sulphide veins containing disseminated to massive pyrite and chalcopyrite radiate outwards from the MBX stock in the propylitic alteration zone. The best-developed veins range from 0.3 to 3.0 metres thick and contain 3 to 100 grams per tonne gold, 0.2 to 10% copper, 1 to 3% sphalerite, and traces of arsenopyrite and galena (Faulkner *et al.*, 1990).

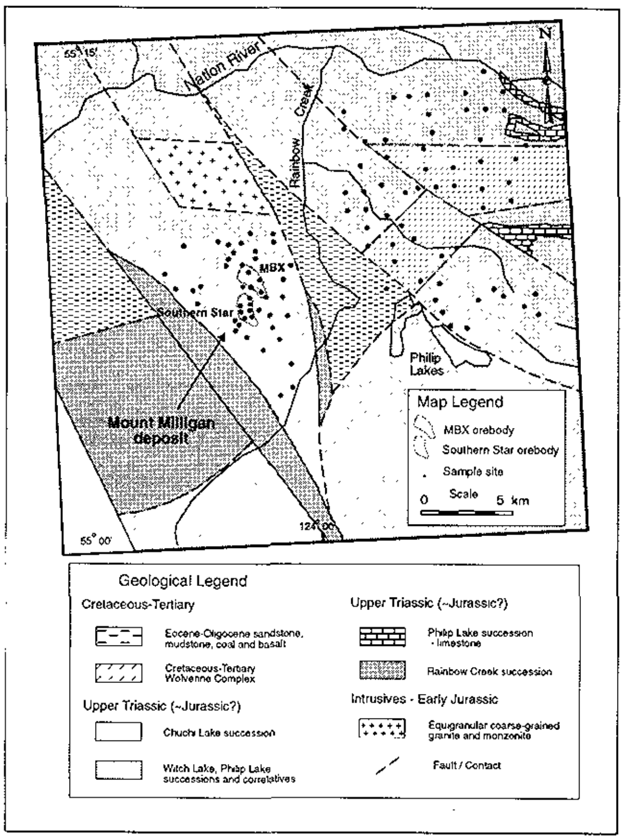

Figure 18-2. Geology and sample locations, Mount Milligan study area. Geology modified from Nelson *et al.*, (1991) and Struik (1992).

SURFICIAL GEOLOGY

The last glacial event in the Mount Milligan region occurred during the Late Wisconsinan (Fraser Glaciation) be-

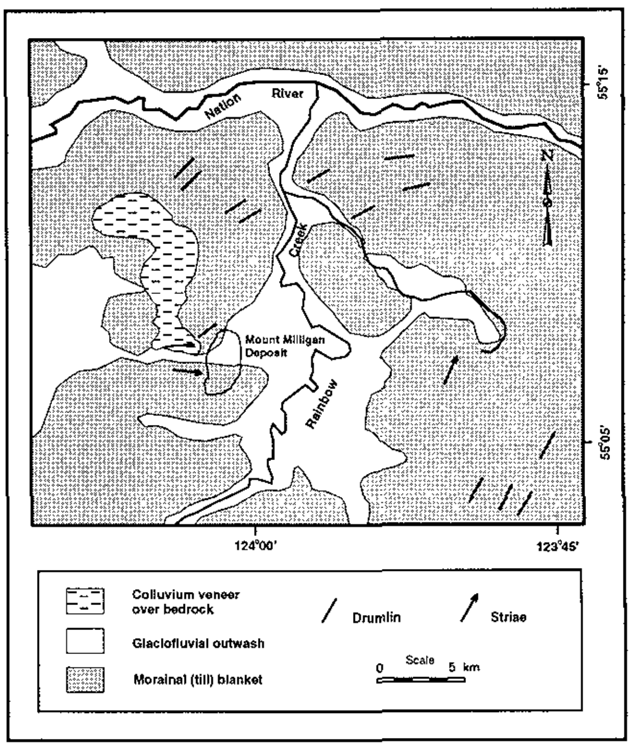

Figure 18-3. Simplified surficial geology of the Mount Milligan area, from Kerr and Sibbick (1992).

tween 25 940±380 years B.P. (GSC-573) and 10 100±90 years B.P. (GSC-2036). Regional ice movement during this event was primarily to the northeast, as interpreted from ice-flow indicators such as well developed striae scoured into bedrock and drumlinoid features developed in unconsolidated sediments. This observation of regional flow is in accordance with earlier studies by Armstrong (1949) to the north, west and south of the Milligan area, and more recently by Plouffe (1991, 1992) in the Stuart and Fraser lakes area to the southwest. In the McLeod Lake region to the southeast, Struik and Fuller (1988) mapped the extent of glacial lake deposits and noted the presence of mineralized clasts in morainal deposits.

Surficial sediments of the study area include till, glaciofluvial and fluvial sand and gravel, glaciolacustrine sand, silt and clay, colluvium and organic materials (Kerr, 1991). Two surficial units predominate: an extensive morainal (till) blanket and large glaciofluvial outwash complexes (Figure 18-3). Till was deposited during the last glacial episode and is commonly hummocky and drumlinized. It consists of a dense matrix-supported diamicton composed of very poorly sorted, angular to well rounded pebbles to cobbles in a sand-silt-clay matrix. These sediments are more continuous in the east half of the map area, from south of Philip Lakes to north of Nation River. Flow was towards the northeast during full glacial conditions. South of Nation River, a gradual change in flow direction towards the east is indicated by drumlinoid features.

Large concentrations of glaciofluvial sand and gravel dominate the central part of the study area along the axis of Rainbow Creek, Nation River valley to the north and to the west of the Mount Milligan deposit. These outwash-sediment complexes consist of sinuous esker ridges up to 10 kilometres long, kame deposits and a series of broad overlapping outwash fans deposited by glacial meltwater during ice retreat. They represent the end product of a long period of glacial and fluvial erosion, transportation and reworking of many types of surficial sediments. Within the narrow Nation River valley, glaciofluvial sediments are locally overlain by up to 20 metres of glaciolacustrine silt and clay. These sediments were deposited during ice retreat in a glacial lake with an elevation of approximately 850 metres. Colluvial sediments derived from till and weathered bedrock form a veneer over steep hillsides and valley walls in the highlands north and south of the Mount Milligan deposit. Highlands to the northeast of the Philip Lakes are also mantled by colluvial sediment.

Drift thickness is highly variable, ranging from less than 1 metre on rocky highlands to over 80 metres in the Rainbow Creek area (Kerr and Sibbick, 1992). Thicknesses in excess of 100 metres are common directly east of the Mount Milligan deposit (Kerr and Bobrowsky, 1991). Ronning (1989) has reported overburden depths in excess of 200 metres in the Nation Lakes area to the west.

Humo-ferric podzols are the main soil type of the region. Modifications of the original till substrate by soil-forming processes extend to an average depth of approximately 0.5 metre. Oxidation of the parent materials generally extends to a depth of 2 metres.

METHODS

SAMPLE COLLECTION

Till samples were collected down-ice from the Mount Milligan deposit for a distance of 20 kilometres to the east-northeast (Figure 18-2). A total of 121 till samples, including field duplicates, was collected from 108 hand-dug pits within a 150 square kilometre area. Sampling was concentrated in two distinct areas where till is the predominant surficial sediment: in the vicinity of the deposit, and in the region east of Rainbow Creek. The intervening area, consisting of glaciofluvial outwash, was not sampled, in order to maintain media consistency. Samples were collected on a 1-kilometre grid spacing. Additional sites were sampled in the vicinity of the deposit where exposures of till are more common. The oxdized C-horizon was preferentially sampled at depths of 0.5 to 1.5 metres. Field samples weighed from 2 to 5 kilograms. Samples were air dried in the field and sent to the British Columbia Geological Survey Branch Analytical Sciences Laboratory in Victoria for further processing.

SAMPLE PREPARATION AND ANALYSIS

At the laboratory, the samples were removed from their plastic bags and thoroughly air dried at room temperature. Each sample was coned and quartered to obtain a representative subsample which was then dry sieved to three size fractions corresponding to the fine sand (-250+125 μm), very fine sand (-125+62.5 μm) and the silt-clay (-62.5 μm) fractions. The two coarsest fractions (-250+125and -125+62.5 μm) were then wet sieved to remove any fines adhering to the grains. After redrying, a 20-gram split of the -250+125micron fraction was pulverized in a tungsten carbide mill to approximately 74 micron (200 mesh ASTM). Following this, the three fractions were split to acquire representative analytical subsamples. Instrumental neutron activation analysis (INAA) for thirty elements was performed on 5 to 10-gram subsamples, whereas 0.5-gram subsamples were analysed for thirty elements by an aqua regia digestion followed by inductively coupled plasma emission spectroscopy (ICP-ES) analysis. Table 18-1 lists the analytical methods and detection limits for the elements discussed in this study.

RESULTS AND DISCUSSION

DATA QUALITY

Data quality was determined using duplicate field samples (13 pairs) and analytical duplicates (6 pairs). Duplicate field samples provide an estimate of the total variation within a sampling program, including within site, within sample and analytical variation. Analytical duplicates estimate the variation within a subsample and variation inherent to the analytical method. These variations can be used to estimate the precision of the data. Precision was determined by calculating the average precision of a group of duplicate pairs for each element and size fraction. However, the limited number of duplicate pairs reduces the reliability of the precision estimates. Table 18-2 shows the total precision of

TABLE 18-1
ANALYTICAL METHODS AND DETECTION LIMITS FOR ELEMENTS USED IN THIS STUDY

Element	Method	D.L.	Element	Method	D. L.
Al	ICP	0.01%	Mn	ICP	1
As	INAA	0.5	Na	ICP	0.01%
Au	INAA	2 ppb	Nd	INAA	5
Ba	INAA	50	Ni	ICP	1
Ca	ICP	0.01%	Pb	ICP	2
Ce	INAA	3	Rb	INAA	5
Co	INAA	1	Sb	INAA	0.1
Cr	INAA	5	Sm	INAA	0.1
Cu	ICP	1	Tb	INAA	0.5
Eu	INAA	0.2	Th	INAA	0.2
Fe	INAA	0.01%	U	INAA	0.5
K	ICP	0.01%	V	ICP	2
La	INAA	0.5	Yb	INAA	0.2
Lu	INAA	0.05	Zn	ICP	1
Mg	ICP	0.01%			

(Detection limits (D.L.) in ppm unless otherwise noted)

TABLE 18-2
TOTAL PRECISION (FIELD PLUS ANALYTICAL) BY SIZE FRACTION FOR TEN SELECTED ELEMENTS

	Size Fraction / Precision		
Element	-250+125	-125+63	-63
Cu	32.5	40.3	42.1
Au	94.7	143.6	116.3
As	36.3	45.4	38.9
Sb	21.2	25.6	31.8
K	24.9	41.8	38.0
Fe	13.0	24.5	21.6
Mn	31.6	40.0	46.0
Ni	17.4	20.0	27.9
Co	16.2	29.7	24.3
Cr	26.5	36.0	30.1

Precision estimated at 95% confidence level
All values in percent and based on 13 duplicate pairs

ten elements from each size fraction. Total precision for each element is reasonable, ranging from ±13% (iron, -250+125 µm fraction) to ±45% (arsenic, -125+62.5 µm fraction). The notable exception is gold with precision ranging from ±95% (-250+125µm fraction) to ±144% (-125+62.5 µm fraction). Expectedly, analytical precision (Table 18-3) is less than the total precision for most elements, varying from ±4% (antimony, -250+125 µmfraction) to ±42% (potassium, -125+62.5µm fraction). Again, gold is an exception, with precision ranging from ±70%

TABLE 18-3
ANALYTICAL PRECISION BY SIZE FRACTION FOR TEN SELECTED ELEMENTS

	Size Fraction (microns)		
Element	-250+125	-125+62.5	-62.5
Cu	14.83	15.53	11.80
Au	106.3	69.58	183.76
As	26.91	15.84	14.67
Sb	3.94	14.12	8.57
K	20.29	41.69	27.40
Fe	19.17	10.48	9.52
Mn	13.88	9.13	4.99
Ni	17.47	18.74	7.87
Co	20.57	15.12	13.30
Cr	12.45	13.46	9.25

Precision estimated at 95% confidence level
Values expressed as percent relative standard deviation (%RSD) and based on 6 analytical duplicates

(–125+62.5 µm fraction) to ±184% (-62.5µm fraction). Analytical precision estimates are lowest in the -62.5µm fraction for seven of the ten elements (Cu, As, Fe, Mn, Ni, Co and Cr). Precision estimates for gold are lowest in the -125+62.5 µm fraction and highest in the -62.5–micron fraction. This suggests that grinding of the coarse (–250+125 µm fraction) or the use of a finer (-62.5 µm fraction) does not reduce sample variability when small (5 to 10 g) samples are analysed. The high variability of gold results from the occurrence of gold within the sample matrix as rare, discrete grains, resulting in the 'nugget effect' (Harris, 1982). Gold particles up to 100 microns in diameter are reported from the Mount Milligan deposit (Faulkner *et al.*, 1990). To provide a representative analysis of a sample containing gold grains of this size, analytical subsample sizes weighing 100 to 1000 grams are required, depending on the concentration of gold in the sample and the size fraction analysed (Clifton *et al.*, 1969). Sample weights used for gold analysis in this study (5 to 10 g) are not considered representative. Use of larger sample sizes or the analysis of heavy minerals from the two coarse fractions are possible methods of improving the reproducibility of the gold analyses. However, the presence of anomalous gold concentrations can be considered a reasonable indication of the presence of anomalous gold within the till. Background concentrations of gold, however, should not exclude the possibility that anomalous gold concentrations may be present.

CONCENTRATION OF ELEMENTS

Twenty-nine elements were selected for study (Cu, Au, Pb, Zn, As, Ba, Fe, Mn, Sb, Na, Ca, Mg, K, Al, Ni, Co, Cr, V, Rb, U, Th, La, Ce, Tb, Yb, Lu, Eu, Nd and Sm). Elements excluded from this study had an excess of values at or below analytical detection limits. Summary statistics for the selected elements are listed by size fraction in Table 18-4. Overall, median element values are highest in the -62.5µm

TABLE 18-4
SUMMARY STATISTICS FOR THE 29 ELEMENTS CONSIDERED IN THIS STUDY

-250+125 micron fraction

Element	Al	As	Au	Ba	Ca	Ce	Co	Cr	Cu	Eu	Fe	K	La	Lu	Mg	Mn	Na	Nd	Ni	Pb	Rb	Sb	Sm	Tb	Th	U	V	Yb	Zn
Minimum	0.88	0.5	2	730	0.39	19	17	57	16	0.7	2.19	0.06	10	0.14	0.36	233	1.42	5	14	2	30	0.4	1.8	0.5	1.4	0.5	29	1.1	23
Maximum	3.79	77.0	590	1500	1.93	56	71	330	652	1.9	8.11	0.93	31	0.70	2.26	1315	3.17	22	72	11	170	7.4	6.0	1.4	6.8	6.2	170	4.1	176
Mean	1.54	10	20	1123.2	0.7	28.6	27.6	140.7	74.9	0.92	4.62	0.12	13.9	0.29	0.86	528.9	2.49	11.7	25.3	4.8	66.8	2	2.87	0.56	2.79	1.15	81.4	1.79	45.9
Median	1.43	7.9	5	1100	0.67	26	25	130	53	0.9	4.32	0.10	13	0.27	0.78	453	2.51	11	24	4	65	1.6	2.7	0.5	2.5	1	80	1.7	37
Mode	1.48	11	2	1100	0.7	26	25	120	36	0.9	3.53	0.08	12	0.26	0.71	334	2.73	11	23	2	62	1	2.7	0.5	2.4	0.5	89	1.4	29
St Dev	0.53	8.78	60.87	132.11	0.2	7.16	8.15	48.22	78.73	0.18	1.18	0.10	3.95	0.08	0.32	224.5	0.36	3.7	8.58	2.31	18.33	1.2	0.68	0.15	0.98	0.84	21.76	0.48	25.05
C.V.	0.343	0.878	3.037	0.118	0.289	0.251	0.296	0.343	1.051	0.194	0.255	0.850	0.284	0.271	0.375	0.424	0.143	0.316	0.339	0.486	0.274	0.601	0.235	0.263	0.35	0.727	0.267	0.267	0.546

-125+62.5 micron fraction

Element	Al	As	Au	Ba	Ca	Ce	Co	Cr	Cu	Eu	Fe	K	La	Lu	Mg	Mn	Na	Nd	Ni	Pb	Rb	Sb	Sm	Tb	Th	U	V	Yb	Zn
Minimum	0.68	1.4	2	680	0.31	19	6	71	12	0.5	1.85	0.03	11	0.17	0.30	187	1.39	7	14	2	5	0.3	2.0	0.5	1.8	0.5	29	1.2	20
Maximum	3.93	89	1290	1600	1.85	82	40	370	730	2.2	7.16	0.78	47	0.60	2.18	1224	2.75	30	72	17	130	7.2	6.5	1.4	13	6.8	162	3.6	152
Mean	1.27	9.76	45.5	1005.8	0.62	29.5	17.7	173.6	73	0.91	4.24	0.08	15.3	0.29	0.73	467.3	2.21	13	25.1	5.2	56.6	2.11	3.09	0.58	3.27	1.31	83.6	1.92	41.9
Median	1.09	7.3	9	1000	0.59	27	16	170	50	0.9	4.28	0.06	14	0.28	0.66	394	2.28	12	24	5	56	1.7	2.9	0.5	2.9	1.2	83	1.9	36
Mode	1.06	11	2	1100	0.54	26	13	170	24	0.9	2.84	0.05	14	0.25	0.44	206	2.13	12	24	6	51	1.4	3	0.5	2.2	0.5	83	1.8	29
St Dev	0.53	9.89	173	135.52	0.19	8.75	7.46	53.74	85.78	0.19	1.04	0.10	5.06	0.06	0.31	227.6	0.29	4	8.19	2.6	18.97	1.22	0.75	0.18	1.56	0.94	22.61	0.41	21.97
C.V.	0.418	1.014	3.805	0.135	0.309	0.297	0.421	0.31	1.176	0.207	0.245	1.211	0.33	0.198	0.418	0.487	0.13	0.308	0.326	0.499	0.335	0.578	0.242	0.309	0.48	0.714	0.271	0.214	0.524

-62.5 micron fraction

Element	Al	As	Au	Ba	Ca	Ce	Co	Cr	Cu	Eu	Fe	K	La	Lu	Mg	Mn	Na	Nd	Ni	Pb	Rb	Sb	Sm	Tb	Th	U	V	Yb	Zn
Minimum	1.13	3.4	2	580	0.38	27	10	87	20	0.8	2.72	0.03	14	0.24	0.37	238	1.35	5	18	2	5	0.5	2.6	0.5	2.7	0.5	43	1.7	27
Maximum	4.03	160	732	1400	2.31	110	48	270	2182	2.5	8.24	1.26	72	0.63	2.32	2245	2.59	50	79	35	140	8	9.1	1.3	19	9.6	143	4.8	191
Mean	1.97	17.14	45.5	934	0.76	42.6	19.9	157.6	135.8	1.13	4.85	0.12	22.5	0.38	0.88	556.4	2.03	18.2	35.4	8.5	57.2	2.29	3.95	0.59	4.98	1.72	84.9	2.31	58.3
Median	1.86	12	17	930	0.75	40	19	150	76	1.1	4.66	0.08	21	0.36	0.76	483	2.07	17	33	7	56	1.8	3.7	0.5	4.5	1.7	85	2.3	49
Mode	1.62	11	3	1000	0.71	37	15	150	20	1.1	3.98	0.07	18	0.3	0.65	264	2.01	15	37	6	5	1.2	3.6	0.5	3.9	0.5	75	2	33
Range	2.9	156.6	730	820	1.93	83	38	183	2162	1.7	5.52	1.23	58	0.39	1.95	2007	1.24	45	61	33	135	7.5	6.5	0.8	16.3	9.1	100	3.1	164
St Dev	0.55	20.15	88.01	139.22	0.23	12.45	7.32	37.03	228.8	0.21	1.2	0.14	7.39	0.08	0.38	281.6	0.25	5.95	11.14	5.26	23.63	1.53	0.91	0.19	2.04	1.19	18.57	0.44	28.74
C.V.	0.279	1.175	1.933	0.149	0.305	0.292	0.368	0.235	1.685	0.185	0.247	1.195	0.329	0.222	0.426	0.506	0.121	0.327	0.315	0.622	0.413	0.67	0.231	0.329	0.41	0.69	0.219	0.19	0.493

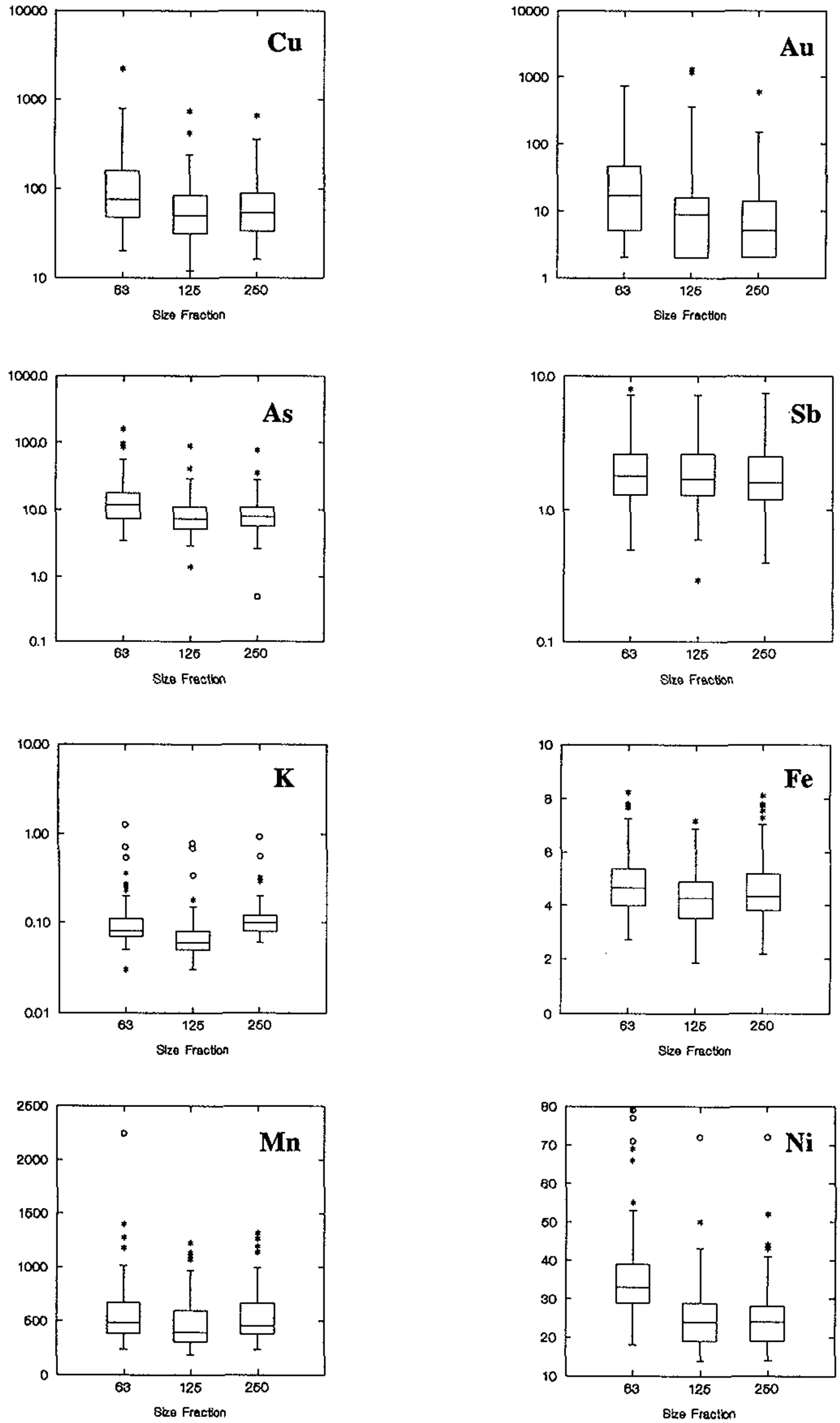

Figure 18-4. Box plots of element concentrations by size fraction for eight selected elements.

fraction, accounting for 21 of the 29 elements. Maximum element abundances also occur most frequently (20 of 29 elements) in the -62.5 µm fraction. Box plots (Figure 18-4) for eight selected elements highlight the range and distribution of element concentrations for the three size fractions.

TABLE 18-5
CORRELATIONS BETWEEN SIZE FRACTIONS FOR TEN SELECTED ELEMENTS

	Correlation between fractions		
Element	-250+125 vs -125+62.5	-250+125 vs -62.5	-125+63 vs -62.5
Cu	0.988	0.936	0.911
Au	0.619	0.562	0.836
As	0.973	0.921	0.898
Sb	0.855	0.904	0.793
K	0.927	0.870	0.755
Fe	0.762	0.790	0.691
Mn	0.884	0.800	0.623
Ni	0.891	0.803	0.796
Co	0.671	0.837	0.532
Cr	0.649	0.753	0.615

N = 108 Rsig(.95) = 0.159

Concentration ranges for each size fraction generally overlap one another. Median values for copper, gold, arsenic and nickel in the -62.5-micron fraction and potassium in the -250+125 micron fraction either equal or exceed the 75th percentile value of the two other fractions. In the -62.5-micron fraction, less than 10% of the gold values are at or below detection limit. Detection limit concentrations for gold in the -125+62.5 and -250+125 micron fractions, however, constitute 30 and 40% of the data respectively.

Four elements, arsenic, gold, copper and potassium, have coefficients of variation (C.V.) which exceed 0.70 in all three size fractions (Table 18-4). Garrett *et al.* (1980) showed that elements with coefficients of variation less than 0.70 provide little geochemical indication of mineralization. Significant correlations for all elements between size fractions (Table 18-5) suggest a similar origin for the sediment of each size fraction.

PATHFINDER ELEMENTS

Symbol plots based on thresholds derived from probability plots were used to determine which elements reported higher concentrations in the vicinity of the Mount Milligan deposit. Based on this estimate, potential pathfinder elements for each size fraction were selected from the original group of twenty-nine. Table 18-6 lists the selected

TABLE 18-6
POPULATION DISTRIBUTIONS AND ANOMALY THRESHOLDS FOR PATHFINDER ELEMENTS

	-250+125 micron fraction						-125+62.5 micron fraction						-62.5 micron fraction					
Element	N	Transf	Popl'n	% of Data	Popl'n Mean	Thresh	N	Transf	Popl'n	% of Data	Popl'n Mean	Thresh	N	Transf	Popl'n	% of Data	Popl'n Mean	Thresh
Cu	107	Arith	1	71.0	41.9	73	107	Log	1	47.0	27.7	43	107	Arith	1	70.0	61.5	119
			2	19.0	99.0	114			2	53.0	85.1				2	15.5	160.0	148
			3	10.0	180.0										3	14.5	291.0	
Au	80	Log	1	60.0	7.8	16	75	Log	1	12.0	3.2	4	83	Log	1	65.0	14.8	40
			2	31.0	27.8	65			2	73.0	11.7	32			2	35.0	91.2	
			3	9.0	113.5				3	15.0	102.3							
As	107	Log	1	61.0	5.8	8.9	107	Log	1	71.0	5.9	10.1	108	Log	1	40.0	8.3	10.7
			2	31.0	11.8	16.6			2	22.5	12.8	17.6			2	35.0	12.8	14.2
			3	8.0	23.6				3	6.5	28.2				3	25.0	30.2	
Sb	106	Log	1	60.0	1.27	2.0	108	Log	1	92.0	1.70	3.6	108	Log	1	87.0	1.69	3.2
			2	32.0	2.55	3.7			2	8.0	5.06				2	13.0	5.18	
			3	8.0	4.63													
									3									
K	104	Arith	1	70.0	0.083	0.11	106	Arith	1	66.0	0.045	0.07	105	Log	1	92.0	0.063	0.15
			2	24.0	0.123	0.14			2	29.0	0.092	0.11			2	8.0	0.224	
			3	6.0	0.171				3	5.0	0.150							
Co	106	Log	1	94.0	25.4	34.5	107	Log	1	55.0	12.2	16.7	108	Log	1	45.0	13.4	17.3
			2	6.0	39.4				2	45.0	24.0				2	45.0	22.1	25.9
															3	10.0	33.9	
Fe							108	Log	1	44.0	3.34	4.35	108	Log	1	85.0	4.41	5.90
									2	46.0	4.70	5.45			2	15.0	7.00	
									3	8.0	6.46							
Mn							108	Log	1	47.0	281	382	95	Log	1	83.0	150.4	186.7
									2	24.0	441	501			2	17.0	203.7	
									3	29.0	737							

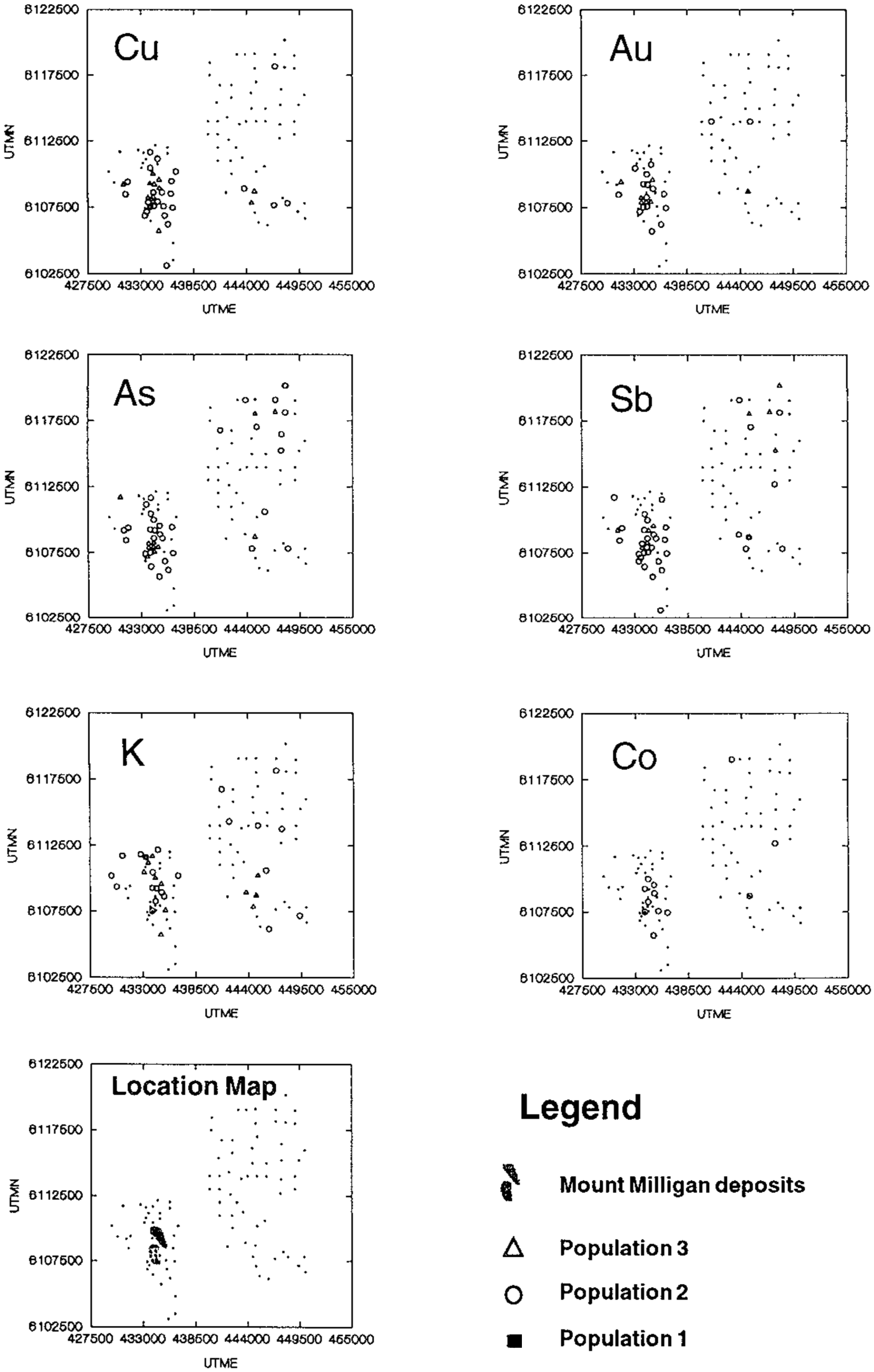

Figure 18-5. Spatial distribution of selected elements, -250+125 μm fraction.

elements for each size fraction and corresponding values calculated from probability plots. Two or three population models were defined for each element. Two population models were defined as background (population 1) and anomalous (population 2) populations. Elements displaying three populations were subdivided into background (population 1), intermediate (population 2) and anomalous (population 3) populations. Those elements not included as pathfinders showed either unimodal distributions or higher concentrations in the eastern half of the study area underlain by Wolverine Complex metamorphic rocks.

-250+125 MICRON FRACTION

Anomalous populations of the elements copper, gold, arsenic, antimony, potassium and cobalt in the -250+125-micron fraction occur above and in the immediate vicinity of the Mount Milligan deposit (Figure 18-5). Three populations are observed for copper, gold, arsenic, antimony and potassium whereas cobalt is represented by two populations. In general, copper, gold, arsenic, antimony and potassium show mixtures of populations 2 and 3 in the vicinity of the deposit. Tight groupings of anomalous (population 3) copper, gold and arsenic concentrations lie directly above the Southern Star deposit. A mixture of population 2 and 3 concentrations for arsenic and antimony are found in the northeast corner of the study area. A coincident group of copper, potassium, arsenic and antimony population 2 and 3 concentration sites are present in the southeast corner of the study area, near the northern end of the Philip Lakes.

-125+62.5 MICRON FRACTION

Eight elements in the -125+62.5-micron fraction, copper, gold, arsenic, antimony, potassium, cobalt, iron and manganese, are anomalous in tills overlying and in the vicinity of the deposit (Figure 18-6). Three populations are defined for gold, arsenic, potassium, iron and manganese. A two-population model was applied to copper, antimony and cobalt. Most of the sample sites west of Rainbow Creek are anomalous in copper and cobalt. Population 2 gold values occur throughout the study area, whereas anomalous (population 3) gold concentrations are found overlying the Southern Star deposit. North and east of Philip Lakes, a similar group of anomalous (population 3) values are present for copper, cobalt, iron and manganese. Population 2 and 3 concentrations of potassium overlie the MBX deposit, but are conspicuously absent over the Southern Star deposit. Broad areas of population 2 values for gold, manganese and potassium are observed in the northeast quadrant of the study area. Anomalous manganese concentrations are found throughout the study area, but appear to be prevalent near the deposit. Antimony anomalies are rare in this fraction except for two small, adjacent areas over the deposit.

-62.5 MICRON FRACTION

The elements copper, gold, arsenic, antimony, potassium, cobalt, iron and chromium provide anomalous values in the -62.5-micron fraction of samples overlying and surrounding the deposit (Figure 18-7). Three populations of data are observed for copper, arsenic and cobalt whereas gold, antimony, potassium, iron and chromium are represented by a two-population model. Copper, arsenic, antimony and iron are anomalous above the Southern Star zone. Intermediate and/or anomalous populations of arsenic and cobalt are present in the northeast quadrant of the study area. An east-west linear group of intermediate and anomalous concentrations of copper, arsenic, cobalt and iron is present east of Philip Lakes. With the exception of three sites, anomalous gold concentrations are restricted to the area west of Rainbow Creek. As in the -125+62.5-micron fraction, anomalous potassium values are found overlying the MBX zone but not over the Southern Star zone. Anomalous chromium values are present along the southern edge of the Southern Star zone and above the MBX zone.

CLUSTER ANALYSIS

The elevated concentrations of these elements in the vicinity of the deposit may be a result of differences in rock types between the Mount Milligan area and the area east of Rainbow Creek. To test this possibility, samples underlain by the Witch Lake formation, a primary host for the Mount Milligan deposits, were analysed by cluster analysis to determine associations between the selected elements. An assumption of this test is that the sediment of each site is derived locally. Figure 18-8 shows the results of Pearson cluster analysis on the data for 66 samples underlain by Witch Lake rocks. In the -250+125 fraction, close groupings between copper-antimony-arsenic and cobalt-potassium are observed whereas gold shows a weaker association with the other elements. In the -125+62.5-micron fraction, strong clustering is evident within and between the groups copper-cobalt-manganese-iron and arsenic-antimony. Associations between gold and potassium with the remaining elements are less developed. Element correlations in the -62.5-micron fraction fall into two groups, gold-antimony-arsenic and copper-iron-cobalt, which also associate closely with each other. The remaining elements, potassium and chromium, are not strongly associated with either of these two groups.

Observed element clusters for each size fraction appear to be a result of primary bedrock relationships and the effect of differential weathering of the till size-fractions. Associations in the coarse fraction (-250+125 µm) indicate a grouping between mineralization (copper-antimony-arsenic) and lithology/alteration (cobalt-potassium) elements. In the –125+62.5 µm fraction, the clustering of copper-cobalt-manganese-iron and arsenic-antimony suggests that iron (±manganese) oxides are present and have adsorbed copper, arsenic and antimony liberated from oxidized sulphides. Strong associations between cobalt, iron and manganese are either the result of cobalt in the crystal lattice of primary iron minerals or the result of the preferential adsorption of cobalt by iron or manganese oxides in soils (Kabata-Pendias and Pendias, 1991). Closer grouping of cobalt-iron-copper and arsenic-antimony-gold in the -62.5-micron fraction further suggests that these elements have become bound to iron oxides. The poor association of gold with other elements in the two coarsest fractions, and its stronger association with cobalt-iron-copper and arsenic-antimony in the -62.5-micron fraction, probably represents the liberation of fine-grained

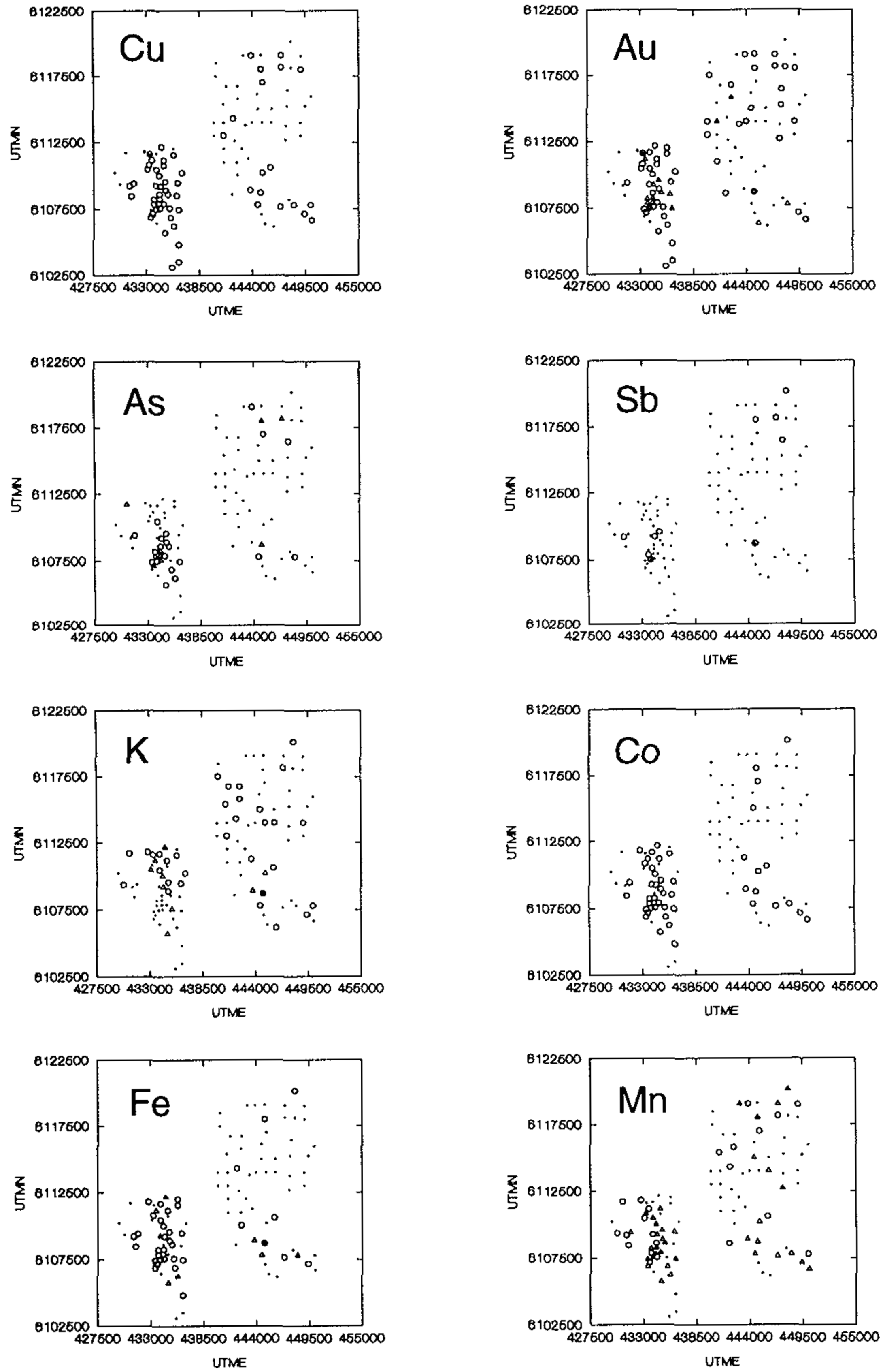

Figure 18-6. Spatial distribution of selected elements, -125+62.5 µm fraction.

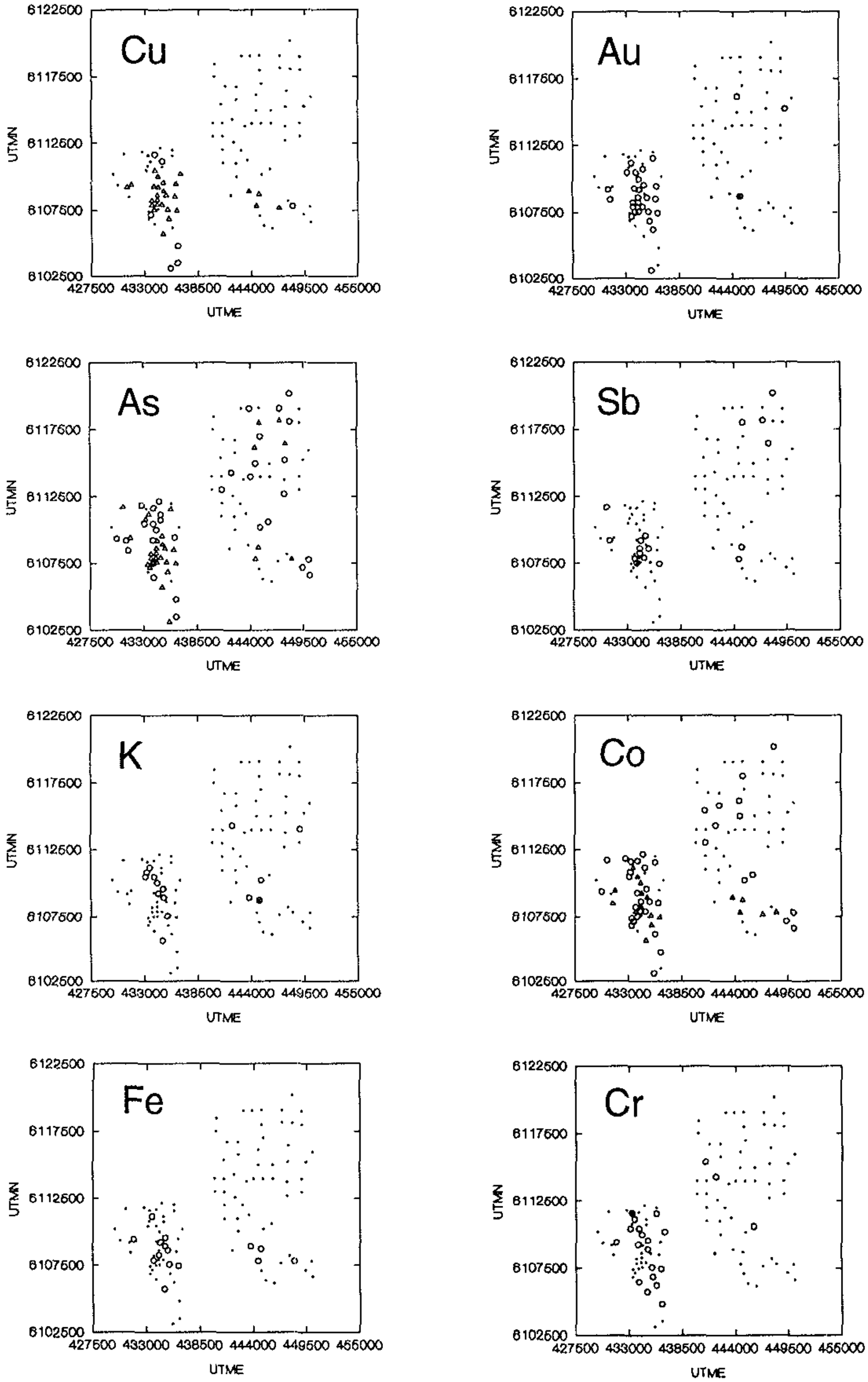

Figure 18-7. Spatial distribution of selected elements, -62.5 μm fraction.

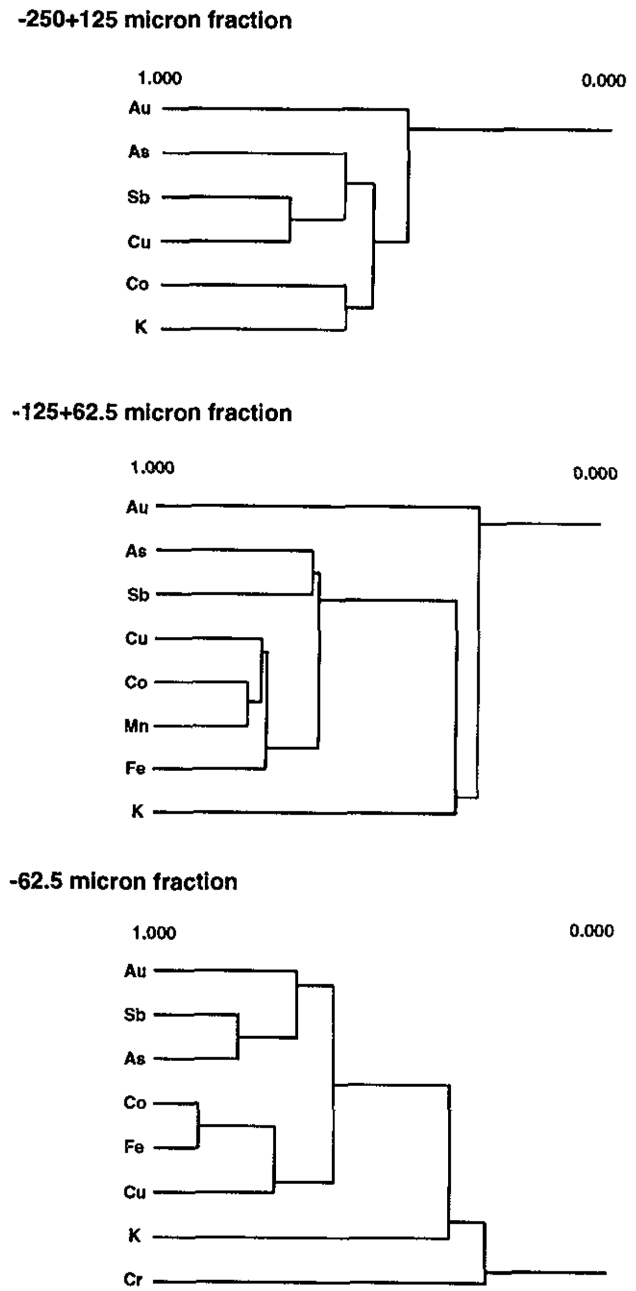

Figure 18-8. Results of cluster analysis on 66 samples underlain by Witch Lake formation rocks.

gold from sulphides during weathering and incorporation into iron oxides.

Based on spatial distributions and inter-element associations, copper, gold, arsenic, antimony and potassium are considered pathfinders for the Mount Milligan deposit in all three size fractions. Iron is a pathfinder element in the -125+62.5 and -62.5 µm fractions. The mineralogy of the deposit suggests that anomalous concentrations of copper and gold originate primarily from the porphyry deposit, whereas anomalous arsenic and antimony are probably derived from polymetallic veins, such as the Esker vein, peripheral to the porphyry mineralization. Anomalous iron concentrations are a product of both the porphyry/vein mineralization and the extensive pyrite halo surrounding the deposit. The remaining elements, cobalt, manganese and chromium, reflect secondary weathering processes or variations in source lithology. Weak, but significant associations between potassium and the pathfinder elements are apparent. DeLong *et al.* (1991) observed a direct correlation between bedrock concentrations of copper and gold and the intensity of potassic alteration in the deposit. The weak association of potassium with the other pathfinders reflects the difference in mineral phases hosting copper, gold, arsenic, antimony (sulphides) and potassium (silicates) and the analytical methods used. Aqua regia decomposes silicates (*eg.* potassium feldspar) incompletely, whereas sulphides are almost completely dissolved. Instrumental neutron activation analysis, used for the determination of gold, arsenic and antimony, provide total element concentrations. Therefore, determination of potassium by aqua regia - ICP may only partially represent the actual potassium content of a sample, whereas copper, gold, arsenic and antimony values represent the total concentration. Clays, which contain significant potassium, are readily decomposed by aqua regia. It is possible that the source of potassium anomalies associated with the deposit originate from potassic or propyltically altered bedrock weathered to produce clays amenable to digestion by aqua regia.

THRESHOLDS AND CONTRASTS

Summary information on the population distributions estimated from probability plots and the resultant thresholds for the pathfinder elements are listed in Table 18-6. Table 18-7 reports contrast ratios calculated for these elements. Contrast ratios are a measure of the difference between anomalous and background values, indicating the ability of a sample medium to distinguish between mineralized and unmineralized bedrock sources. The ratios were derived by dividing the mean of the anomalous population by the mean of the background population. Ratios for the elements, copper, arsenic, antimony, iron and potassium range from approximately 1.5 to 5, whereas gold contrasts are higher, varying from 6 to 15. With the exception of gold, differences in contrast ratios between size fractions are relatively low, not exceeding 65%. For gold, contrast ratios decrease with decreasing size fraction. However, poor reproducibility due to the nugget effect makes the gold contrast ratios strongly suspect.

TABLE 18-7
CONTRAST RATIOS CALCULATED FOR PATHFINDER ELEMENTS

	Size Fraction (microns)		
Element	-250+125	-125+62.5	-62.5
Cu	4.30	3.07	4.73
Au	14.55	8.71	6.16
As	4.08	4.82	4.79
Sb	3.65	5.06	3.07
K	2.06	3.33	2.70
Fe	1.84	1.37	1.59

The similarity in contrast ratios suggests that there is little difference in the ability of the size fractions to distinguish between mineralized bedrock and background bedrock sources. Although threshold values differ between fractions, each fraction provides a similar definition between anomalous and background sources. Corresponding copper, gold, arsenic, antimony and potassium anomaly patterns for each size fraction support this interpretation (Figures 18-5, 6 and 7).

DISPERSAL LENGTH AND SAMPLING DENSITY

Estimation of dispersal distances from Mount Milligan is complicated by the presence of a wide band of glaciofluvial sediment, 3 to 5 kilometres wide, infilling the valley of Rainbow Creek. A broad zone of anomalous multi-element concentrations centred over the Mount Milligan deposit has an approximate dimension of 3 by 3 kilometres (Figures 18-5, 6 and 7). Clusters of elevated and/or anomalous concentrations of arsenic and antimony occur in all three size fractions up to 15 kilometres northeast (down-ice) from the deposit (Figures 18-5, 6 and 7). Anomalous or elevated copper, gold and potassium values in the -125+62.5-micron fraction are also observed in the northeast quadrant of the study area as far as 15 kilometres from the deposit. However, the patterns exhibited by these elements east of Rainbow Creek suggest they reflect local lithological differences (*eg.* Witch Lake formation *versus* Wolverine Complex) and not down-ice dispersal from Mount Milligan.

Northeast of Philip Lakes, coincident anomalous and/or elevated concentrations of copper in all three fractions form an east-west elongate pattern perpendicular to ice-flow direction (Figures 18-5, 6 and 7). Similar patterns, albeit less well defined, are also observed for arsenic and potassium. Elevated patterns for gold and antimony are not evident. Mineralized boulders and limited exposures of sheared, altered and weakly mineralized volcanic rocks have been reported along the north shore of the Philip Lakes (Cooke, 1989; 1991). Struik (1992) has mapped a northwest-trending fault which parallels the north shore of the Philip Lakes (Figure 18-2), to which the mineralization is probably related. It is highly likely that the east-west elongate pattern of elevated element concentrations results from the glacial dispersal of altered or mineralized bedrock localized along this fault. Background concentrations in till samples from adjacent to the eastern arm of the Philip Lakes (Figures 18-5, 6 and 7) imply that these samples are up-ice of the fault zone. Using this as a limit to the up-ice extent of mineralization, a maximum dispersal distance of 4 to 6 kilometres can be estimated for this area, based on element distribution patterns. Interestingly, distinct dispersal patterns are observed for iron, manganese and cobalt in the -125+62.5-micron fraction and iron and cobalt in the -62.5-micron fraction. This may reflect the concentration of iron oxides in the finer fractions of the till resulting from the weathering of sulphides.

Dispersal distances of approximately 5 kilometres and probably not more than 10 kilometres place constraints on the necessary sampling density required to detect the Mount Milligan deposit. Sinclair (1975) has demonstrated that to maximize the detection of elliptical-shaped anomalies (such as ribbon or fan-shaped anomalies in till) a sampling density corresponding to $\sqrt{2}/2$ times the length and width of the anomaly is required. Assuming an anomaly width of 3 kilometres (the width of the Mount Milligan anomaly) and a dispersal length of 5 kilometres, till samples collected on a 3.5 by 2-kilometre grid (long axis parallel to ice-flow direction) should intersect dispersal trains from porphyry mineralization similar to Mount Milligan. Changes in the alignment of the grid, resulting from variations in ice-flow direction, could be eliminated by reducing the grid spacing to 2 by 2 kilometres. Lower sampling densities could be used, but the probability of detecting mineralization would decrease.

SELECTION OF BEST SIZE FRACTION

Selection of the best size fraction for use in regional till surveys should provide a fraction with the best data quality, highest overall anomaly contrast and the most diagnostic dispersal patterns which indicate the source of mineralization. Results of this study indicate that there are few differences between the three size fractions in the Mount Milligan area. Similar pathfinder elements and contrast ratios exist in each fraction. The limited number of field and analytical duplicates suggest that no increase in data quality is provided by prefering one fraction over another. Relationships between elements in each fraction suggest that the products of weathered sulphides are preferentially concentrated in the finer fractions, probably associated with iron oxides. Median element concentrations are higher in the -62.5-micron fraction, most notably for gold, where detection limit values comprise less than 10% of the data. Shilts (1984) has noted that most metals preferentially concentrate in the fine fractions of till, specifically in the clay fraction. DiLabio (1985) has noted that gold concentrations are higher in the finer fractions of weathered till, reflecting the original grain size of gold in the deposit and the grain size of gold adsorbing phases. Based on these observations, the -62.5-micron till fraction is recommended as the best size fraction for defining the presence of the Mount Milligan deposit. Although similar results would also be achieved using the two coarse fractions, the -62.5-micron fraction provides the advantage of significantly fewer detection limit values for gold.

CONCLUSIONS

Based on the foregoing, the following conclusions regarding the till geochemistry of the Mount Milligan area and recommendations for regional geochemical drift exploration surveys may be drawn:

- Pathfinder elements for the Mount Milligan deposit include copper, gold, arsenic, antimony and potassium. Iron may also be a suitable indicator of pyrite alteration halos often associated with mineral deposits of this type.
- There is very little difference in the geochemical responses of the three media. Analysis of either the -250+125, -125+62.5 or -62.5-micron size fraction of weathered till provides similar patterns which indicate the presence of the Mount Milligan deposit.

- Analysis of the -62.5-micron fraction is preferred, however, due to its higher element concentrations; especially in the case of gold.
- Dispersal lengths of approximately 5 kilometres from the deposits are observed. Longer dispersal distances, on the order of 10 to 15 kilometres, are not readily apparent.
- Sampling densities for regional till surveys of one sample per 4 square kilometres (2 by 2 kilometre grid spacing) are recommended for porphyry copper-gold exploration.

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LAKE SEDIMENT VERSUS STREAM SEDIMENT GEOCHEMISTRY FOR REGIONAL MINERAL EXPLORATION IN THE INTERIOR PLATEAU OF BRITISH COLUMBIA

By Steven Earle, Grasswood Geoscience

INTRODUCTION

Regional geochemical programs are carried out with the objective of evaluating large areas of land effectively and efficiently, and experience has shown that the sediments from drainage systems, either stream sediments or lake sediments, are the most useful media for regional surveys in many parts of the world (Rose *et al.*, 1979). Drainage surveys are particularly applicable to regional exploration because a single sample can provide information about the geochemistry of a relatively large area. The usefulness of that information will depend on a variety of different factors, such as the size of the drainage basin, the relative mobility of elements within the drainage system, the characteristics of the sample material available, and the consistency of the geochemistry at sampling sites.

Stream sediment geochemistry has been applied in many different terrains, and under both wet and dry climatic conditions. Lake sediment geochemistry has been applied most commonly in low-relief areas where stream drainage systems are not well developed and where the climate and topography are such that lakes are abundant.

The choice between using lakes and streams for sampling has been largely based on the criterion of finding enough sample sites for adequate regional coverage. If lakes are few and far between there is little point in trying to use lake sediment geochemistry. If streams are poorly developed or difficult to reach, there is little point in trying to use stream sediment geochemistry. In areas where both lake and stream sampling sites are well distributed, a choice between the two media should be based on a consideration of which provides the most useful exploration data.

One important factor controlling the quality of a regional sampling survey is the consistency of the mechanical and chemical composition of the sample medium, in particular the proportions of clay-sized material, iron and manganese oxides and hydroxides, and organic matter. Another critical factor is the consistency of geochemical conditions at the sample sites, that is the degree of variability in parameters such as pH and oxidation potential.

In most high-relief areas streams are rich in sediment, and the sediment is predominantly clastic in composition, with little organic matter. As a result, it is possible to collect relatively consistent samples over large areas. An exception to this observation is in the rain forest of the Pacific Coast of British Columbia, where stream sediment contents are commonly quite low. Here fine-grained sediments trapped within mosses have been found to provide a consistent sampling medium (Matysek and Day, 1988).

In low-relief areas streams are typically characterized by low levels of clastic sediment, with highly variable organic matter compositions. In many such areas lakes are well distributed, and in comparison with the stream sediments, lake-centre sediments and lake-bottom environments are physically and chemically consistent. It has been shown that sediments from the deeper basins of lakes can be sampled quickly and inexpensively (Coker *et al.*, 1979).

Due to the relatively steep topography of the Cordillera, stream sediment geochemistry has been the sampling medium of choice throughout much of British Columbia. This is not necessarily because of a scarcity of lakes, as lakes are quite common even in some of the most mountainous terrains, but because stream sediment geochemistry has been shown to be an effective exploration method in many areas, and there has been some reluctance to experiment with other techniques.

In contrast to the adjacent mountain belts, the Interior Plateau region of British Columbia is characterized by relatively subdued topography. In many parts of this region stream drainage systems are not well developed, but lakes are abundant. As shown on Figure 19-1, the Interior Plateau extends through the central part of the province, from the

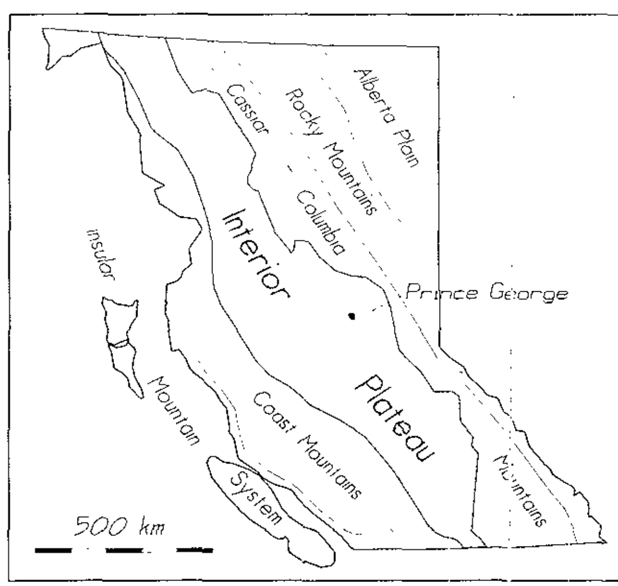

Figure 19-1. Physiographic regions of British Columbia (after Farley, 1979).

United States border to the Yukon border, and reaches a maximum width of approximately 400 kilometres in the Prince George area.

The objective in this paper is to compare the effectiveness of stream sediment *versus* lake sediment geochemistry in the Interior Plateau region. Previous work in the application of lake sediment geochemistry in this environment is reviewed, and comparative results of stream sediment and lake sediment sampling programs are described and discussed.

PREVIOUS WORK

Although several reports have been published concerning the application of lake sediment geochemistry to exploration in British Columbia, very little attention has been focused on the issue of the relative effectiveness of lake sediments *versus* stream sediments, either in British Columbia or elsewhere.

A lake sediment sampling program in the Salmon and Muskeg rivers area (NTS 93J) was reported by Spilsbury and Fletcher (1974). Near-shore clastic lake sediments were collected, and although it was noted that copper and zinc contents were related to iron and sand contents, the authors concluded that the drift cover in the area had the effect of masking geochemical differences which might have been related to bedrock variations.

Hoffman (1976) and Hoffman and Fletcher (1976) reported the results of a 500-sample lake sediment program carried out in the Nechako River drainage basin (NTS 93F and 93G). In this case organic-rich samples were collected from the centres of the lake basins, and it was shown that lake sediment geochemistry reflects regional variations in bedrock lithology, and that lake sediment anomalies are associated with all known mineral occurrences. In detailed geochemical studies around areas of copper and molybdenum mineralization at Capoose Lake, Hoffman and Fletcher (1981) showed the strong response of copper and molybdenum in lake sediments, but pointed out that within-lake geochemical variations can be considerable. Positive results were also obtained by Mehrtens *et al.* (1973), Mehrtens (1975) and Hoffman and Fletcher (1981) in the Chutanli area. In this case there is some evidence that molybdenum anomalies in lake sediments provide a larger exploration target than those in stream sediments. The geochemistry of stream sediments, soils, bogs, surface water and vegetation in the Capoose area has also been studied by Boyle and Troup (1975).

The results of a 2797-sample lake sediment survey carried out in the western part of the Nechako Plateau (NTS 93E, 93F, 93K and 93L) were described by Gintautas (1984) and Gintautas and Levinson (1984). Again, a close relationship between lake geochemistry and that of the drainage-basin rock type was observed. Gintautas also pointed out the relatively high degree of limnological variability in this area.

An assessment of the applicability of lake sediments for regional geochemical surveys within NTS sheet 93C, 93F and 93K of the Nechako Plateau was carried out by Earle (1993). It was concluded that regional lake sediment surveys would be feasible within this area, although the lake density is relatively low in some parts of the region. This study included a comparison of the Regional Geochemical Survey (RGS) lake and stream sediment data from the eastern part of map sheet 93L, which showed that, around mineralized areas, the response in lake sediments is equivalent to or more pronounced than that for stream sediments. The importance of considering limnological variability in interpreting lake sediment geochemistry in the Nechako region was stressed.

A field study of lake sediment geochemistry in the Nechako Plateau area was recently carried out by the British Columbia Geological Survey Branch (Cook, 1993).

COMPARISON OF LAKE SEDIMENT AND STREAM SEDIMENT DATA SETS

Lake and stream sediment data sets from the Bulkley River area (93L), and from the Gibraltar mine area (93B) have been compared, with the objective of determining which type of data most clearly reflects the known mineral deposits in these regions. The study areas are shown on Figure 19-2.

BULKLEY RIVER AREA

Both stream and lake sediment samples were collected from the eastern part of map sheet 93L, as part of a 1987 RGS program (Johnson *et al.*, 1987). Within this area, stream sediments were collected at 353 sites, while lake sediments were collected at 218 sites. In order to compensate for the discrepancy in numbers of samples, the distributions have been smoothed to a 2500-metre square grid, using 1500-metre radius circular smoothing windows, and inverse distance weighting. Inter-element relationships have also been examined and, where appropriate, a linear regression procedure has been used to compensate for apparent dependencies on organic matter and iron and manganese levels. The smoothed distributions for gold, silver and

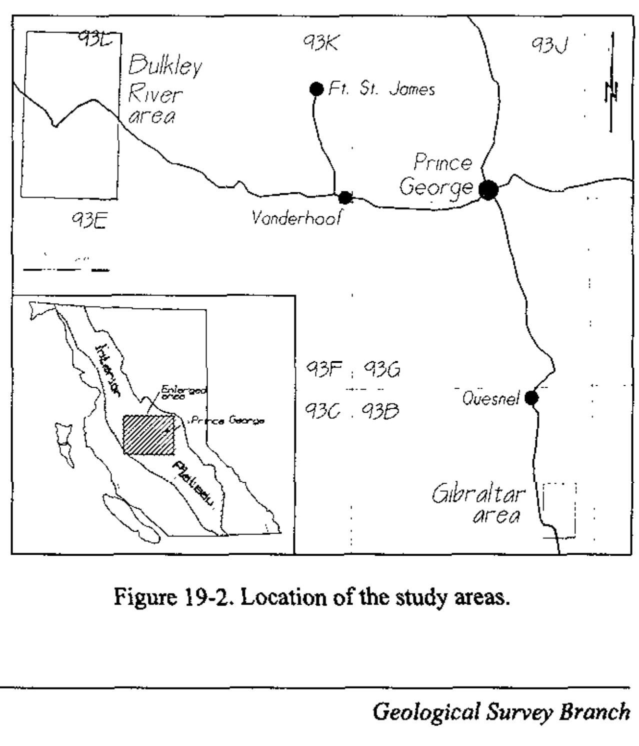

Figure 19-2. Location of the study areas.

zinc are included here as Figures 19-3, 4 and 5. Spatial variations in the data are portrayed using differing symbol sizes, where the cutoff levels are based on percentiles. The 70, 80, 90 and 95th percentiles have been used where practical, although in some cases, there is too little variability in the data for this to be feasible. Gold, silver and zinc mineral occurrences, taken from the MINFILE map for 93L, are also shown on these figures.

Smoothed distributions of gold in stream and lake sediments are shown on Figure 19-3. In the stream sediments there are strong anomalies around Dome Mountain, Cronin and Equity Silver, but there are also numerous anomalies in the western part of the study area, distant from any known mineral occurrences. In the lake sediments there are strong anomalies at Cronin, to the west of Dome Mountain, to the south of Grouse Mountain, to the west of Equity Silver, and at Silver Queen. There are numerous gold anomalies along the western shore of Babine Lake and in the area south of Silver Queen, both areas where no significant gold mineralization is known. The range of gold concentrations in lake sediments is much lower than that for stream sediments. In both cases the background is around 3 ppb. The 97th percentile is 25 ppb for stream sediments, and only 7 ppb for lake sediments.

Smoothed distributions of silver in stream and lake sediments are shown on Figure 19-4. In this case the silver residual, as determined from regression with manganese, iron and LOI as the independent variables, is plotted for the lake sediments. The silver distribution in stream sediments is very irregular, and although there are anomalies in some of the mineralized areas, there are many other anomalies in presumed background areas. The lake sediment silver distribution is more clearly defined. There are strong anomalies around the silver-zinc mineralization at Grouse Mountain and at Silver Queen, and also to the east of Richfield Creek.

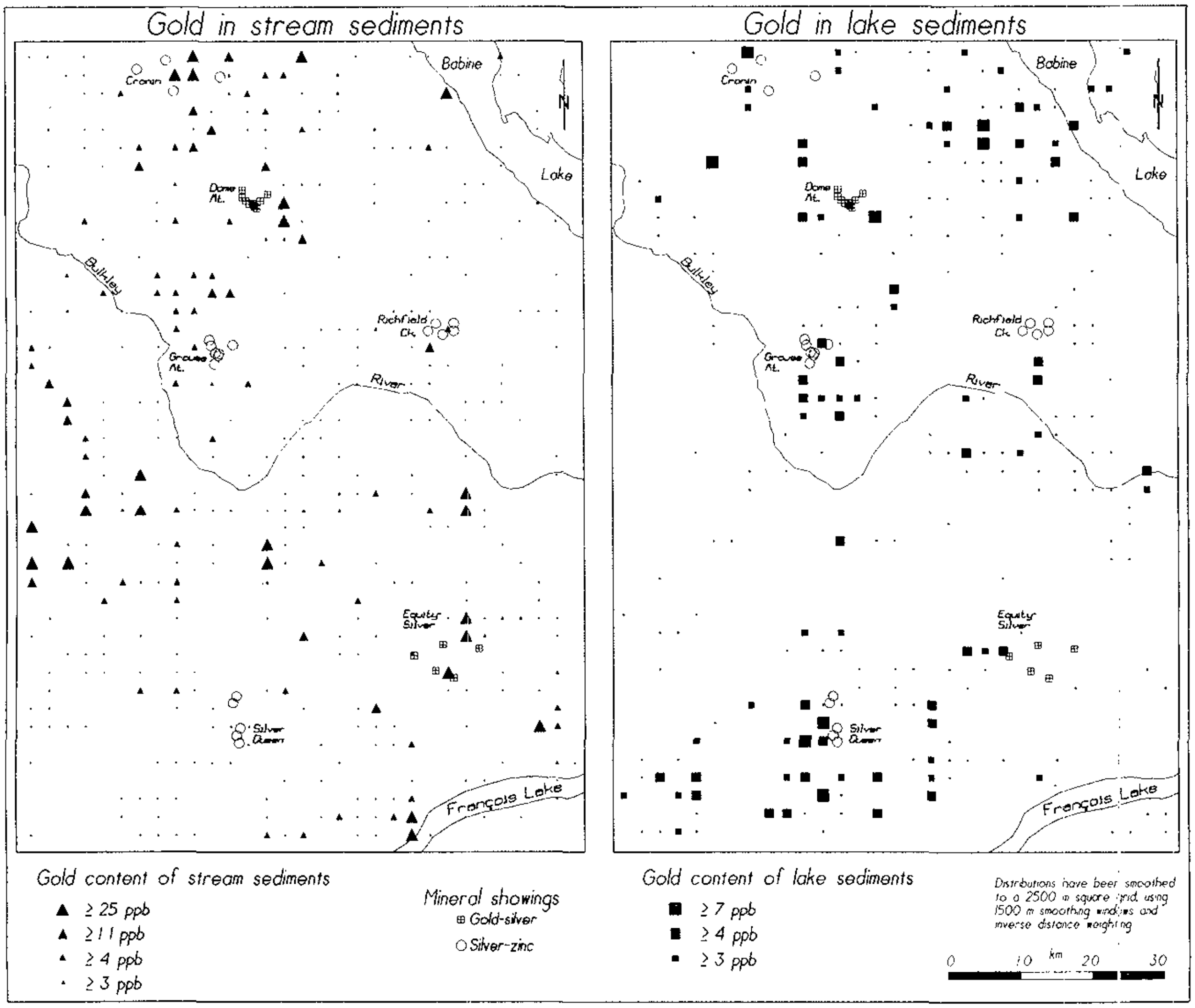

Figure 19-3. Regional distribution of gold in lake and stream sediments in the Bulkley River area (93L).

There are isolated silver anomalies near Equity Silver, Dome Mountain and Cronin.

The zinc distributions are shown on Figure 19-5, and in this case residuals are plotted for both stream and lake sediments, following regression against iron and manganese for the lake sediments and against iron, manganese and organic matter for the stream sediments. The stream sediment zinc distribution is again quite irregular. There are strong anomalies in the Cronin area and to the west of Silver Queen, but there is also an extensive anomaly southwest of the Bulkley River, within what is presumed to be a background area. In the lake sediments there are strong and well defined zinc anomalies associated with the silver-zinc mineralization at Silver Queen and Grouse Mountain, and there are several other anomalies scattered around the study area.

A more detailed look at the lake and stream sediment gold distributions in the Dome Mountain and Grouse Mountain areas is given on Figure 19-6. The Dome Mountain area is characterized by quartz veins within Hazelton Group tuff and andesite. The veins are mineralized with galena, arsenopyrite, pyrite and sphalerite (MINFILE 93L 022). The Dome Mountain or Forks deposit is one of several similar occurrences in this area, which have been known since 1914 (McIntyre, 1985). Ore was shipped from the deposit in 1938 and 1940, and again during 1992 and 1993. Production ceased in June of 1993, but resumption is planned (Northern Miner, 1993b). Reserves are currently estimated at 325 000 tons grading 12.3 grams gold per tonne (Northern Miner, 1993a). At Grouse Mountain, silver, zinc, copper and gold-bearing veins are also hosted by Hazelton Group volcanic rocks.

There are several very strong gold anomalies in stream sediments draining the eastern side of the Dome Mountain area, but there is only one strong lake sediment gold anomaly. On the other hand, there are several moderate lake sediment gold anomalies in the Grouse Mountain area, but the only significant stream sediment gold anomaly is in one sample collected from approximately 5 kilometres to the north of the showings. To some extent these discrepancies can be attributed to the sampling pattern. At Dome Moun-

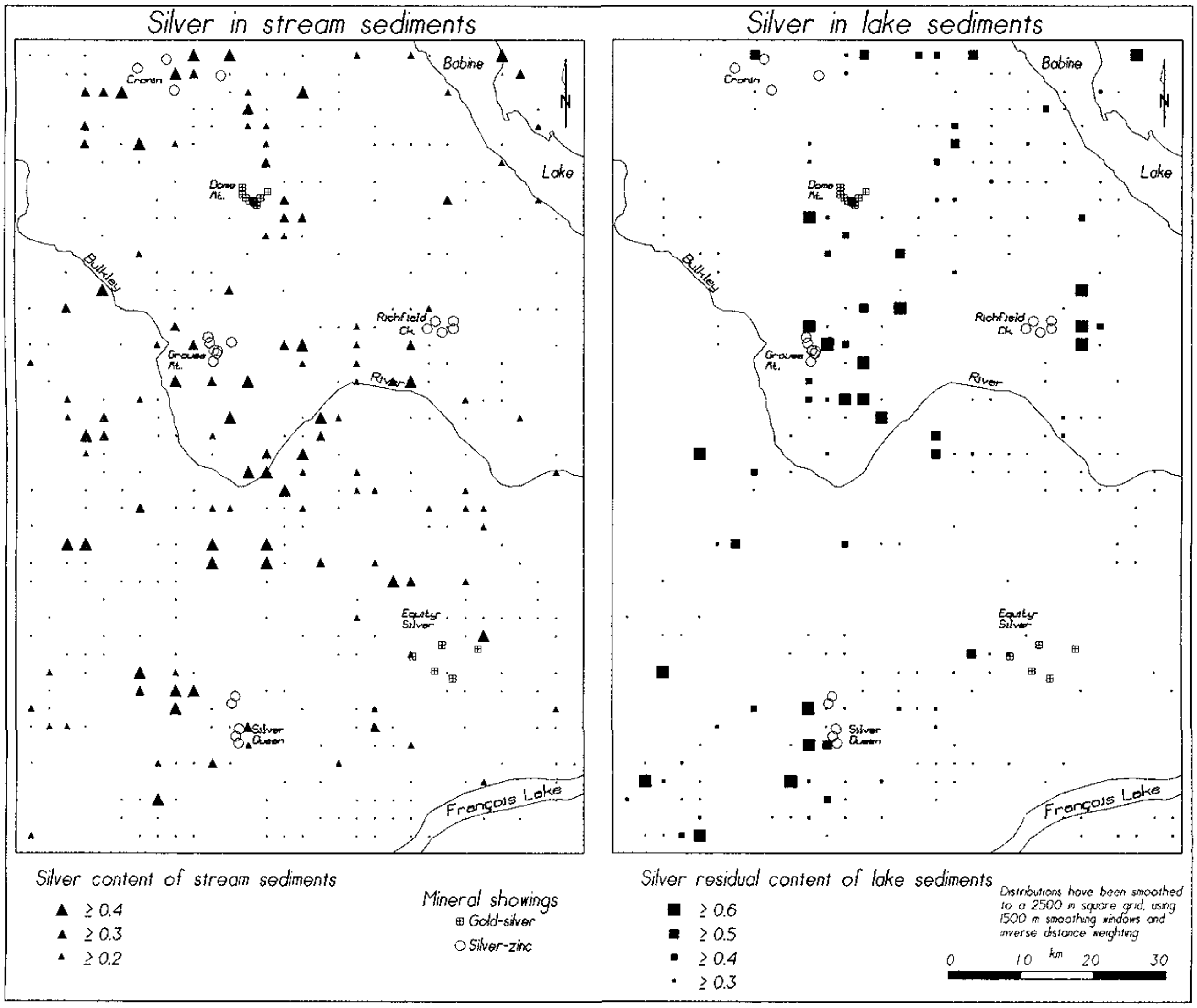

Figure 19-4. Regional distribution of silver in lake and stream sediments in the Bulkley River area (93L).

tain, for example, only one lake sediment sample was collected on the eastern side of the area of mineral occurrences, while at Grouse Mountain the nearest stream sediment sample was collected 2 kilometres to the west of the area of the showings.

Silver and zinc data from the Silver Queen area are also shown in more detail on Figures 19-7 and 8. The Silver Queen area is underlain by Endako Group rocks, primarily of dacitic composition, and the dacite is intruded by a microdiorite sill. Both the dacite and microdiorite are intruded by felsite porphyry and basalt dikes and sills, and all of these rocks are cut by quartz vein systems mineralized with sphalerite, chalcopyrite, galena, tetrahedrite, tennanite and pyrite. The deposit is located on the eastern side of Owen Lake, and was mined in the early 1970s. Current estimated reserves are 1 730 000 tonnes grading 328 grams per tonne silver, 2.74 grams per tonne gold and 6.2% zinc (MINFILE 93L 002). Several other similar deposits occur in the area east of Owen Lake, including the Cole deposit, which has reserves of 145 152 tonnes grading 302 grams per tonne silver (MINFILE 93L 162).

There are moderate and strong lake sediment silver anomalies within Owen Lake (Figure 19-7). Most other lakes show background levels, although one lake 8 kilometres to the east and another 7 kilometres to the southwest are also anomalous in silver. There is only one weak stream sediment silver anomaly in the area of the mineral occurrences, while there are three strong anomalies in a drainage system about 6 kilometres to the northwest of the area. In this case the area of mineral occurrences was sampled quite adequately by both stream and lake sediment samples.

There are five strong and moderately strong zinc anomalies in Owen Lake and in two smaller lakes within the mineralized area, but there are only weak zinc anomalies in the stream sediments of this area (Figure 19-8). The strongest stream sediment zinc anomalies are 6 kilometres to the northwest.

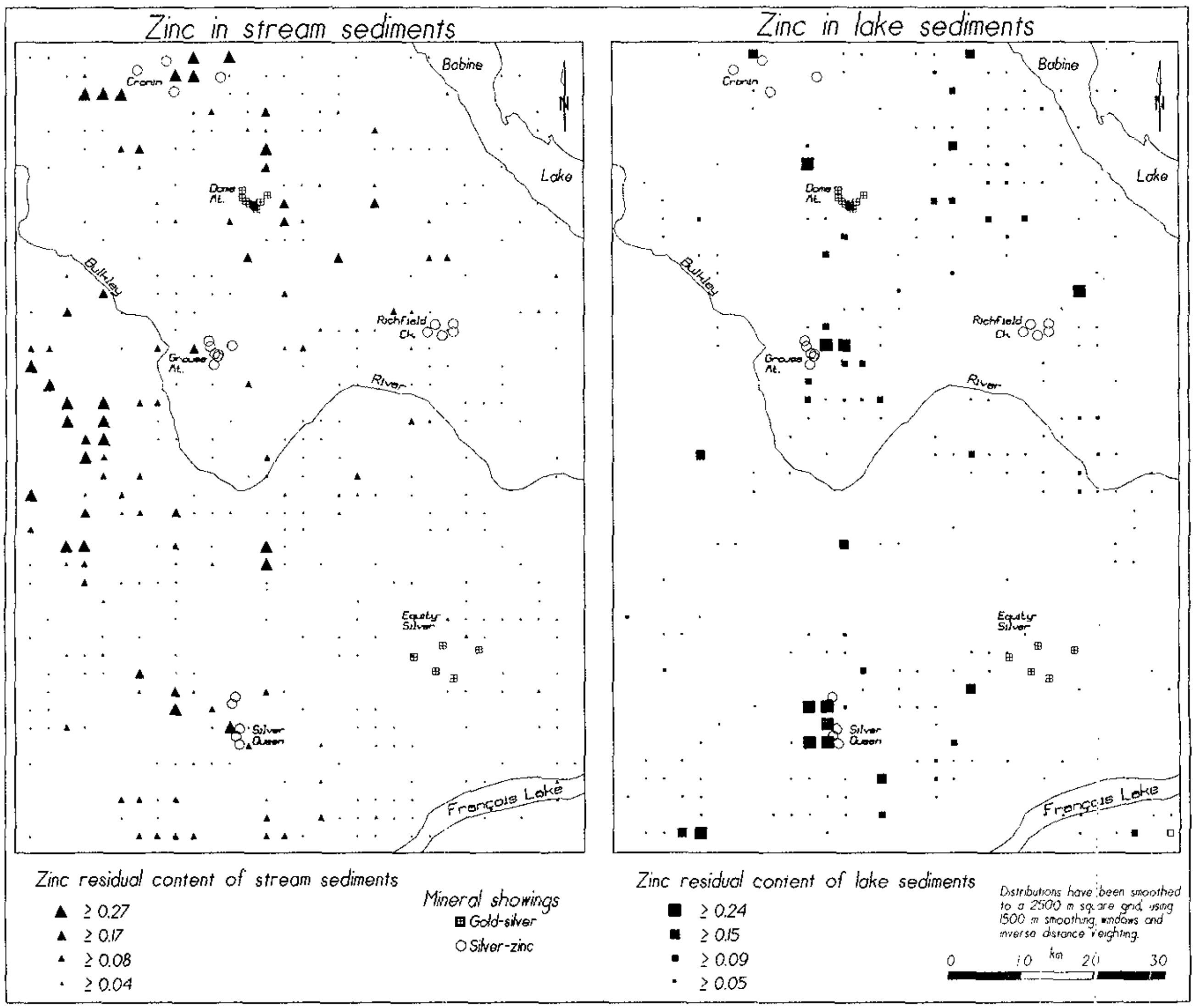

Figure 19-5. Regional distribution of zinc in lake and stream sediments in the Bulkley River area (93L).

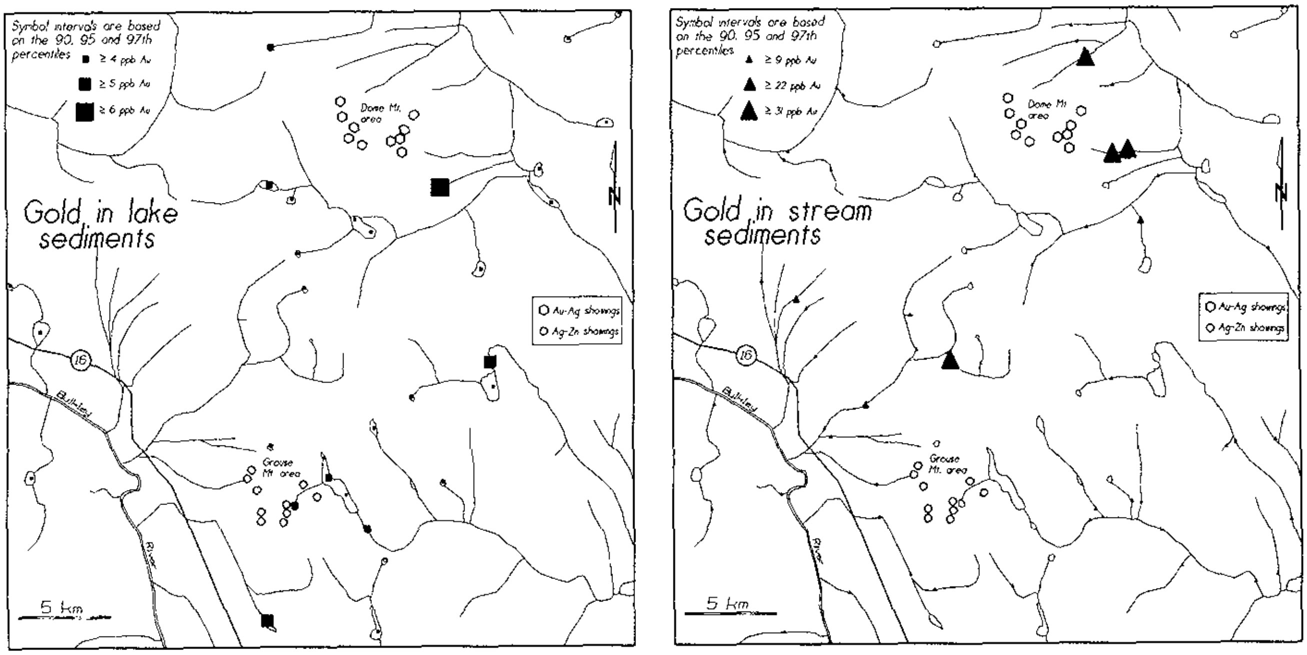

Figure 19-6. Gold in lake and stream sediments in the Dome Mountain - Grouse Mountain area (93L).

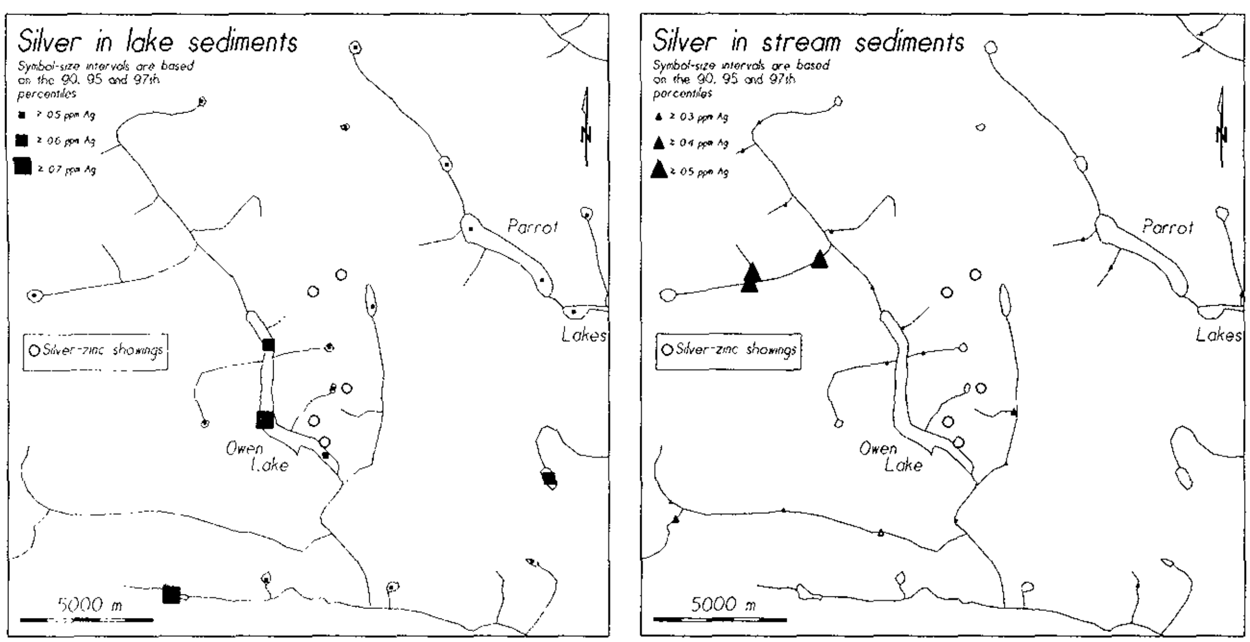

Figure 19-7. Silver in lake and stream sediments in the Silver Queen area (93L).

GIBRALTAR MINE AREA

During the early 1970s an extensive lake sediment sampling program was carried out in central British Columbia by Rio Tinto Canadian Exploration Ltd. The area around what is now the Gibraltar mine was sampled in some detail as part of this program. The sampling was completed after the ore deposit was discovered, but before mining or any other work which may have led to contamination of the lake sediments had commenced (Coker *et al.*, 1979). Gibraltar is a 326 million tonne porphyry copper-molybdenum deposit, with average copper and molybdenum grades of 0.37% and 0.01%, respectively.

Stream sediment data for this area are available from an RGS program conducted in 1980 (MEMPR, 1980). The stream sediment sampling was carried out after commencement of mining.

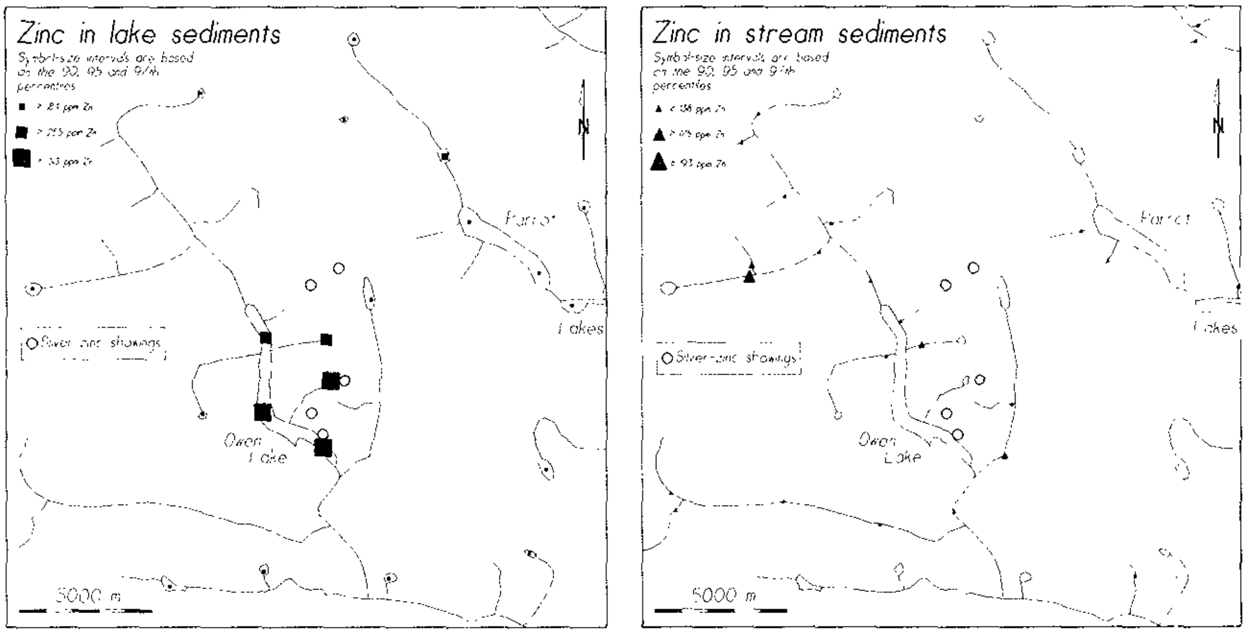

Figure 19-8. Zinc in lake and stream sediments in the Silver Queen area (93L).

The data for 40 lake-centre sediment samples and 22 stream sediment samples for the area around the Gibraltar mine are shown on Figures 19-9 and 10. Again, symbols of different sizes have been used to represent the metal concentrations. In this case the symbol-size intervals are based on the 80, 90, 95 and 97th percentiles determined from all 40 of the lake sediment samples and from 102 stream sediment samples collected from a 40 by 50 kilometre area around the mine. Relatively few stream sediments were collected in the immediate mine area, and this limits the relevance of a direct comparison of the geochemical distributions.

There are moderate and strong lake sediment copper anomalies throughout a 10 by 15 kilometre area surrounding the mine, but levels are particularly high within a few kilometres of the ore zones, where three samples have in excess of 300 ppm copper (Figure 19-9). On the other hand, several stream sediment samples collected from near the mine have relatively low copper concentrations, and the only samples with significant copper enrichment (80 ppm) were collected at least 6 kilometres away.

There is a 7 by 7 kilometre area of moderate to strong molybdenum anomalies around the Gibraltar mine, including three samples with levels in excess of 26 ppm (Figure 19-10). As indicated on the map shown by Coker *et al.* (1979), the lake sediment molybdenum background in this area is in the range of 1 to 2 ppm, which is similar to that of the Capoose and Fish lakes area (*cf.* Hoffman and Fletcher, 1981). Lake sediment samples collected from as much as 10 kilometres away from the mine in several directions have greater than 12 ppm molybdenum. In contrast, none of the stream sediments collected from the vicinity of the deposit have significant molybdenum enrichment, and the only sample with more than 5 ppm molybdenum is approximately 6 kilometres away from the orebodies. Of the twelve samples collected from within 10 kilometres of the mine, only two have more than 1 ppm molybdenum.

It must be reiterated that this comparison of lake and stream sediment data from Gibraltar is not entirely fair because of the differences in the sampling patterns. Nevertheless, there are strong and extensive copper and molybdenum anomalies in lake sediments in the Gibraltar area, and although the sampling is sparse, the evidence suggests that the stream sediment anomalies are neither as extensive nor as strong as those seen in the lake sediments.

DISCUSSION

Lake sediment and stream sediment geochemical data from various mineralized areas within the Nechako Plateau area of central British Columbia have been compared. In the vicinity of silver-zinc deposits at Silver Queen and around copper-molybdenum orebodies at Gibraltar it is evident that lake sediment geochemistry is more useful for exploration than stream sediment geochemistry. At Silver Queen, for example, there are strong silver and zinc lake sediment anomalies associated with the known deposits, but there is almost no enrichment of silver and zinc in stream sediments. At Gibraltar there are strong and extensive anomalies of both copper and molybdenum in lake sediments, but relatively weak and sporadic anomalies in stream sediments.

The results for gold in the vicinity of gold-silver deposits at Dome Mountain and around silver-zinc occurrences at Grouse Mountain are less conclusive. At Dome Mountain the stream sediment anomalies appear to be better defined, while at Grouse Mountain the lake sediment anomalies appear to be more definitive. In both cases the differences

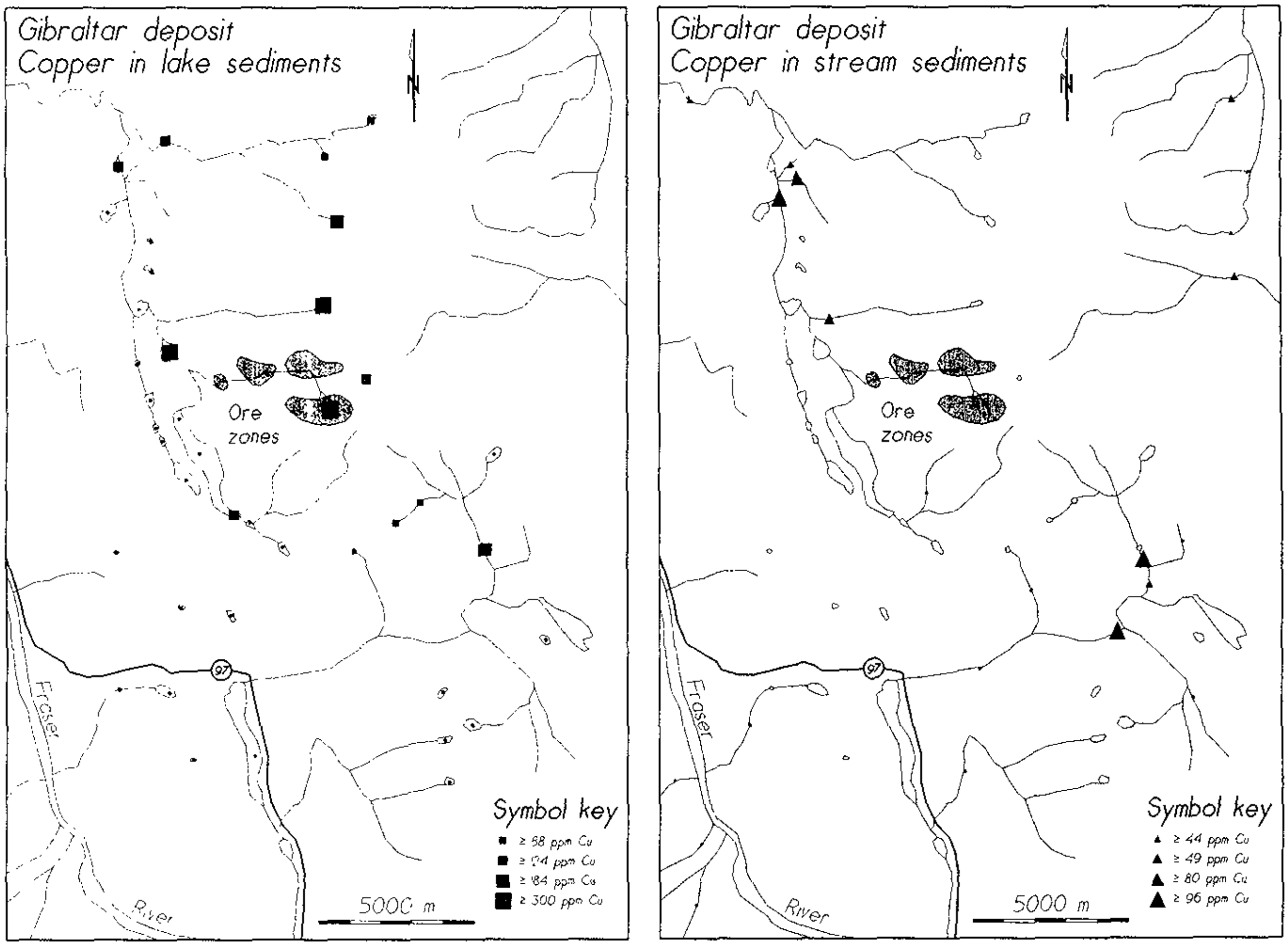

Figure 19-9. Copper in lake and stream sediments in the Gibraltar mine area (93B).

could be ascribed to differences in the sampling patterns, however the anomaly contrast in stream sediments is higher than that for lake sediments.

Based on the evidence from these three areas it appears that, in this plateau region of central British Columbia, lake sediment sampling is a more effective tool for regional geochemical exploration than stream sediment sampling. There are several reasons why this might be so, but the relative consistency of the sampling medium and the sampling environments is probably a major factor. As noted above, lake-centre sediments are generally consistent both mechanically and chemically. They are rich in organic matter, and they are consistently fine grained, with high clay contents. The lake-bottom environment is also relatively consistent. Even in oligotrophic lakes the degree of oxygenation within the organic-rich sediments is low (*cf.* Coker *et al.*, 1979).

In contrast, stream sediments are quite inconsistent, both mechanically and chemically, and stream environments are highly variable. This is particularly true in this area of diverse topography and drainage conditions. Stream sediments can range from very fine grained material dominated by clay, to coarse sandy and gravelly material with little or no clay component. Although samples are sieved prior to analysis, normal sieving procedures do not necessarily standardize the ratio between sand, silt and clay-sized material. An 80-mesh sieve (0.18 mm), for example, will exclude material larger than fine sand, but this gives no control over the proportions of fine sand, silt and clay. Even a -200-mesh sieve (0.074 mm) does not separate silt from clay. Sieved material from some stream sediment samples may be comprised almost entirely of clay, while that from others may contain virtually no clay at all. Considering the importance of clay minerals and clay-sized material in adsorbing trace-metals (Rose *et al.*, 1979), this is can be a significant factor.

Under most conditions fine-grained organic matter is a more important adsorbing substrate than clay (Rose *et al*, 1979; Coker *et al.* 1979; Stumm and Morgan, 1971), and in this environment stream sediments may have quite large variations in organic content. The stream sediment samples collected as part of the RGS survey in the eastern half of map sheet 93L have an organic content range (as LOI) of 0.5 to 42%. The levels are generally low. Only 3% of the samples have more than 15% organic matter, while 85% of the samples have between 1 and 10% organic matter. The lake sediments collected in this same area have an LOI range of 0.5 to 83%, but in this case the levels are generally high. Over 85% of the samples have more than 15% organic matter. Studies of metal - organic matter relationships in lake

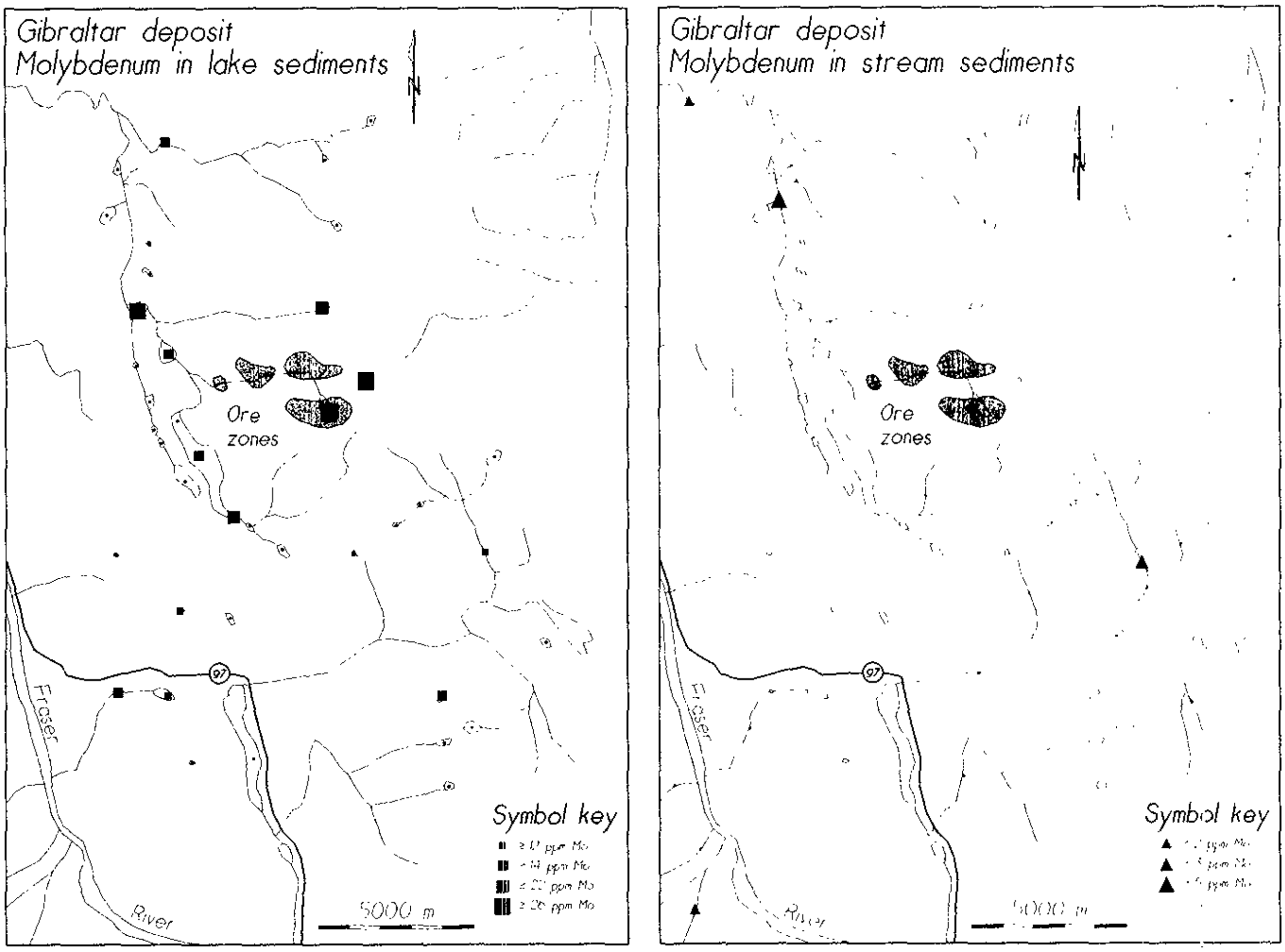

Figure 19-10. Molybdenum in lake and stream sediments in the Gibraltar mine area (93B).

environments have shown that, in general, metals are strongly controlled by organic levels up to approximately 15% LOI, and that beyond that level increases in organic matter do not significantly effect metal concentrations (Garret and Hornbrook, 1976; Coker *et al.*, 1979).

Variability within stream sediments is a particular problem for elements such as gold, which are partly or entirely transported as particles (Matysek and Saxby, 1987; Fletcher and Day, 1988; Day and Fletcher, 1989; Fletcher, 1990). In studies of the spatial and temporal variability of gold within high-energy stream beds Fletcher (1990) has shown that there can be variations of up to three orders of magnitude (less than 1 ppb to nearly 1000 ppb gold in the fine fraction of sediment samples) within a distance of only a few tens of metres. The main factor contributing to these discrepancies is the choice of sample location with respect to fluvial features such as bars. Temporal differences of similar magnitude were also noted, and these are ascribed to the effects of major flooding events.

In addition to the variabilities in the nature of stream sediment, streams are also much more variable than lake-bottom environments in terms of their overall geochemistry. For example, under turbulent conditions stream waters will always be saturated with oxygen. Oxidizing conditions will prevail in the water, and even within the sediment pore waters as long as organic matter levels are low. Where stream flow rates are low and the sediments are clay-rich and partly organic, dissolved oxygen levels will be lower, and reducing conditions may prevail within the sediments.

These factors of variability in sediment composition and environment may be partly responsible for the relatively low correlation between stream sediment anomalies and the incidence of mineral occurrences in this area. Another important factor is that in lake sediments the anomaly levels of many constituents (excluding gold) are higher and show greater contrast with background than those for stream sediments. The result is that lake sediment anomalies are easier to detect analytically. This is particularly important for elements such as molybdenum, lead and silver, which are present at levels quite close to the analytical detection limits. Furthermore, the higher contrast lake sediment anomalies are easier to recognize in data interpretation.

CONCLUSIONS

A comparison of lake sediment and stream sediment geochemical data from three different types of mineral deposits in two areas of the Interior Plateau has shown that, in general, lake sediments provide more effective exploration information in this environment.

Lake sediment copper and molybdenum data clearly define the location of the Gibraltar copper-molybdenum deposits, and lake sediment silver and zinc data clearly define the location of the Silver Queen and adjacent silver-zinc deposits. Stream sediment geochemistry is effective at Gibraltar, however, the anomaly levels are relatively low and the patterns inconsistent, but stream sediments are quite ineffective at Silver Queen. The Dome Mountain area gold-silver deposits are delineated by both stream and lake sediment gold data, although the anomaly to background contrast is higher in the stream sediments.

It is postulated that the observed differences in the geochemical responses are partly due to the inconsistency of stream sediment compositions and stream geochemical environments in this area of relatively low relief.

Lake sediment geochemistry could be used effectively in regional exploration programs in any parts of the Cordillera characterized by relatively subdued topography. These include most of the Interior Plateau, most of the Queen Charlotte Islands, much of Vancouver Island and most of the central and northern parts of the Yukon. Most of western Alaska could also be effectively explored using lake sediment geochemistry. Although regional stream sediment surveys have already been carried out in many of these regions, it is likely that lake sediment geochemical data would yield useful new exploration information.

ACKNOWLEDGMENTS

The author is grateful to Paul Matysek, Steve Cook and Steve Sibbick of the Environmental Geology Section, British Columbia Geological Survey, for their assistance in providing access to the RGS data used in this report, and for valuable discussions.

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GOLD DISTRIBUTION IN LAKE SEDIMENTS NEAR EPITHERMAL GOLD OCCURRENCES IN THE NORTHERN INTERIOR PLATEAU, BRITISH COLUMBIA

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INTRODUCTION

Stream sediments are the preferred sampling medium for reconnaissance-scale Regional Geochemical Surveys (RGS) over most of British Columbia. However, the subdued topography, abundance of lakes and relatively poor drainage of the Nechako Plateau in the northern Interior suggest that lake sediments may be a more appropriate medium in this area. Mineral exploration in the region has been limited by extensive drift cover, poor bedrock exposure and a young volcanic cover. Epithermal precious metal deposits are presently the most important exploration target, and lake sediment geochemistry is a potentially highly effective tool to delineate both regional geochemical patterns and anomalous metal concentrations related to these deposits. Most Canadian lake sediment geochemistry studies have focused on the Shield and Appalachian environments of eastern and northern Canada, where there are considerable differences in climate, physiography and surficial geology relative to central British Columbia. Subsequently there is a paucity of case histories upon which to build Cordilleran interpretive models. This study addresses geochemical controls on metal distributions for three lakes adjacent to epithermal gold-silver occurrences in the northern Interior Plateau. These, Wolf Pond, Clisbako Lake and Bentzi Lake, are hosted by Eocene Ootsa Lake Group felsic volcanic rocks in NTS map areas 93C (Anahim Lake) and 93F (Nechako River). The study presents and interprets data for the content and distribution of gold and other elements in lake sediments. The lakes, which represent a cross-section of limnological types, were sampled as part of a broader study of the relation of lake sediment geochemistry to various mineral deposit types in the northern Interior (Cook, 1993a, b). Results presented here are preliminary, and additional work will appear elsewhere.

PROGRAM OBJECTIVES

Lake sediments have been used successfully as an exploration medium for base metal deposits in the northern Interior Plateau for almost 25 years. Sediment geochemistry reflects the presence of weathering sulphide minerals from a bulk silver prospect near Capoose Lake (Hoffman, 1976; Hoffman and Fletcher, 1981), porphyry molybdenum-copper mineralization near Chutanli Lake (Mehrtens *et al.*, 1973; Mehrtens, 1975) and epithermal/skarn mineralization near Square Lake (Hoffman and Smith, 1982). Lake sediment geochemistry has also been successful in locating gold-silver mineralization at the Wolf occurrence (Andrew, 1988), but studies of gold in lake sediment (Schmitt *et al.*, 1993; Friske, 1991; Davenport and Nolan, 1989; Rogers, 1988; Fox *et al.*, 1987; Coker *et al.*, 1982) have been largely restricted to Shield or Appalachian environments. Accordingly, the objectives of this study are to determine the:

- extent to which lake sediment geochemistry reflects the presence of nearby epithermal precious metal occurrences;
- distribution patterns of gold and other elements in lake sediments;
- effectiveness of lake sediments as an exploration medium for gold; and
- most effective sampling, analytical and interpretive techniques for gold exploration in the northern Interior.

Ongoing studies are also evaluating field sample sizes, sampling and analytical variability, effective regional sampling densities, comparative analytical methods, the usefulness of sequential extractions, water geochemistry, and the effect of limnological variations on sediment geochemistry of lakes within and between different geological units. An important objective of the program is the development of Cordilleran models for the transport and accumulation of gold and other elements (*e.g.* Timperley and Allan, 1974) under a range of geological and limnological conditions.

SCOPE OF FIELD STUDIES

Orientation studies were carried out during the period late July to mid-September, 1992. The program centred on lakes characteristic of eutrophic, mesotrophic, oligotrophic and unstratified limnological environments above each of two rock units: Eocene Ootsa Lake Group felsic volcanic rocks hosting epithermal gold-silver occurrences, and various plutonic rocks hosting porphyry copper-molybdenum deposits and occurrences. Lakes were chosen largely on documented trophic status (Balkwill, 1991) and proximity to known mineral occurrences in the MINFILE database. Further details of the program, based partly on recommendations of Earle (1993), are provided by Cook (1993a); only results from three lakes adjacent to epithermal gold-silver prospects (Wolf, Clisbako, Holy Cross) are discussed here. A total of 149 sediment samples were collected at 105 sites on the three lakes (Table 20-1).

TABLE 20-1
SUMMARY SAMPLING, PHYSICAL AND WATER GEOCHEMISTRY DATA ON WOLF, CLISBAKO AND BENTZI LAKES

Lake	Wolf	Clisbako	Bentzi
NTS	93F/03	93C/09	93F/15
Elevation (m)	~1173	~1280	~855
Trophic Status	Eutrophic	-	Mesotrophic
Lake Area (km2)	Pond (<.25)	.25 to 1	1.82
Maximum Depth (m)	8	10.5	35
Sediment Sites	7	40	58
Sediment Samples	12	57	80
Temp/Oxygen Profiles	1	3	5
pH (surface)	6.02	7.30	7.60
pH (bottom)	6.09	7.30	7.39
Sulphate (ppm; surface)	4	5	1
Sulphate (ppm; bottom)	2	4	1
Mineral Occurrence Commodities	Wolf (Au, Ag)	Clisbako (Au, Ag)	Holy Cross (Au, Ag, Cu, Zn)

Note: Bentzi Lake elevation and surface area from Walsh and Philip (1977). Maximum depth shown is sample depth, not lake depth. Lake-bottom waters were collected approximately 1 metre above the sediment-water interface at Wolf (3 metres) and Clisbako (7.5 metres); Bentzi Lake measurement was made at 28 metres.

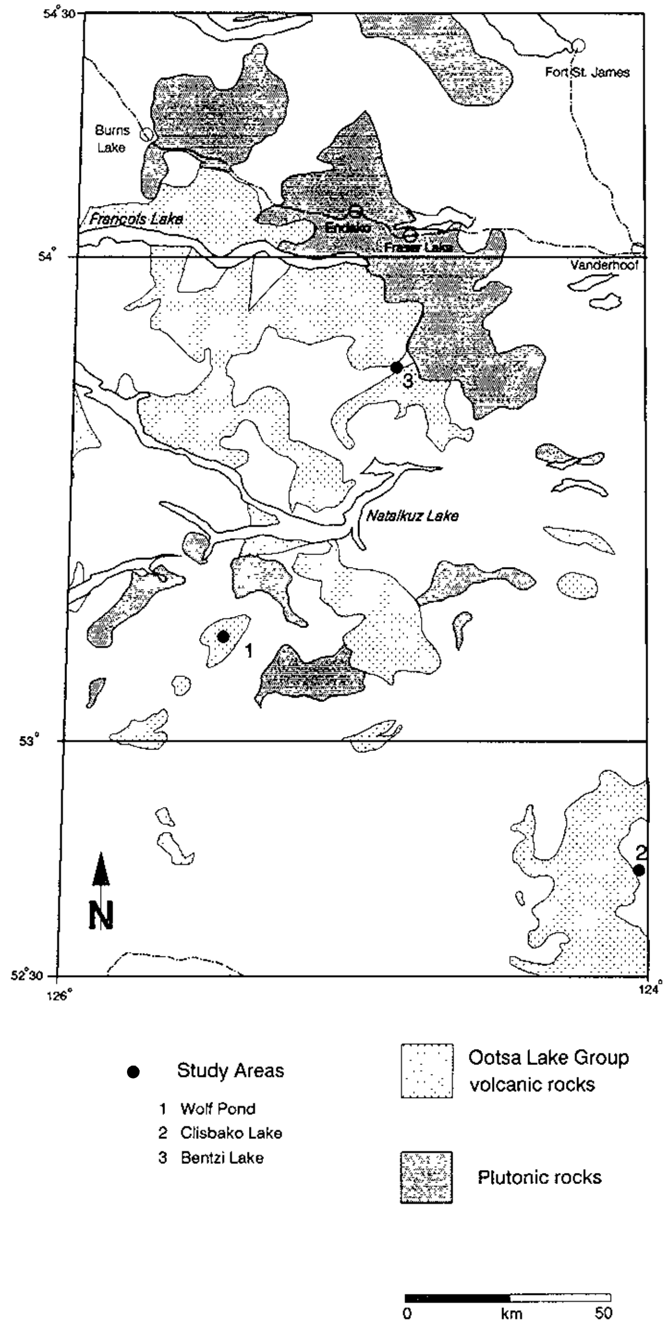

Figure 20-1. Generalized geology and locations of lake sediment orientation studies in the northern Interior of British Columbia, showing their relation to Eocene Ootsa Lake Group volcanic rocks (geology modified from Tipper *et al.*, 1979).

DESCRIPTION OF THE STUDY AREAS

LOCATION AND PHYSIOGRAPHY

The study area (Figure 20-1) is bounded east and west by Vanderhoof and Burns Lake, respectively, and extends northward from the Clisbako River to the Francois Lake area. Most of the area lies on the Nechako Plateau, the northernmost subdivision of the Interior Plateau (Holland, 1976), although its southern limit extends onto the Fraser Plateau. The low and rolling terrain generally lies between 1000 to 1500 metres elevation. The area is thickly forested and bedrock is obscured by extensive drift cover. Over 90% of the Nechako River map area is drift covered (Tipper, 1963), with till and glaciofluvial outwash the predominant materials.

REGIONAL GEOLOGY AND OOTSA LAKE GROUP METALLOGENY

The study area is within the Intermontane Belt. Here, volcanic and sedimentary rocks of the Lower to Middle Jurassic Hazelton Group are intruded by Late Jurassic, Late Cretaceous and Tertiary felsic plutonic rocks. These are overlain by continental Eocene Ootsa Lake Group volcanics, Oligocene and Miocene Endako Group volcanics, and Miocene-Pliocene basalt flows. Areas underlain by Ootsa Lake Group volcanics (approximately 50 Ma, Diakow and Koyanagi, 1988) are the focus of this study, and these areas are exposed in two general regions. The first extends from the Nechako River to the west side of Francois Lake (Figure 20-1); the second is west of Quesnel, between the Chilcotin and West Road rivers (Duffell, 1959; Tipper, 1963). Diakow and Mihalynuk (1987) recognized six lithologic divisions in the Ootsa Lake Group, which comprises a differentiated succession of andesitic to rhyolitic flows and pyroclastic rocks. Sedimentary rocks, although not common, are interspersed throughout the sequence. Interest in the precious metal potential of the Ootsa Lake Group has increased in recent years. The Wolf and Clisbako prospects are epithermal gold-silver occurrences currently or recently under exploration. The Wolf prospect is hosted by felsic flows, tuffs and subvolcanic porphyries, whereas the Clisbako prospect is hosted by basaltic to rhyolitic tuffs, flows and volcanic breccias. Gold mineralization in both areas is associated with low-sulphide quartz stockwork zones.

DESCRIPTIONS OF INDIVIDUAL STUDY AREAS

WOLF POND (NTS 93F/03)

Wolf Pond (elevation: ~1173 m) is located approximately 100 kilometres south-southwest of Fraser Lake and about 5 kilometres southeast of Entiako Lake. It can be reached by either the Holy Cross and Kluskus-Natalkuz ('500') forestry roads from Fraser Lake, or the Kluskus forestry road from Vanderhoof, and then via the Kluskus-Ootsa and Kluskus-Malaput forestry roads to a spur road leading to the Wolf property. Wolf Pond is a small eutrophic pond, approximately 60 by 35 metres, with a maximum depth of about 4.5 metres (Photo 20-1). One temperature and oxygen profile recorded in the centre of the pond shows dissolved oxygen content decreasing from 6.1 ppm at the surface to 0.4 ppm at a depth of 5 metres (Figure 20-2). Bottom-water pH (6.09) is the lowest of the three lakes (Table 20-1).

SURFICIAL GEOLOGY AND PHYSIOGRAPHY

Wolf Pond is situated within a narrow intermontane bog (Figure 20-3) in the rugged uplands of the Entiako Spur of the Fawnie Range, where relief is moderate. The area is heavily forested, and no logging has occurred in the immediate area. Prominent drumlins and striae indicate that ice flowed in a northeasterly direction across the Wolf property (Giles and Levson, 1994; Ryder, 1993). A discontinuous till mantle, up to 2 metres thick, covers rolling to hummocky outcrop on the two hills adjacent to Wolf Pond, while glaciofluvial sands and gravels are exposed at lower elevations along the Entiako Spur. The Wolf Pond watershed is small, with drainage restricted to adjacent hillsides to the east and west, and is largely underlain by quartz feldspar porphyry and rhyolite. The Lookout zone occurs within the

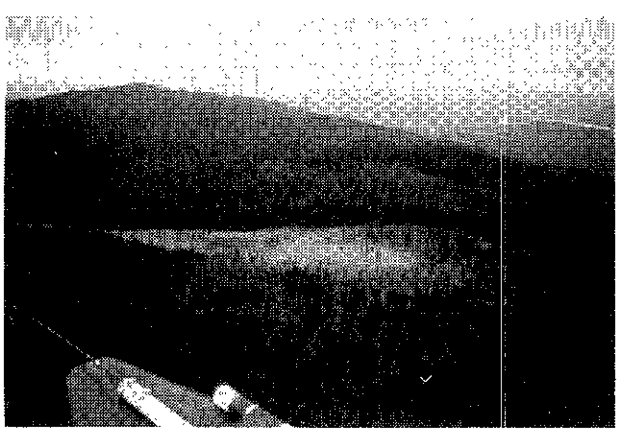

Photo 20-1. Wolf Pond, looking to the southwest.

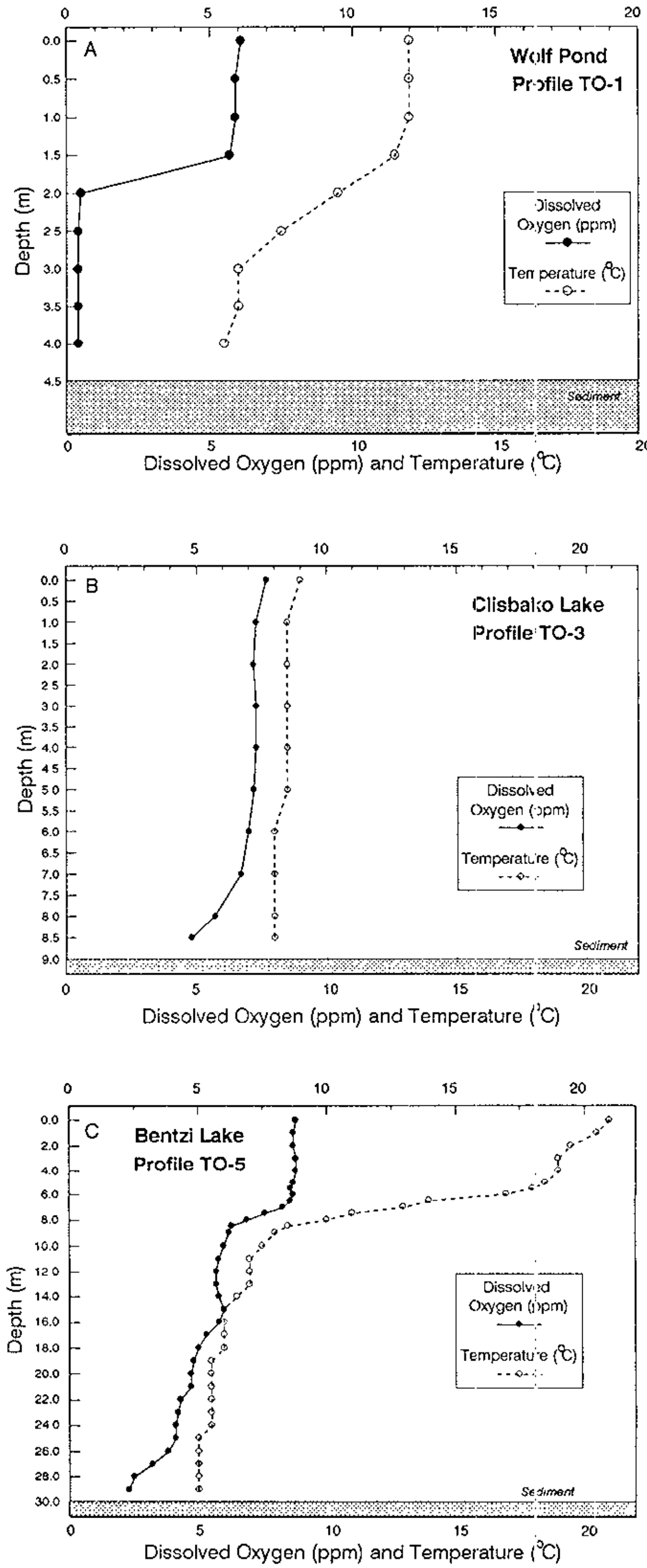

Figure 20-2. Temperature and dissolved oxygen profiles of profundal basin water columns in A) Wolf Pond; B) Clisbako Lake; and C) Bentzi Lake.

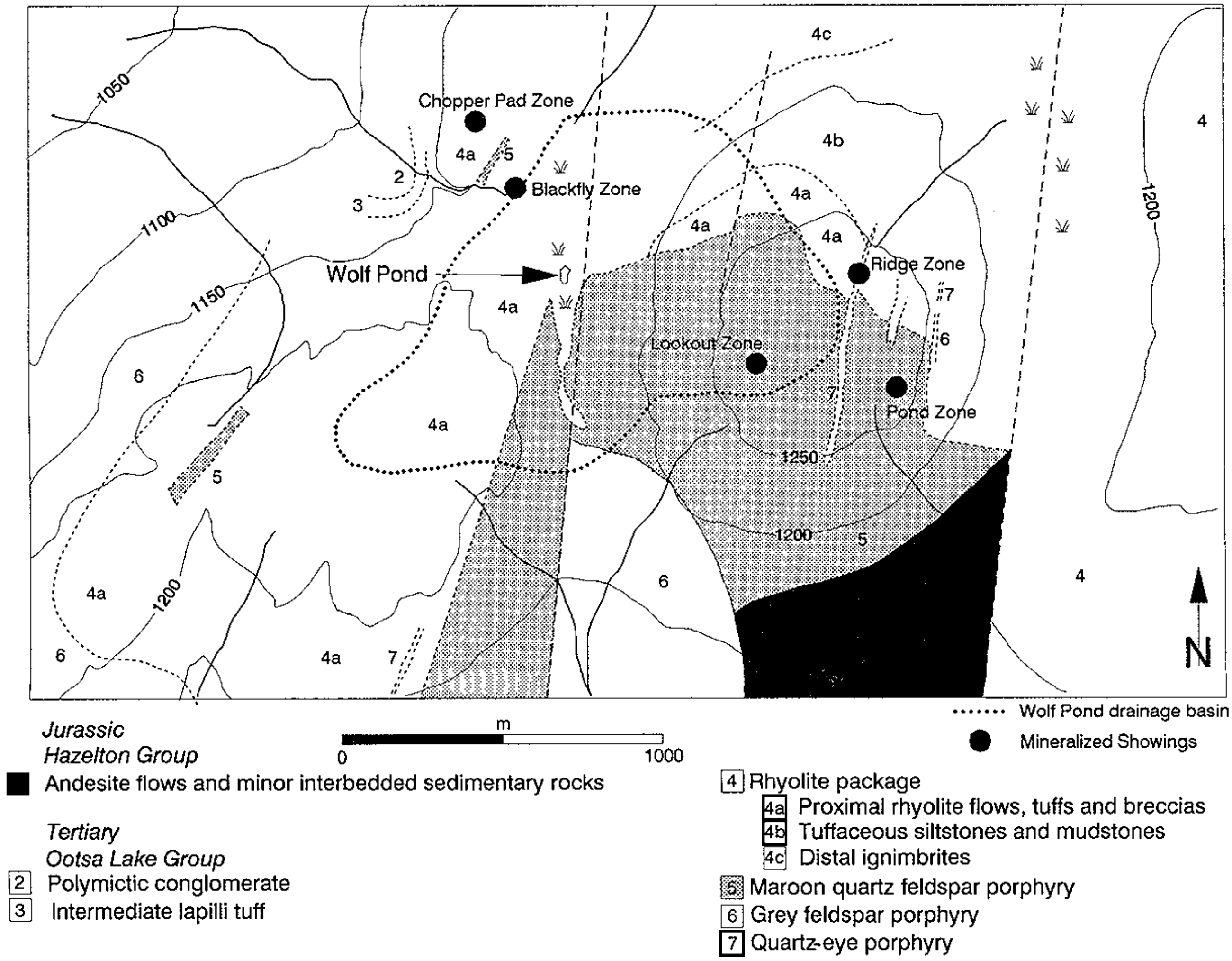

Figure 20-3. Location and geology of the Wolf prospect, showing location of Wolf Pond relative to zones of known epithermal mineralization. Geology generalized after Schroeter and Lane (1994). The dashed line defines the approximate limit of the Wolf Pond drainage basin. Contour interval: 50 metres.

watershed on the hillside just east of the lake. The other mineralized zones are outside the drainage basin.

BEDROCK GEOLOGY AND MINERAL DEPOSITS

Wolf Pond overlies an inferred contact of rhyolite flows, tuffs and breccias (unit 4) and maroon quartz feldspar porphyry (unit 5). The flows and tuffs, together with younger subvolcanic rhyolite porphyries, are host to the Wolf gold-silver prospect (Minfile 093F 045). The prospect is a low-sulphidation adularia-sericite epithermal deposit (Schroeter and Lane, 1994). It comprises five mineralized zones, one of which (Lookout zone) lies within the Wolf Pond watershed. Mineralization within the Lookout zone is structurally controlled and occurs in northerly trending quartz-carbonate veins in maroon quartz feldspar porphyry; other zones occur as siliceous stockworks and hydrothermal breccias (Schroeter and Lane, 1994). Overall, mineralization is micron-sized and occurs as electrum, native silver, silver sulphides and sulphosalts (Andrew, 1988). Some of the highest gold concentrations occur in repeatedly brecciated and silicified zones within the rhyolite (Schroeter and Lane, 1994; Andrew *et al.*, 1986), which are typically bordered by zones of argillic or sericitic alteration. The Wolf claims were staked by Rio Algom Exploration Inc. in 1982 following the discovery of anomalous silver, zinc, arsenic and molybdenum concentrations in Wolf Pond sediments (Dawson, 1988).

CLISBAKO LAKE (NTS 93C/09)

Clisbako Lake (elevation: ~1280 m) is located about 100 kilometres west of Quesnel and about 40 kilometres southwest of Nazko. Access from Quesnel is by the Quesnel-Nazko Highway to Marmot Lake, and then via the Michelle Creek (3900) and Michelle Creek - Canyon Mountain (4200) forestry roads to a spur logging road leading to the lake. Clisbako Lake is about 700 metres long and has a maximum depth of about 9 metres within a single basin (Photo 20-2). Surface and bottom waters exhibit a neutral

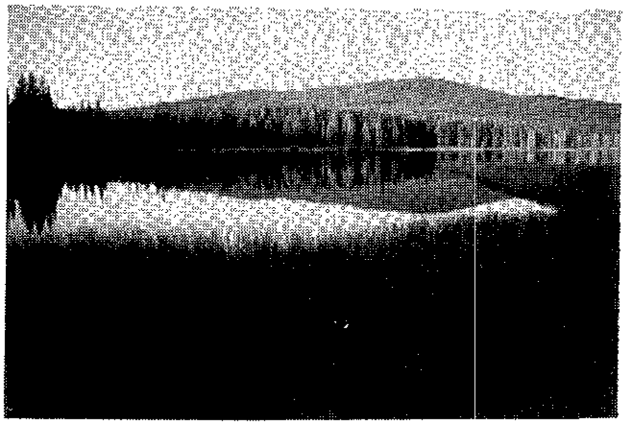

Photo 20-2. East side of Clisbako Lake, looking to the southwest.

pH (Table 20-1). Surface-water dissolved oxygen concentrations of 7.7 ppm decreased to a low of 4.8 ppm in the deepest part of the lake, and temperature profiles were relatively constant (Figure 20-2). Trophic status is unknown; unstratified temperature and oxygen profiles at three sites may have resulted from water column turnover with the onset of cold weather in mid-September 1992.

SURFICIAL GEOLOGY AND PHYSIOGRAPHY

The Clisbako area has low to moderate relief (Figure 20-4) and drift cover is extensive. Bedrock exposures cover only about 4% of the property, and are generally confined to gulleys and incised stream drainages (Dawson, 1991). Logging in the immediate area is most extensive on the north side of the lake, where a clearcut extends to within a few metres of the shore. Late Wisconsinan glacial movement was in a north-northeasterly direction across the eastern part of the Clusko River map area (Proudfoot and Allison, 1993). Canyon Mountain and Mount Dent rise to elevations of 1464 metres and 1676 metres, respectively, south and southwest of the lake. Slopes are till covered, with exposed bedrock on higher ground partially covered by a locally derived till and colluvium veneer. Hummocky moraine and the Clisbako River lowlands cover much of the area east and north of Clisbako Lake. Glaciofluvial sand and gravel deposited from a northeast-flowing meltwater channel cover much of the area south of the lake. Minor meltwater channels and eskers also occur at high elevations in the western part of the watershed. Clisbako Lake drains north

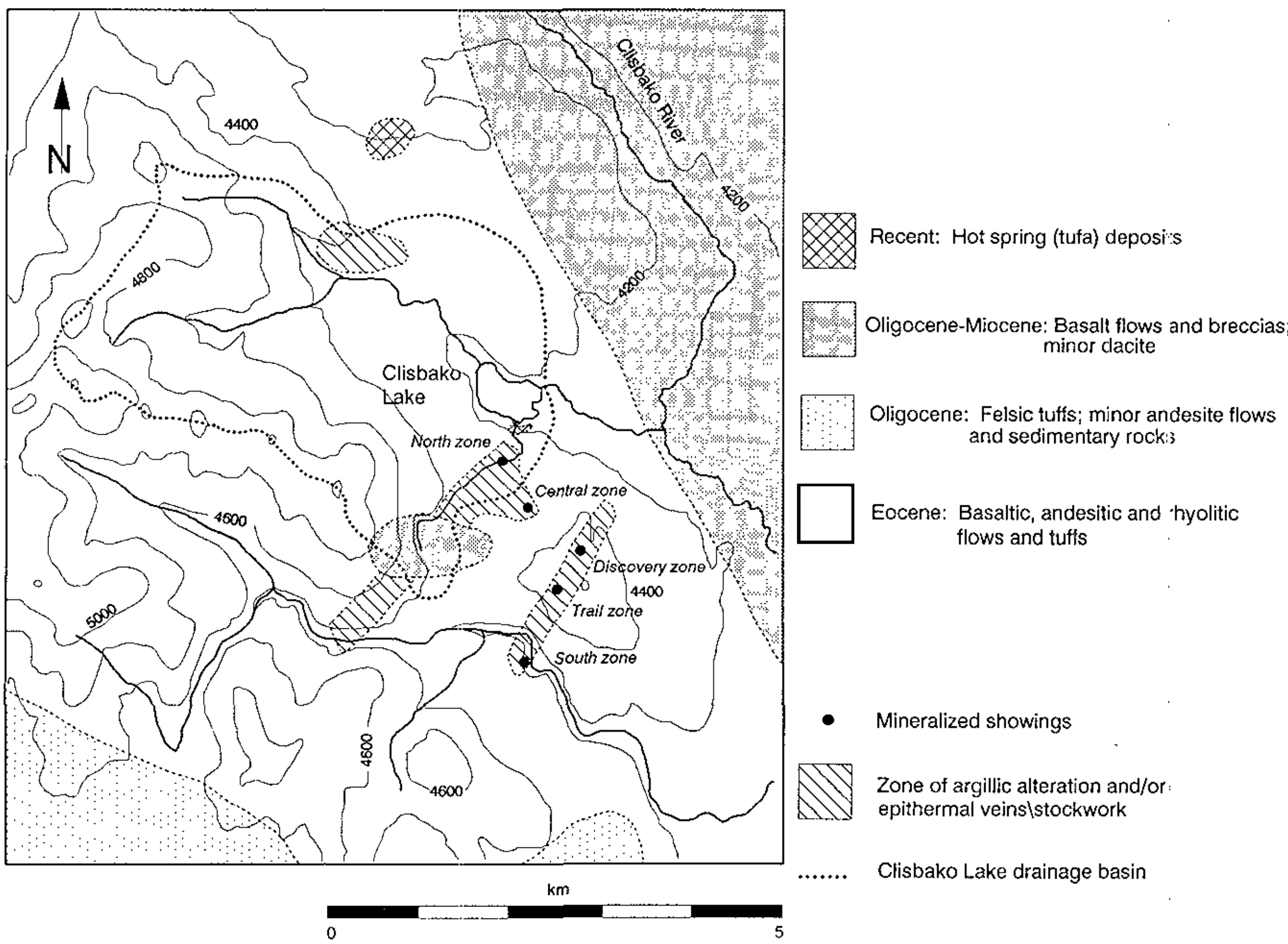

Figure 20-4. Location and geology of the Clisbako prospect, showing location of Clisbako lake relative to zones of epithermal alteration and mineralization. Geology after Dawson (1991). The dashed line defines the approximate limit of the Clisbako Lake drainage basin. Contour interval: 200 feet.

through the Nazko, Blackwater and Fraser rivers. The lake watershed covers an area of about 14 square kilometres, and drainage into Clisbako Lake is predominantly from the west. Two unnamed streams enter the lake, one from the west and a smaller one from the south.

BEDROCK GEOLOGY AND MINERAL DEPOSITS

Oligocene-Miocene basalt flows and pyroclastic rocks of the Endako Group outcrop on Canyon Mountain southeast of the lake. They also underlie the adjacent Clisbako River plain, but are not exposed within the watershed of Clisbako Lake. Felsic to intermediate subaerial flows and pyroclastic rocks of the Eocene Ootsa Lake Group underlie Clisbako Lake and the surrounding area (Figure 20-4). Here, the Clisbako gold-silver prospect (MINFILE 093C 016) is hosted by basaltic to rhyolitic tuffs, flows and volcanic breccias exhibiting intense silicification and argillic alteration. Several alteration zones have been identified, although not all lie within the Clisbako Lake watershed (Figure 20-4). The largest, the South, Central and North zones, have exposed strike lengths of up to 450 metres (Schroeter and Lane, 1992). Gold mineralization is associated with low-sulphide quartz stockwork zones. Gold concentrations up to 1076 ppb and silver concentrations up to 73 ppm, as well as elevated concentrations of mercury, arsenic, antimony and barium, were reported by Dawson (1991). The Clisbako claims were staked in 1990 by Eighty-Eight Resources Ltd. and optioned by Minnova Inc. in 1991. The prospect has been interpreted to be a high-level volcanic-hosted epithermal system similar to those in the western United States (Dawson, 1991; Schroeter and Lane, 1992).

BENTZI LAKE (NTS 93F/15)

Bentzi Lake (elevation: 855 m) is located 9 kilometres east of Holy Cross Mountain approximately 30 kilometres south of Fraser Lake. The Holy Cross forestry road passes just west of the lake, which can be accessed through an adjacent hunting camp south of Targe Creek. The lake is approximately 2.5 kilometres long and has a maximum depth of 31.5 metres. It is the only lake in this study for which a bathymetric map is available (Walsh and Philip, 1977). The lake contains two sub-basins; a major profundal basin in the central part of the lake, where the maximum depth was recorded, and a lesser sub-basin within the northwestern arm of the lake. A large shoal in the central part of the lake rises to within 1.5 metres of the surface, paralleling a narrow subaqueous channel (24 m) leading into the profundal basin. Surface and bottom waters exhibit a neutral pH (Table 20-1). Temperature and oxygen profiles recorded at five sites in Bentzi Lake show it to be mesotrophic (almost eutrophic); surface-water dissolved oxygen measurements of 8.6 to 8.8

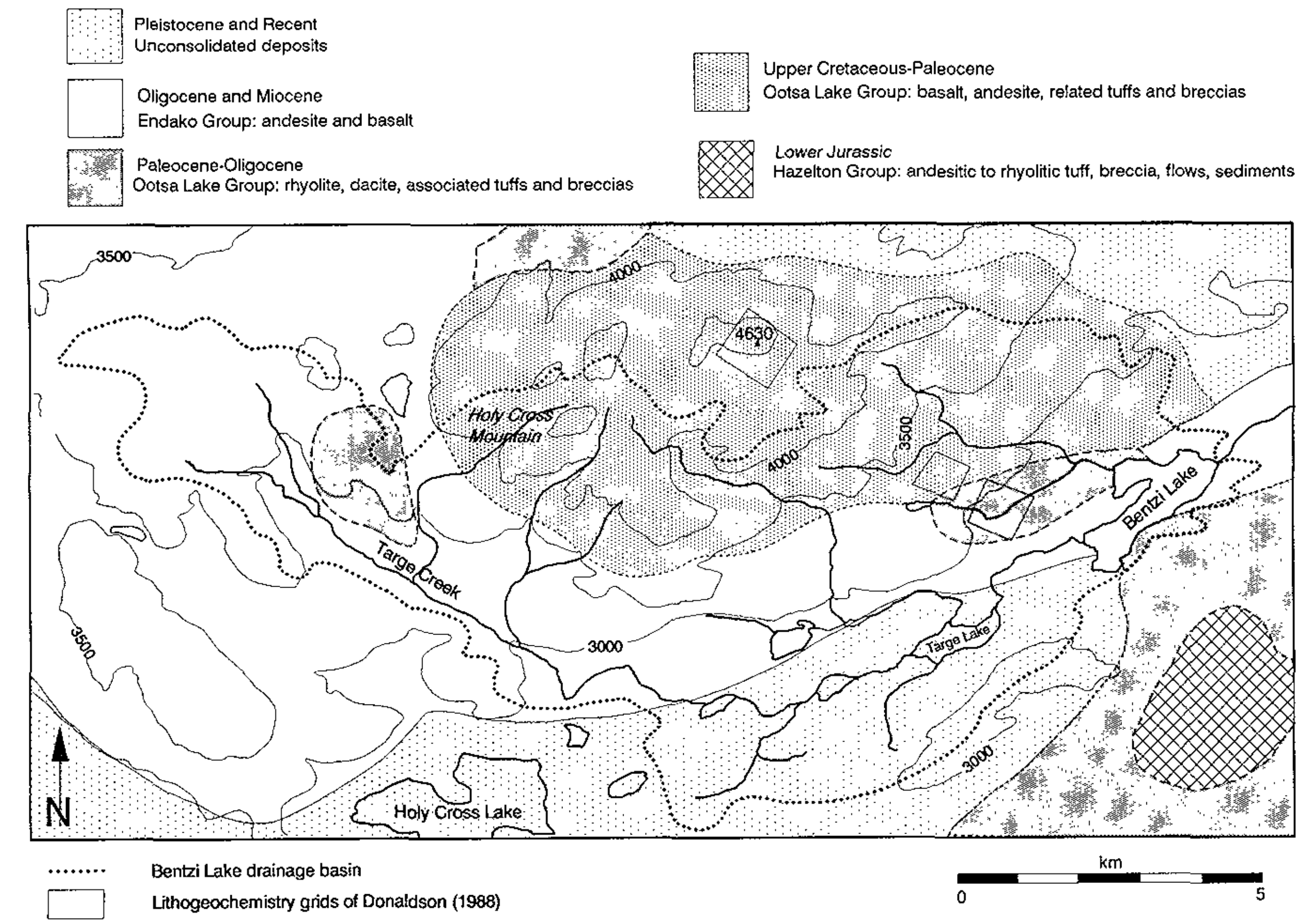

Figure 20-5. Location and geology of the Holy Cross prospect, showing location of Bentzi Lake in relation to areas of epithermal alteration (lines denote approximate shape of lithogeochemistry grids of Donaldson, 1988). Geology after Tipper (1963) and Tipper *et al.* (1979). The dashed line defines the approximate limit of the Bentzi Lake drainage basin. Contour interval: 500 feet.

ppm decrease to a low of 2.3 ppm near maximum depth (Figure 20-2).

SURFICIAL GEOLOGY AND PHYSIOGRAPHY

The area around Bentzi Lake (Figure 20-5) is heavily forested and largely drift covered; outcrop is exposed on only 5% of the HC claim group (Donaldson, 1988). To the north, south and east, the area is overlain by a veneer to blanket of till with a northeast-striking drumlin topography. Much of the area west of the lake is covered with fluvial sand and gravel, with lesser amounts of till and organic sediments. Higher elevations on Holy Cross Mountain (elevation: 1411 m) have hummocky topography and bedrock outcrops with a colluvial veneer, while lower slopes are overlain by veneers to blankets of till. There is no logging activity immediately around Bentzi Lake, but there has been considerable logging in the Holy Cross Mountain area.

Bentzi Lake drains to the northeast through the Tahultzu Creek - Nechako River drainage system. Drainage into Bentzi Lake is predominantly from the west through two major inlets, the Targe Creek inlet and the Northwest inlet. The Targe Creek watershed flows into the main basin, draining a considerably larger region than the Northwest inlet watershed. However, much of Targe Creek drains through a swampy lowland area, whereas the Northwest inlet drains an area of greater relief. Up to 80 ppb gold in stream sediments and up to 380 ppb gold in panned heavy mineral concentrates were reported from the creek draining into Northwest inlet by Donaldson (1988).

BEDROCK GEOLOGY AND MINERAL DEPOSITS

Bentzi Lake is situated above Endako Group volcanic rocks, but volcanics of the Ootsa Lake Group are exposed to the west and southeast. These rocks host the Holy Cross epithermal gold-silver-copper-zinc occurrence (MINFILE 093F 029) and comprise three units of altered and unaltered andesite, rhyolite and tuff (Donaldson, 1988). The first unit consists of massive maroon to grey andesite, porphyritic andesite and massive basalt, and the second unit consists of pervasively silicified flow-banded rhyolite and rhyolite breccia. The third and least abundant unit comprises andesitic to dacitic tuff, felsic lapilli and crystal tuff. Areas of pervasive quartz-chalcedony veining in the rhyolite unit contain gold concentrations up to 310 ppb, and zones of kaolinite alteration in the two lower units contain elevated copper-lead-zinc-silver concentrations. Specular hematite and pyrite occur in all units. The occurrence was originally staked (HC claims) by Noranda in 1987.

FIELD AND LABORATORY METHODOLOGY

SAMPLE COLLECTION

Lake sediments were collected from a zodiac or canoe with a Hornbrook-type torpedo sampler using standard sampling procedures of Friske (1991). Samples were stored in kraft paper bags and sample depth, colour, composition and odour were recorded at each site. Sites were located along profiles traversing deep and shallow-water parts of main basins and sub-basins, and at all stream inflows. The number of sites on each lake ranged from a minimum of seven in small Wolf Pond to a maximum of fifty-eight in Bentzi Lake (Table 20-1). Sites were chosen to evaluate the relationship between trace element patterns and mineral occurrence location, bathymetry, organic matter content, drainage inflow and outflow and sediment texture.

Two water samples were collected in 250-millilitre polyethylene bottles from the centre of each lake: a surface sample and a near-bottom sample. The first sample was taken approximately 15 centimetres beneath the surface, to minimize collection of surface scum, and the second was collected with a Van Dorn sampler 1 to 2 metres above the lake bottom. Bottles were rinsed in the water to be sampled prior to collection, and observations of water colour and suspended matter were recorded. The boat was anchored in place during both water sampling and temperature/oxygen profiling to prevent movement. Water samples were stored in a cooler and refrigerated prior to analysis.

DISSOLVED OXYGEN AND TEMPERATURE PROFILING

Dissolved oxygen and temperature measurements were made to verify pre-existing Fisheries Branch (B.C Ministry of Environment, Lands and Parks) data, to determine the trophic status of smaller lakes for which data are lacking, and to investigate the variability of these measurements within separate sub-basins of individual lakes. Water column profiles were measured at one to five sites on each lake,

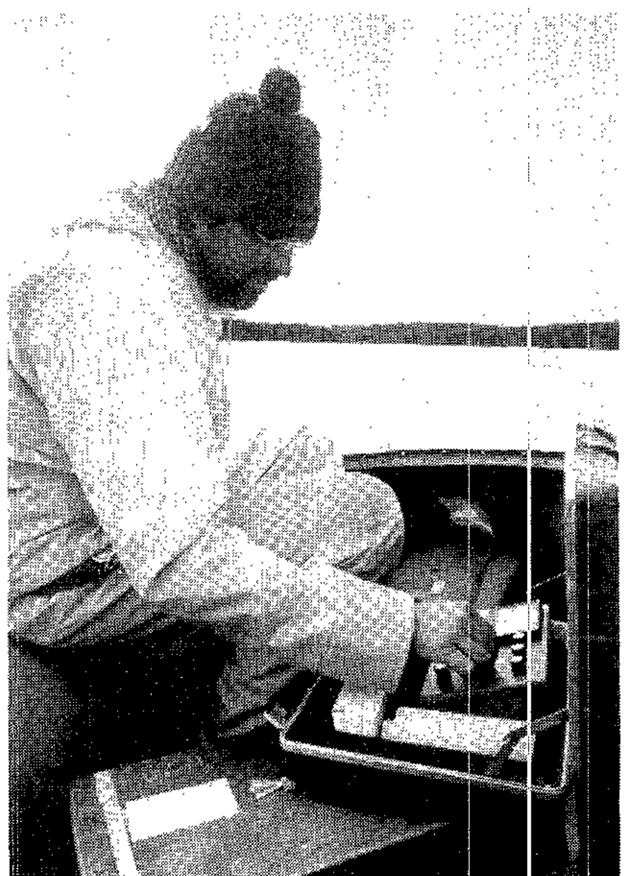

Photo 20-3. Measurement of lake water temperature and dissolved oxygen content.

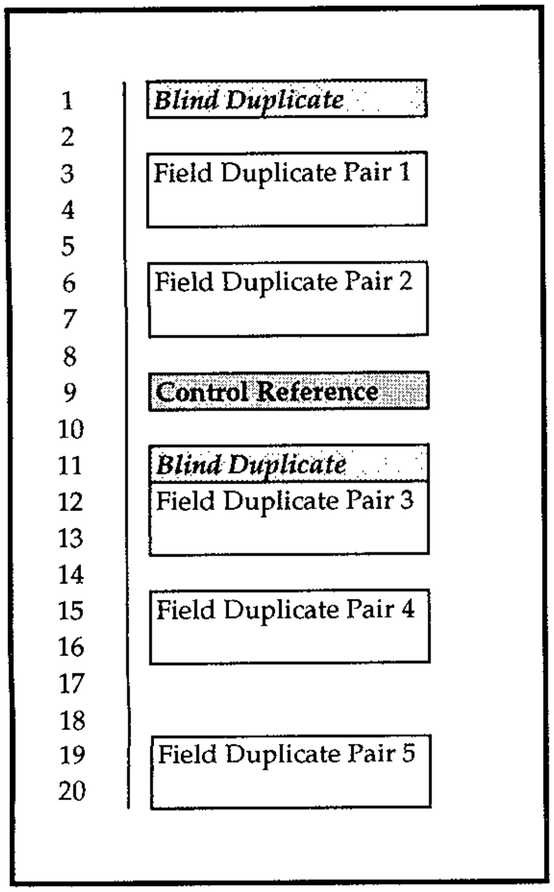

Figure 20-6. Typical sample collection scheme. The modified 20-sample collection block incorporates twelve routine samples and five field duplicates. Two blind duplicates and a control reference standard are inserted in prep laboratory prior to analysis.

using a YSI Model 57 oxygen meter with cable probe (Photo 20-3). Measurements were generally made, at 1-metre intervals, in the centre of all major sub-basins and at two near-shore sites to a maximum depth of 29 metres. The instrument was calibrated for lake elevation and air temperature prior to measurement at each lake, and data were collected only during the afternoon period to standardize measurement conditions. Prevailing weather conditions were also recorded at the start of each profile. Measurements generally corraborated earlier Fisheries Branch data at most lakes, although considerable within-lake variations were encountered. Measurements at Clisbako Lake were inconclusive due to the onset of cold weather in mid-September, 1992. A total of nine profiles were surveyed in the three lakes; profiles from the deepest part of each lake are shown in Figure 20-2.

SAMPLE PREPARATION AND ANALYSIS

Lake sediment samples were initially field dried and then shipped to Rossbacher Laboratory, Burnaby, for final drying at 60°C. Sample preparation was performed at Bondar-Clegg and Company, North Vancouver. Dry sediment samples were weighed, and disaggregated inside a plastic bag using a rubber mallet. The entire sample, to a maximum of 250 grams, was pulverized to approximately -150 mesh in a ceramic ring mill. Two analytical splits were taken from the pulverized material. The first 30-gram subsample was submitted to Activation Laboratories, Mississauga, for determination of gold and 34 additional elements by instrumental neutron activation analysis (INAA). The second was analyzed for zinc, copper, lead, silver, arsenic, molybdenum, iron, manganese and 22 additional elements, plus loss on ignition, by inductively coupled plasma - atomic emis-

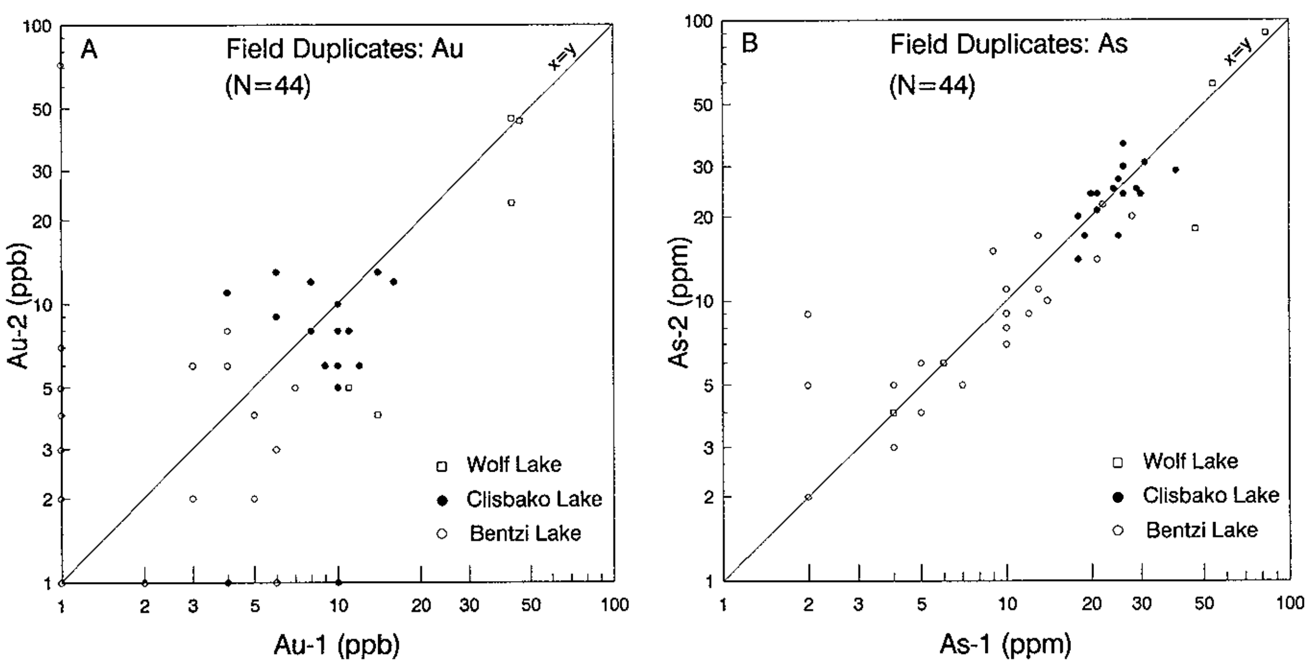

Figure 20-7. Log scatterplot of field duplicate A) gold determinations (ppb; INAA) and; B) arsenic determinations (ppm; ICP) from samples from Wolf (n=5), Clisbako (n=17) and Bentzi (n=22) Lakes.

sion spectrometry (ICP-AES) following an aqua regia digestion.

Water samples were filtered through 0.45-micron filters at the Analytical Sciences Laboratory of the Geological Survey Branch, Victoria, and submitted to Eco-Tech Laboratories, Kamloops. Samples were acidified and analyzed for 30 elements by inductively coupled plasma - atomic emission spectrometry (ICP-AES). Sulphate and pH values were also determined. Standards and distilled water blanks were included in the sample suite to monitor analytical accuracy. Only sulphate and pH data are included in this paper.

QUALITY CONTROL PROCEDURES

SAMPLING DESIGN

An unbalanced nested sampling design similar to that described by Garrett (1979) was used to assess sampling and analytical variation. The sampling scheme is a modified version of that used for the Regional Geochemical Survey (RGS). Each block of twenty samples (Figure 20-6) comprises twelve routine samples and:

- five field duplicate samples, to assess sampling variability;
- two analytical duplicate samples, inserted after sample preparation to determine analytical precision; and
- one control reference standard, to monitor analytical accuracy.

EVALUATION OF SAMPLING VARIABILITY, ANALYTICAL PRECISION AND ACCURACY

A total of 44 field duplicate samples were collected at sites in the three lakes. Results of gold and arsenic determinations on the field duplicates are shown in Figure 20-7. Two of the five field duplicates in each block of samples were randomly selected for further use as analytical duplicate splits, and inserted as blind duplicates into the analytical suites to monitor analytical precision. Appropriate ranges of copper and gold-bearing standards, together with silica blanks, were inserted into the analytical suites to monitor analytical accuracy. Complete quality control results will be reported elsewhere, but up to eleven replicate analyses of each of three gold standards (medians: 5, 14, and 38 ppb Au) returned relative standard deviations (RSD) of 43.2, 24.2 and 19.6%, respectively.

RESULTS

BASIC STATISTICS

Summary statistics for gold and other elements are shown in Table 20-2, with selected data listings for all three lakes given in Tables 20-3, 4 and 5. Concentrations below the stated detection limits (gold: 2 ppb) are reported as a value equivalent to one-half the detection limit. Elevated gold concentrations, relative to regional background, occur in sediments of each lake, with Wolf Pond exhibiting the greatest concentrations of the three (Figure 20-8). Median concentrations of 43 ppb gold (range: 11 to 56 ppb) occur at seven sites in Wolf Pond, while median concentrations of 9 ppb gold (range: 1 to 16 ppb) occur in forty sites in Clisbako Lake. The median gold concentration at Bentzi Lake (1 ppb) is below detection limit at 58 sites draining the Holy Cross prospect; nevertheless, elevated gold concentrations up to 9 ppb occur locally in the sediments.

Concentrations of other elements differ considerably among the three lakes, with the greatest number of anomalous elements occurring in Wolf Pond. Here, elevated concentrations of several elements including silver (median: 2.2 ppm), arsenic (median: 47 ppm), zinc (median: 306 ppm), molybdenum (median: 18 ppm) and antimony (median: 2 ppm INAA) occur in sediments of the small pond. Clisbako and Bentzi Lake sediments exhibit fewer elements with anomalous concentrations. Elevated median concentrations of 24 ppm arsenic and 3.1 ppm antimony occur in Clisbako sediments, with maximum values of 46 ppm and 6.2 ppm, respectively. Analysis of several Clisbako Lake samples for mercury (atomic absorption spectrometry), as part of a separate study by the author, returned a maximum value of 170 ppb mercury. There are no elevated median element concen-

TABLE 20-2
LAKE SEDIMENT GEOCHEMISTRY: SUMMARY STATISTICS FOR SELECTED ELEMENTS

		Au (ppb) INAA	Sb (ppm) INAA	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	Co (ppm)	Cd (ppm)	As (ppm)	Cr (ppm)	Ni (ppm)	Mn (ppm)	Fe (%)	LOI (%)
WOLF (N=7)	Median	43	2	18	71	8	306	2.2	14	0.5	47	21	21	302	3.37	52.3
	Mean	32.57	1.60	15.86	54.29	7.86	230.43	1.61	9.43	0.53	35.57	16.29	15.71	262.71	2.41	51.07
	S.D.	18.55	0.99	5.27	26.48	4.91	131.18	0.99	7.35	0.26	31.68	8.44	10.24	157.28	1.83	7.69
	Range	(11-56)	(0.4-2.7)	(9-23)	(22-81)	(2-16)	(90-372)	(0.5-2.6)	(1-17)	(0.2-0.9)	(2-83)	(7-24)	(2-26)	(87-511)	(0.4-4.73)	(40.7-64.1)
CLISBAKO (N=40)	Median	9	3.1	3	35.5	2	99.5	0.1	12	0.2	24	27.5	52	745	2.685	50.25
	Mean	8.88	3.47	3.03	33.55	3.63	89.20	0.12	11.43	0.25	24.45	26.05	50.50	785.80	2.64	46.04
	S.D.	3.77	1.18	1.35	11.76	3.18	22.24	0.06	2.53	0.10	7.21	6.14	13.37	279.26	0.89	16.93
	Range	(1-16)	(2.1-6.2)	(1-6)	(8-59)	(2-20)	(54-130)	(0.1-0.4)	(6-16)	(0.2-0.6)	(7-46)	(16-35)	(22-74)	(369-1745)	(0.95-4.86)	(7.1-70.5)
BENTZI (N=58)	Median	1	1.7	4	53	4	93.5	0.2	9	0.2	8.5	17.5	14.5	549.5	2.165	35.9
	Mean	2.59	1.77	3.41	51.31	4.16	96.86	0.21	9.34	0.28	10.10	16.31	14.26	1561.81	2.83	31.37
	S.D.	2.08	0.55	1.88	25.13	1.71	25.21	0.13	2.22	0.18	7.92	4.01	4.46	3527.71	2.27	13.25
	Range	(1-9)	(0.5-3.4)	(1-8)	(9-100)	(2-7)	(39-143)	(0.1-0.6)	(5-15)	(0.2-1.3)	(2-35)	(5-23)	(5-23)	(257-18752)	(1.56-11.64)	(4.2-49.2)

TABLE 20-3
LAKE SEDIMENT GEOCHEMISTRY DATA
FOR SELECTED ELEMENTS: WOLF POND

Lake	NTS	Sample	Depth (m)	Rep Status	Au (ppb) INAA	As (ppm) INAA	Sb (ppm) INAA	Ba (ppm) INAA	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	As (ppm)	Co (ppm)	Cd (ppm)	Cr (ppm)	Ni (ppm)	Mn (ppm)	Fe (%)	LOI (%)
WOLF	93F	923602	7.5	0	15	6.4	0.6	<50	9	26	2	95	0.6	2	2	0.5	7	6	156	0.40	64.1
	93F	923603	8	10	43	55.0	2.3	280	18	72	8	316	2.3	54	14	0.6	21	26	353	3.52	52.3
	93F	923605	8	20	46	61.0	2.2	240	19	76	6	331	2.3	59	14	0.9	22	25	368	3.76	53.6
	93F	923606	8	10	46	80.0	2.5	240	23	81	12	372	2.2	83	17	0.4	24	24	511	4.73	49.4
	93F	923607	8	20	45	82.0	2.4	230	24	77	14	374	2.1	90	20	0.3	25	20	504	4.98	50.4
	93F	923608	8	10	43	47.0	2.0	270	18	71	8	306	2.6	47	14	0.8	23	21	302	3.37	55.1
	93F	923609	7.5	20	23	19.0	1.1	170	14	54	7	191	1.7	18	4	0.6	13	9	163	1.40	65.8
	93F	923610	5	10	11	6.7	0.4	<50	10	22	6	90	0.5	4	1	0.2	7	7	92	0.47	43.6
	93F	923612	5	20	5	4.7	0.4	<50	10	12	6	76	0.2	4	1	0.2	6	6	72	0.20	35.9
	93F	923613	6.5	10	14	6.1	0.7	<50	13	31	3	91	0.6	6	2	0.3	8	2	87	0.66	40.7
	93F	923614	5	20	4	4.4	0.4	<50	13	12	3	66	0.2	6	1	0.2	4	5	56	0.19	30.3
	93F	923615	8	0	56	60.0	2.7	290	20	77	16	343	2.5	53	16	0.9	24	24	338	3.70	52.3

Note: Rep status of 0 indicates a routine sample; rep status of 10 and 20 indicate the first and second samples of a field duplicate pair, respectively.

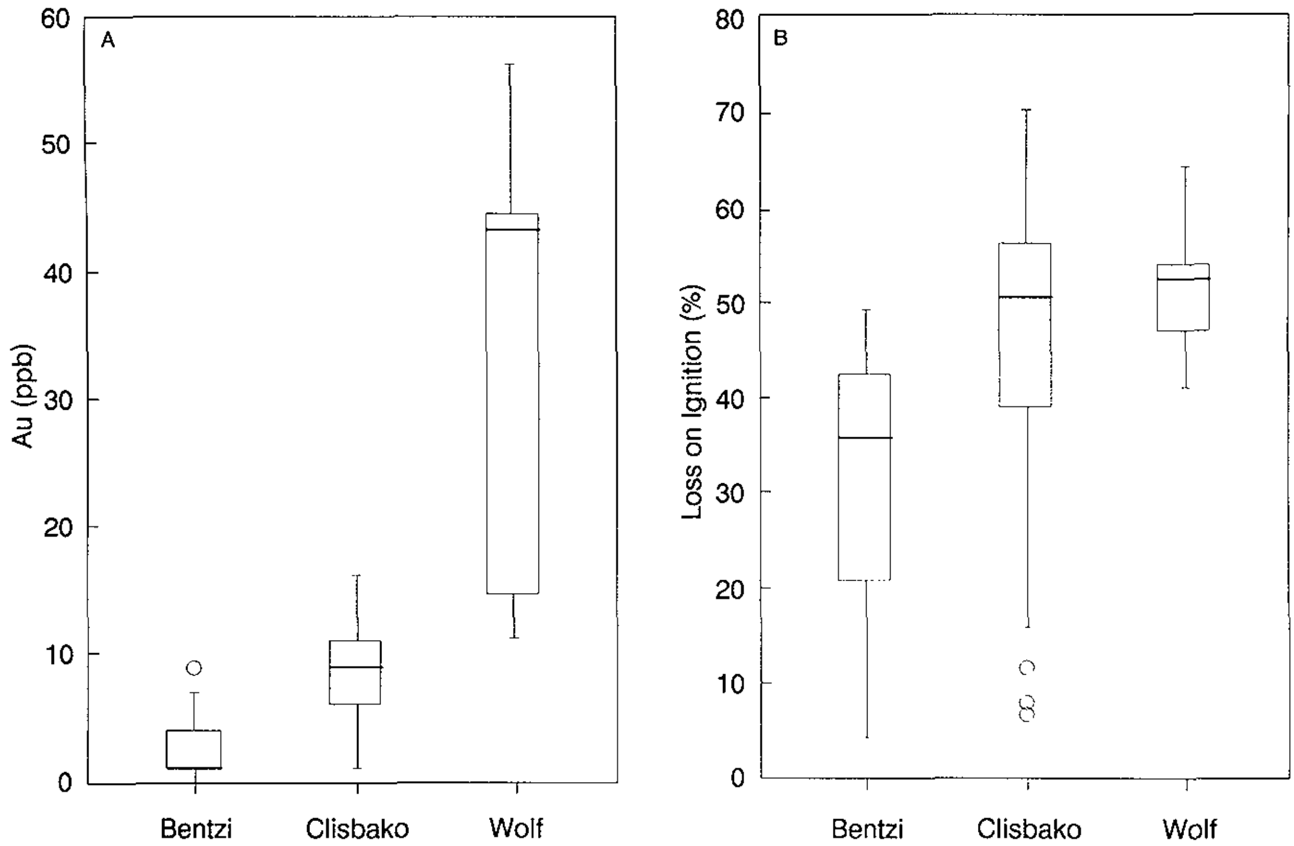

Figure 21-8. Boxplots showing variations in A) gold (ppb); and B) loss on ignition (%) among sediments of Bentzi (n=58), Clisbako (n=40) and Wolf (n=7) lakes. Median concentrations are denoted by the bold line in each box; 50% of the data for each lake lies within the box.

TABLE 20-4
LAKE SEDIMENT GEOCHEMISTRY DATA FOR SELECTED ELEMENTS: CLISBAKO LAKE

Lake	NTS	Sample	Depth (m)	Rep Status	Au (ppb) INAA	As (ppm) INAA	Sb (ppm) INAA	Ba (ppm) INAA	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	As (ppm)	Co (ppm)	Cd (ppm)	Cr (ppm)	Ni (ppm)	Mn (ppm)	Fe (%)	LOI (%)
CLISBAKO	93C	925002	3.5	0	11	21.0	4.6	430	2	37	6	99	0.1	17	11	0.2	28	63	369	1.94	44.5
	93C	925003	4	10	16	33.0	6.2	480	2	41	3	100	0.1	29	13	0.2	30	63	422	2.31	40.5
	93C	925004	4	20	12	30.0	6.7	540	2	36	4	98	0.1	25	12	0.2	30	57	436	2.43	35.0
	93C	925005	5	0	11	34.0	6.2	600	2	33	2	111	0.1	32	16	0.2	27	48	1045	3.11	36.8
	93C	925006	5	0	6	25.0	6.1	790	2	17	3	97	0.1	25	13	0.2	23	35	777	3.10	18.5
	93C	925007	8	10	12	30.0	3.0	320	3	30	2	122	0.1	30	13	0.2	30	55	560	2.52	50.3
	93C	925008	8	20	6	25.0	3.4	210	4	34	7	112	0.1	24	13	0.2	32	57	465	2.31	53.1
	93C	925009	9	0	9	26.0	2.6	330	3	31	4	110	0.1	21	12	0.2	32	56	884	3.66	50.4
	93C	925010	8	10	11	27.0	3.0	200	4	33	6	130	0.1	25	14	0.2	33	67	738	3.31	52.5
	93C	925012	8	20	8	26.0	3.3	270	4	37	2	111	0.1	27	15	0.2	33	58	666	2.95	54.7
	93C	925013	2.5	0	1	9.3	4.9	870	1	8	3	54	0.1	7	8	0.2	20	22	448	2.05	7.1
	93C	925015	5	10	8	20.0	3.9	510	2	32	20	109	0.1	25	13	0.2	32	53	645	3.26	39.9
	93C	925016	5	20	8	22.0	3.8	470	2	32	8	101	0.1	17	13	0.2	31	53	631	3.18	41.4
	93C	925017	5	0	10	49.0	5.6	430	4	50	3	103	0.1	46	15	0.2	28	64	703	2.74	49.9
	93C	925018	4	0	3	20.0	2.2	790	1	10	2	59	0.1	20	11	0.2	18	23	919	3.13	7.8
	93C	925019	7.5	10	10	23.0	3.2	410	3	36	2	105	0.1	21	14	0.2	33	62	647	3.05	37.7
	93C	925020	7.5	20	1	18.0	4.0	420	2	23	9	85	0.1	21	12	0.2	25	46	593	2.03	52.3
	93C	925022	4	0	5	21.0	2.1	760	1	13	8	66	0.1	23	11	0.2	23	31	509	2.24	11.1
	93C	925023	2	0	1	16.0	5.1	560	2	19	8	77	0.1	18	11	0.2	24	42	584	1.82	31.4
	93C	925024	6	10	6	24.0	5.3	670	1	17	2	69	0.1	26	12	0.2	20	26	1289	2.89	17.8
	93C	925025	6	20	13	34.0	5.6	460	5	44	4	120	0.3	36	14	0.4	31	61	682	2.63	45.7
	93C	925026	10.5	10	4	38.0	2.3	-50	3	29	2	118	0.1	40	11	0.4	27	47	1378	4.86	46.8
	93C	925027	10.5	20	1	40.0	2.3	100	1	22	2	73	0.2	29	9	0.2	21	34	1039	3.97	46.9
	93C	925028	9.5	0	5	30.0	2.6	270	3	35	2	104	0.1	31	12	0.3	31	52	924	3.55	50.2
	93C	925029	7	10	8	33.0	3.8	300	3	41	2	111	0.1	31	16	0.6	33	62	678	2.83	49.7
	93C	925030	7	20	8	30.0	3.4	520	3	28	4	95	0.1	31	15	0.2	29	47	483	2.36	31.6
	93C	925032	9	0	7	29.0	2.7	250	3	31	2	101	0.1	26	13	0.5	29	49	919	4.46	49.9
	93C	925033	10	0	8	37.0	2.5	110	1	17	2	58	0.1	22	7	0.2	17	30	587	2.23	42.6
	93C	925034	1	0	9	17.0	2.9	240	4	28	3	66	0.1	23	7	0.2	17	43	1745	1.54	63.1
	93C	925035	1	0	12	13.0	2.8	230	5	30	2	54	0.1	15	6	0.2	19	42	812	0.95	67.2
	93C	925036	1.5	10	14	19.0	3.6	210	6	37	2	57	0.1	21	7	0.2	19	48	688	1.15	67.7
	93C	925038	1.5	20	13	20.0	4.0	200	6	39	6	62	0.2	21	8	0.6	19	50	586	1.25	68.9
	93C	925039	2	10	8	27.0	3.2	180	6	38	3	75	0.1	26	8	0.3	16	48	1199	1.22	70.5
	93C	925040	2	20	12	29.0	4.1	140	7	30	2	44	0.1	30	8	0.2	13	39	669	0.88	72.3
	93C	925042	2	0	7	14.0	3.1	300	4	36	6	55	0.1	17	8	0.3	23	48	763	1.32	56.8
	93C	925043	4	10	9	24.0	2.2	420	5	29	6	71	0.1	24	12	0.2	26	39	708	2.12	33.7
	93C	925044	4	20	6	22.0	2.1	390	5	29	5	75	0.1	25	13	0.2	27	38	730	2.36	30.1
	93C	925045	2	10	10	16.0	2.6	340	4	32	2	54	0.1	18	9	0.5	21	42	997	1.57	47.1
	93C	925046	2	20	5	13.0	2.5	350	4	25	2	60	0.1	14	9	0.2	24	37	856	1.47	38.2
	93C	925047	3	0	11	25.0	3.6	190	4	44	2	69	0.1	30	9	0.2	21	53	938	1.86	65.2
	93C	925048	3.5	0	13	37.0	4.0	180	6	48	2	78	0.1	36	10	0.2	16	54	1036	2.01	70.0
	93C	925049	3	10	10	21.0	3.0	240	3	43	2	80	0.1	19	11	0.2	17	49	945	2.15	60.3
	93C	925052	3	20	8	21.0	3.1	320	3	41	2	79	0.1	17	12	0.2	18	46	1013	2.28	53.5
	93C	925053	7	10	10	20.0	2.5	190	3	38	2	105	0.1	18	12	0.2	30	59	761	3.09	55.8
	93C	925054	7	20	6	22.0	2.5	280	3	38	2	99	0.3	20	13	0.2	32	62	634	2.81	56.5
	93C	925055	5	0	16	36.0	3.7	310	3	59	5	106	0.4	34	14	0.3	33	74	371	2.63	58.6
	93C	925056	5	0	5	17.0	2.1	680	2	20	4	73	0.1	15	14	0.2	20	34	449	2.30	15.5
	93C	925057	7	10	10	23.0	2.6	270	2	39	6	102	0.1	21	12	0.2	33	65	632	2.97	56.1
	93C	925058	6.5	20	10	26.0	3.0	190	2	43	2	95	0.1	24	13	0.2	32	65	485	2.88	55.5
	93C	925059	5	0	16	32.0	3.9	310	3	57	3	105	0.2	28	13	0.4	32	68	752	2.47	54.5
	93C	925060	9.5	0	8	29.0	2.6	220	3	36	2	95	0.1	24	10	0.2	28	52	832	3.79	51.4
	93C	925062	9.5	10	4	28.0	2.5	220	3	38	2	104	0.1	26	10	0.3	30	53	714	3.99	51.2
	93C	925063	9.5	20	11	44.0	4.1	300	3	36	2	98	0.3	24	11	0.2	27	52	698	3.77	51.4
	93C	925064	8	10	6	26.0	3.2	310	3	39	3	110	0.1	20	13	0.2	33	62	756	3.18	53.[illegible]
	93C	925065	8	20	9	25.0	3.0	230	3	41	2	106	0.2	24	14	0.2	34	66	749	3.08	54.[illegible]
	93C	925066	4.5	0	13	26.0	3.1	340	2	46	2	104	0.2	24	12	0.2	35	70	629	3.19	51.4
	93C	925067	8	0	12	30.0	3.5	280	4	45	2	102	0.3	24	14	0.2	35	67	680	2.99	56.7

TABLE 20-5
LAKE SEDIMENT GEOCHEMISTRY DATA FOR
SELECTED ELEMENTS: BENTZI LAKE

Lake	NTS	Sample	Depth (m)	Rep Status	Au (ppb) INAA	As (ppm) INAA	Sb (ppm) INAA	Ba (ppm) INAA	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	As (ppm)	Co (ppm)	Cd (ppm)	Cr (ppm)	Ni (ppm)	Mn (ppm)	Fe (%)	LOI (%)
BENTZI	93F	923202	12.5	10	7	11.0	2.0	910	2	29	6	93	0.1	10	9	0.2	18	14	347	2.29	15.4
	93F	923203	12	20	5	9.4	2.0	1000	1	14	2	80	0.1	7	11	0.3	15	9	337	2.49	4.3
	93F	923204	9.5	0	1	7.6	1.7	930	1	9	4	68	0.1	9	8	0.2	14	5	301	2.65	4.2
	93F	923205	10.5	0	1	8.9	1.6	1000	2	26	3	67	0.1	3	8	0.2	16	11	257	1.98	17.8
	93F	923206	9	10	1	15.0	2.9	840	1	17	3	78	0.1	9	11	0.2	13	11	367	2.48	9.4
	93F	923208	9	20	72	16.0	3.1	860	1	22	4	64	0.1	15	9	0.2	11	9	333	1.93	14.4
	93F	923209	14.5	0	4	12.0	1.7	840	4	32	6	83	0.2	13	13	0.5	16	14	646	2.78	17.8
	93F	923210	16.5	10	2	12.0	2.1	710	5	72	2	109	0.2	13	10	0.2	19	19	494	2.08	39.9
	93F	923212	16.5	20	1	11.0	2.1	730	5	74	4	109	0.3	11	10	0.2	20	18	531	2.13	40.1
	93F	923213	15.5	0	2	10.0	2.0	750	4	72	5	113	0.2	10	10	0.2	23	18	539	2.13	48.6
	93F	923214	12	0	1	7.6	1.9	790	1	14	2	56	0.1	5	7	0.2	11	8	458	1.76	11.3
	93F	923215	24	0	4	17.0	1.8	610	6	82	6	136	0.3	17	12	0.2	20	16	1255	2.75	44.3
	93F	923216	20	10	1	14.0	2.3	710	4	73	7	111	0.3	12	10	0.2	20	18	685	2.13	43.0
	93F	923217	20	20	1	13.0	2.6	690	4	68	2	126	0.3	9	10	0.2	20	17	657	2.15	40.9
	93F	923218	20.5	0	4	19.0	2.3	740	5	73	3	127	0.3	23	11	0.2	19	19	892	2.36	42.8
	93F	923219	13	0	1	16.0	2.8	690	4	44	2	84	0.1	15	10	0.2	13	14	575	2.08	23.4
	93F	923220	27	0	9	13.0	2.2	580	6	85	2	143	0.3	12	12	0.2	18	19	1035	2.01	46.9
	93F	923223	19	10	6	22.0	2.3	790	7	77	3	127	0.3	28	13	0.4	23	23	999	2.89	34.7
	93F	923224	19	20	3	20.0	2.2	860	6	74	4	121	0.3	20	11	0.2	21	19	877	2.66	37.0
	93F	923225	28	0	1	17.0	2.3	720	6	83	6	140	0.4	15	12	0.6	18	20	1199	2.37	46.2
	93F	923226	12	10	4	14.0	2.2	690	4	66	5	110	0.3	13	10	0.2	20	17	490	2.21	37.1
	93F	923227	12	20	6	14.0	2.1	810	5	69	6	124	0.3	17	10	0.2	21	16	500	2.25	38.6
	93F	923228	19	0	5	14.0	2.3	700	4	59	5	130	0.2	14	10	0.2	20	16	897	2.51	35.0
	93F	923229	20	10	1	19.0	2.0	710	6	72	7	142	0.3	22	11	0.2	20	20	1075	2.67	39.9
	93F	923230	20	20	7	17.0	1.9	800	5	66	4	132	0.2	22	11	0.2	21	15	876	2.67	37.3
	93F	923232	24.5	0	6	24.0	2.4	660	8	88	3	130	0.4	27	14	0.6	20	21	1330	2.80	45.3
	93F	923233	20.5	0	1	13.0	2.3	760	5	73	4	113	0.3	16	10	0.2	22	21	761	2.29	41.4
	93F	923234	10.5	10	4	16.0	1.7	830	3	41	2	100	0.2	21	10	0.3	19	12	400	2.57	22.2
	93F	923235	10.5	20	8	17.0	1.8	830	4	53	9	102	0.3	14	10	0.2	20	16	446	2.54	27.2
	93F	923236	35	0	1	24.0	1.6	670	2	45	3	92	0.3	32	15	0.7	9	10	12484	10.53	37.3
	93F	923237	17	10	1	12.0	1.8	860	4	52	3	106	0.1	14	11	0.2	18	16	900	2.60	29.7
	93F	923238	16	20	1	11.0	1.5	900	3	40	5	96	0.2	10	10	0.2	18	14	474	2.68	22.4
	93F	923239	35	0	7	25.0	1.5	670	2	44	2	88	0.3	35	15	1.3	9	10	12360	11.64	36.0
	93F	923240	30	0	5	17.0	2.5	730	5	85	3	122	0.3	16	11	0.2	19	17	1027	2.20	43.3
	93F	923242	12	10	6	9.3	1.6	870	3	45	2	100	0.1	10	9	0.3	19	13	415	2.02	31.3
	93F	923243	12	20	1	9.6	1.5	910	3	38	2	84	0.2	8	8	0.2	18	17	354	1.91	27.4
	93F	923244	15	0	1	11.0	1.7	640	4	61	7	90	0.4	3	9	0.4	17	17	432	1.88	42.8
	93F	923246	10	10	5	8.8	1.5	660	3	58	3	85	0.1	2	8	0.3	17	16	294	1.99	39.9
	93F	923247	10.5	20	4	10.0	1.5	730	3	59	4	85	0.3	5	9	0.2	17	17	294	1.96	39.9
	93F	923248	7.5	0	4	9.9	1.6	840	2	37	2	73	0.2	3	8	0.3	14	13	283	2.01	28.3
	93F	923249	4	0	2	5.8	0.9	880	1	11	4	39	0.1	2	6	0.2	5	6	375	2.01	16.1
	93F	923250	7	10	5	7.2	1.5	820	2	37	4	64	0.1	2	6	0.2	14	13	268	1.78	26.4
	93F	923252	7	20	2	7.6	1.4	860	2	38	4	68	0.3	2	6	0.2	15	12	290	1.85	27.0
	93F	923253	7	0	4	4.9	1.2	940	1	13	2	63	0.1	2	6	0.2	12	8	352	2.80	5.2
	93F	923254	6	0	1	7.2	1.6	990	1	16	4	63	0.1	2	7	0.2	11	7	422	2.55	12.2
	93F	923255	9	0	1	8.1	1.4	970	1	23	4	76	0.3	2	7	0.3	17	10	294	2.40	11.1
	93F	923256	17	10	1	11.0	1.7	430	4	65	5	93	0.5	4	7	0.2	16	14	633	1.76	36.6
	93F	923257	17	20	3	13.0	1.8	580	5	67	5	151	0.2	3	8	0.3	15	16	637	1.77	37.0
	93F	923258	17	10	1	12.0	1.7	520	4	66	5	93	0.4	5	7	0.3	15	13	753	1.78	34.0
	93F	923259	17	20	5	11.0	1.8	500	4	62	7	97	0.3	4	7	0.4	15	14	739	1.77	35.0
	93F	923260	9.5	0	2	8.9	3.4	990	1	37	4	82	0.1	2	8	0.2	15	11	330	2.37	15.8
	93F	923262	17	10	1	12.0	2.2	590	5	74	5	102	0.1	4	9	0.3	18	16	560	1.79	39.4
	93F	923263	16	20	4	11.0	1.9	600	5	77	8	111	0.3	5	9	0.4	19	18	542	1.78	39.8
	93F	923264	11	0	1	12.0	1.8	880	3	54	6	103	0.1	3	10	0.2	18	16	388	2.30	25.1
	93F	923265	15	10	1	13.0	2.0	700	6	80	6	126	0.6	5	9	0.3	18	18	628	1.84	40.6
	93F	923266	15	20	2	13.0	2.0	460	6	77	6	116	0.1	4	9	0.4	18	18	605	1.80	40.6
	93F	923267	14	0	1	13.0	2.2	660	5	100	4	123	0.1	3	11	0.4	20	20	594	2.04	40.8
	93F	923268	15	0	3	12.0	2.5	500	6	91	4	122	0.2	2	11	0.4	20	20	507	1.81	41.5
	93F	923269	28	10	1	13.0	1.8	630	5	79	7	133	0.1	5	9	0.3	18	18	809	2.01	43.8
	93F	923270	29	20	1	14.0	1.6	790	5	79	6	125	0.1	6	9	0.5	18	19	826	2.01	44.2
	93F	923272	34	0	1	23.0	1.4	760	2	50	2	84	0.3	8	6	0.2	8	10	12505	10.41	35.8
	93F	923273	18	0	1	11.0	1.2	910	2	39	5	94	0.4	5	9	0.3	12	10	662	2.93	20.8
	93F	923274	35	10	1	27.0	1.3	1000	1	43	2	79	0.2	7	7	0.2	7	9	18752	11.29	35.6
	93F	923275	35	20	1	18.0	1.4	500	2	63	2	108	0.4	5	7	0.2	12	13	7543	9.67	38.8
	93F	923276	32	0	6	16.0	1.3	540	5	65	2	109	0.4	10	7	0.2	12	15	3446	3.92	38.6
	93F	923277	21	0	1	14.0	1.4	640	5	67	7	110	0.1	6	9	0.2	19	18	671	2.13	42.4
	93F	923279	18	10	4	8.5	1.5	750	4	58	7	112	0.1	2	8	0.2	18	17	427	1.91	36.2
	93F	923280	17	20	1	9.7	1.4	610	4	51	4	94	0.1	9	8	0.2	20	17	423	1.70	38.3
	93F	923282	29.5	0	3	15.0	1.6	720	5	75	7	124	0.2	19	11	0.2	21	20	897	1.94	47.3
	93F	923283	22	10	1	12.0	1.5	580	5	61	4	108	0.1	10	10	0.2	20	17	584	1.85	42.4
	93F	923284	21	20	2	12.0	1.4	620	5	57	4	91	0.2	11	10	0.3	19	15	588	1.88	40.7
	93F	923285	12	0	1	8.4	0.9	1000	1	12	7	74	0.1	7	9	0.2	12	5	313	2.58	8.1
	93F	923286	12.5	10	3	8.5	1.2	570	3	48	5	83	0.1	10	9	0.2	18	15	343	1.56	48.5
	93F	923287	13	20	6	7.2	1.2	470	3	50	4	84	0.1	8	9	0.2	18	19	359	1.56	48.4
	93F	923288	12	0	1	6.6	0.9	800	1	18	5	72	0.1	7	8	0.2	17	12	391	2.04	20.6
	93F	923289	10	0	1	2.5	0.5	440	1	9	3	59	0.1	8	8	0.2	15	9	314	2.42	4.7
	93F	923290	10	0	1	7.9	1.1	870	2	21	2	73	0.1	7	8	0.2	17	12	273	1.77	15.0
	93F	923293	9	10	3	9.7	1.2	600	2	34	5	80	0.1	10	8	0.2	16	11	385	1.79	49.2
	93F	923294	10	20	2	8.7	1.0	610	2	34	3	75	0.1	9	6	0.2	16	14	365	1.84	47.9
	93F	923295	5	0	1	7.1	0.9	690	1	16	3	59	0.1	5	5	0.2	13	9	512	1.87	30.6

trations present in Bentzi Lake, with the possible exception of antimony (median: 1.7 ppm). Nevertheless, elevated arsenic, antimony and copper concentrations up to 35 ppm, 3.4 ppm and 100 ppm, respectively occur locally.

Median organic matter content, expressed as loss on ignition (%), increases with decreasing size of the three lakes studied, ranging from a high of 52.3% at Wolf Pond to a low of 35.9% in Bentzi Lake sediments (Figure 20-8). The highest individual LOI values occur in sediments at Clisbako Lake, where values reach 70.5% in samples containing significant undecomposed organic matter. Wolf Pond sediments contain elevated iron concentrations (median: 3.37%), whereas Clisbako sediments contain elevated manganese concentrations (median: 745 ppm).

CORRELATION ANALYSIS

Pearson log correlation matrices for twelve selected variables and elements from Bentzi and Clisbako Lakes are shown in Figure 20-9. Gold, arsenic and antimony were determined by INAA; remaining elements are ICP determinations. Data for both INAA and ICP arsenic determinations are included. No correlation matrix is given for Wolf Pond, as too few samples were collected to permit meaningful correlations. Significant inter-element correlations, defined as those exceeding the critical value above which they are significantly different from zero at the 95% confidence level (Clisbako: r 0.264; Bentzi: r 0.218), are more numerous in Bentzi Lake sediment (47 significant correlations) than in Clisbako Lake sediment (31 significant correlations). Most significant correlations are positive; there are only three significant negative correlations for each lake.

A number of significant correlations are common to the sediment geochemistry of both lakes. Gold correlates with copper, zinc, molybdenum, arsenic and LOI (Figure 20-10), with most correlations stronger in Clisbako as opposed to Bentzi sediments. Copper, molybdenum, zinc and arsenic also correlate with LOI. Copper also exhibits significant correlations with molybdenum, zinc and arsenic. Sample depth correlates with arsenic, zinc and iron in each lake. Lead and manganese exhibit significant negative correlations.

There are differences in correlation patterns between the two lakes for some elements. In particular, there are numerous significant correlations in Bentzi sediments which are not present in the Clisbako data. These include correlations with depth (Cu, Mo, Mn, LOI), LOI (Sb, Mn), antimony (As, Cu, Zn, Mo, LOI) and molybdenum (As (INAA), Sb, Zn, Pb, depth). As an example of the foregoing, LOI increases with depth in Bentzi Lake and Wolf Pond, but shows no relation to depth in Clisbako Lake (Figure 20-11). Notably, iron and manganese exhibit few significant positive correlations, other than with depth and arsenic, in either of the two lakes. Manganese correlates with copper, zinc, LOI and depth in Bentzi Lake only, while iron correlates with zinc in Clisbako Lake only. Iron and manganese correlate significantly with each other in Bentzi Lake, but not in Clisbako Lake.

CLISBAKO LAKE

	Au (IN)	As (IN)	Sb (IN)	Cu	Zn	Pb	Mo	As	Fe	Mn	LOI	Depth
Au (INAA)	1.00											
As (INAA)	**0.44**	1.00										
Sb (INAA)	0.02	0.13	1.00									
Cu	**0.73**	**0.50**	0.09	1.00								
Zn	**0.27**	**0.63**	0.15	**0.50**	1.00							
Pb	-0.16	-0.25	0.05	-0.11	0.06	1.00						
Mo	**0.48**	0.15	-0.10	**0.70**	0.10	-0.15	1.00					
As	**0.46**	**0.89**	0.14	**0.53**	**0.53**	-0.15	**0.30**	1.00				
Fe	-0.11	**0.52**	-0.10	0.03	**0.73**	-0.08	**-0.32**	**0.37**	1.00			
Mn	0.03	0.09	-0.15	0.05	-0.11	**-0.40**	**0.32**	**0.29**	0.03	1.00		
LOI	**0.65**	**0.37**	-0.05	**0.88**	**0.32**	-0.16	**0.77**	**0.43**	-0.14	0.25	1.00	
Depth	0.01	**0.57**	-0.29	0.10	**0.64**	-0.22	-0.15	**0.34**	**0.83**	0.01	0.10	1.00

BENTZI LAKE

	Au (IN)	As (IN)	Sb (IN)	Cu	Zn	Pb	Mo	As	Fe	Mn	LOI	Depth
Au (INAA)	1.00											
As (INAA)	0.16	1.00										
Sb (INAA)	0.17	**0.57**	1.00									
Cu	**0.24**	**0.68**	**0.59**	1.00								
Zn	**0.24**	**0.65**	**0.59**	**0.88**	1.00							
Pb	**-0.24**	-0.06	0.04	0.20	**0.28**	1.00						
Mo	**0.27**	**0.55**	**0.52**	**0.90**	**0.87**	**0.24**	1.00					
As	**0.24**	**0.61**	**0.22**	**0.30**	**0.48**	-0.12	**0.40**	1.00				
Fe	0.02	**0.52**	-0.09	-0.02	-0.02	**-0.35**	-0.20	**0.36**	1.00			
Mn	0.04	**0.72**	0.07	**0.34**	**0.28**	**-0.25**	0.16	**0.48**	**0.88**	1.00		
LOI	**0.22**	**0.62**	**0.37**	**0.89**	**0.69**	0.18	**0.76**	**0.30**	0.01	**0.39**	1.00	
Depth	0.11	**0.75**	0.20	**0.57**	**0.58**	-0.05	**0.46**	**0.56**	**0.62**	**0.87**	**0.54**	1.00

Figure 20-9. Pearson log correlation matrices for selected elements from Clisbako (n=40) and Bentzi (n=58) lakes. All data except sample depth logged. Significant correlations (Clisbako: r 0.264; Bentzi: r 0.218; 95% confidence level) shown in bold type. Au (IN), As (IN) and Sb (IN) data are INAA results; remainder are ICP determinations.

SPATIAL DISTRIBUTION OF GOLD AND OTHER SELECTED ELEMENTS

Frequency distributions of gold in lake sediments (Figure 20-12) show considerable variation among the three lakes. Clisbako Lake gold concentrations show an approximately normal distribution, whereas those of Bentzi Lake are a more typical positively skewed distribution. Element distribution maps for gold (ppb), arsenic (ppm) and LOI (%) for Wolf Pond, Clisbako and Bentzi lake sediments are given in Figures 20-13 through 15. Site location and sample depth (metres) maps are also shown. Several elements [notably gold, arsenic (Figure 20-13), silver, zinc, iron and manganese] exhibit very similar geochemical patterns in Wolf Pond sediments. High element concentrations occur throughout the pond, but the greatest occur at four sites along a southwest trend in the central part of the basin. These sites occur roughly within the bounds of the 8-metre sample depth contour; lower element concentrations occur in sediment near the pond margins. Molybdenum patterns differ in that anomalous concentrations are much more uniformly distributed throughout the pond, but the highest concentrations, nevertheless, occur in the basin centre. There are no apparent correlations of high element concentrations with LOI in Wolf Pond, although anomalous samples do exhibit a rather narrow range of LOI values between 49.4 and 55.1%. The similarity of anomalous element concentrations

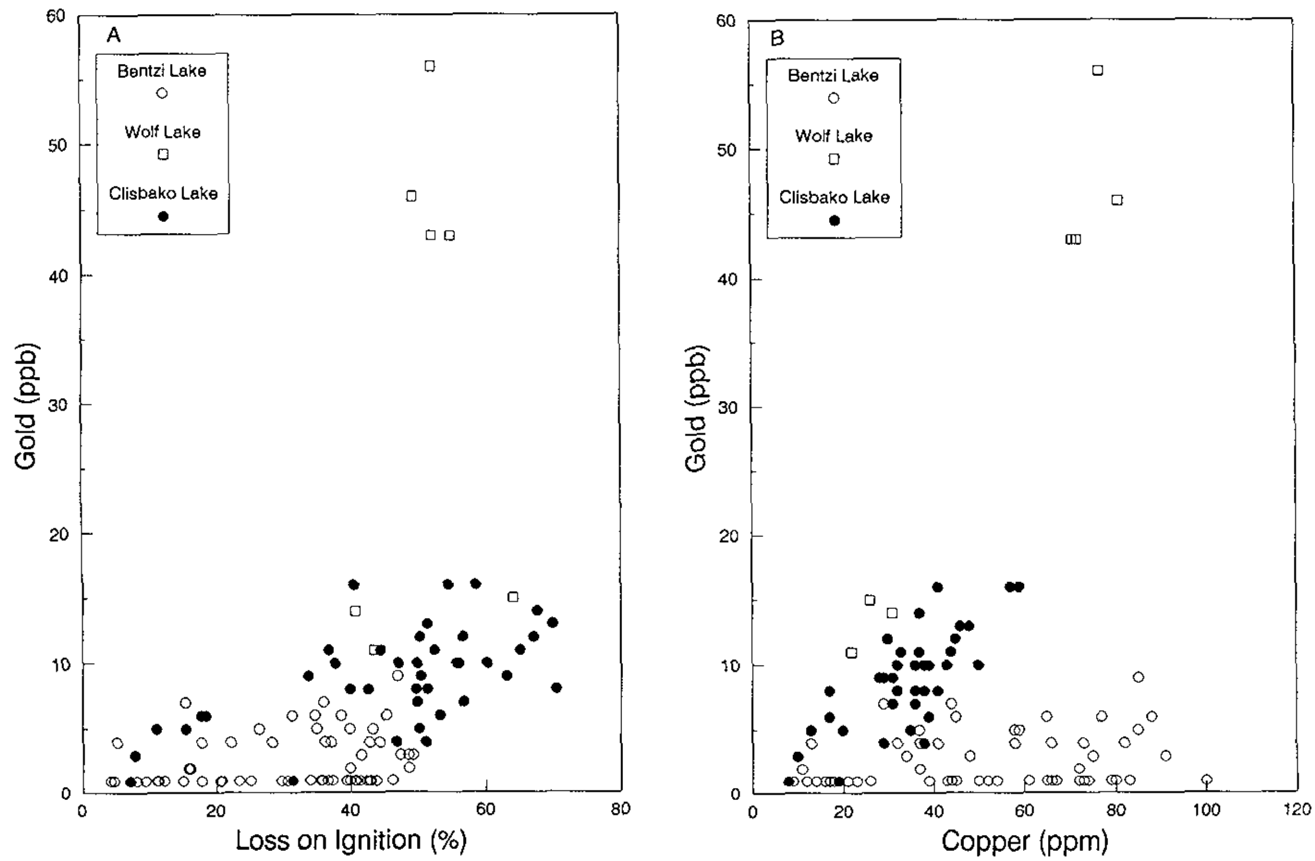

Figure 20-10. Scatterplots of gold (ppb) versus: A) loss on ignition (%); and B) copper (ppm) for Wolf, Clisbako and Bentzi Lakes (N=105).

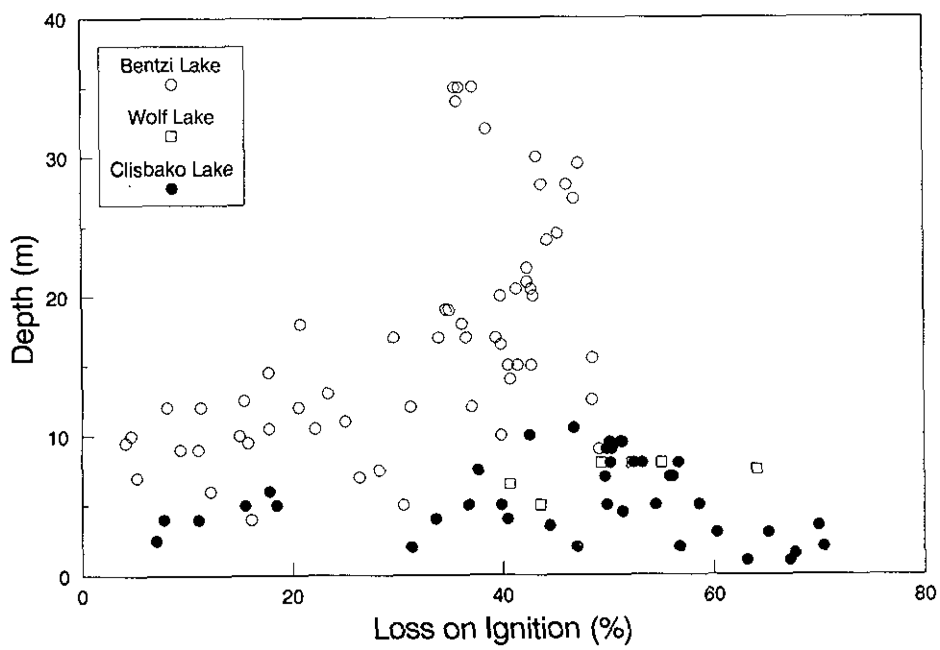

Figure 20-11. Scatterplot of loss on ignition (%) versus depth (m) for Wolf, Clisbako and Bentzi Lakes (N=105).

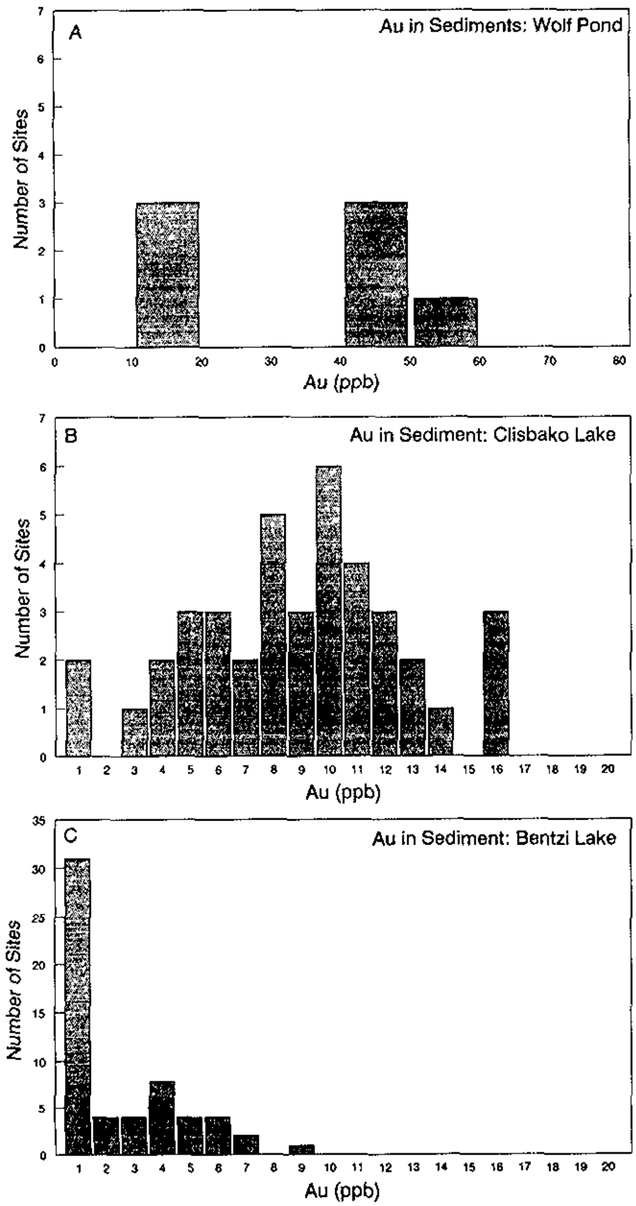

Figure 20-12. Frequency distributions of gold in sediment of Wolf (n=7), Clisbako (n=40) and Bentzi (n=58) lakes.

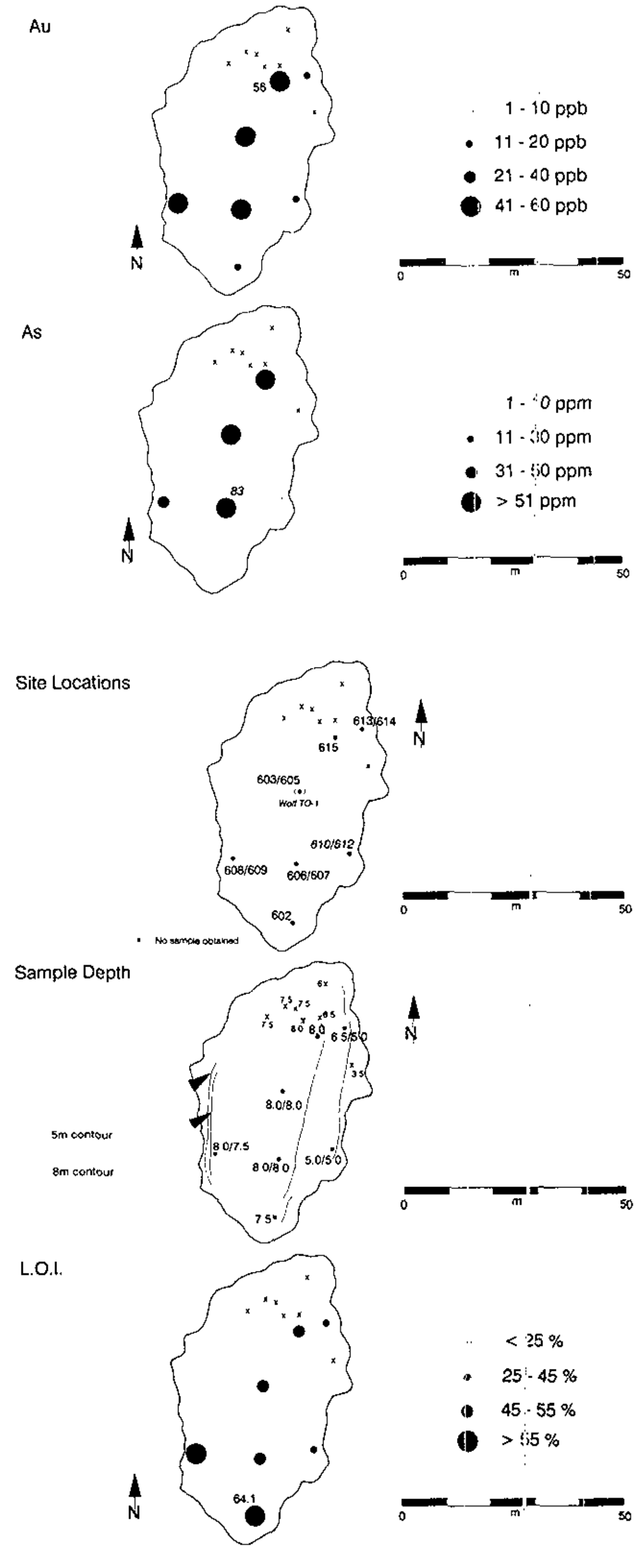

Figure 20-13. Wolf Pond, showing distribution of gold (ppb), arsenic (ppm) and loss on ignition (%), and site locations and sample depths (m).

indicates that metals are relatively uniformly distributed throughout the sediment, both between and within (field duplicates) site locations.

Clisbako Lake (Figure 20-14) has the most complex gold geochemistry patterns of the three lakes studied. As with Bentzi Lake, gold has little correlation with depth, and the highest values are not located in the deepest part of the lake. Although elevated gold concentrations occur throughout Clisbako Lake, there are three groupings of high gold values (10 ppb), each with different characteristics and potentially different sources. The first comprises four sites along the southwest side of the lake, where sediment sampled on the profundal slope at depths of 4.5 to 8 metres con-

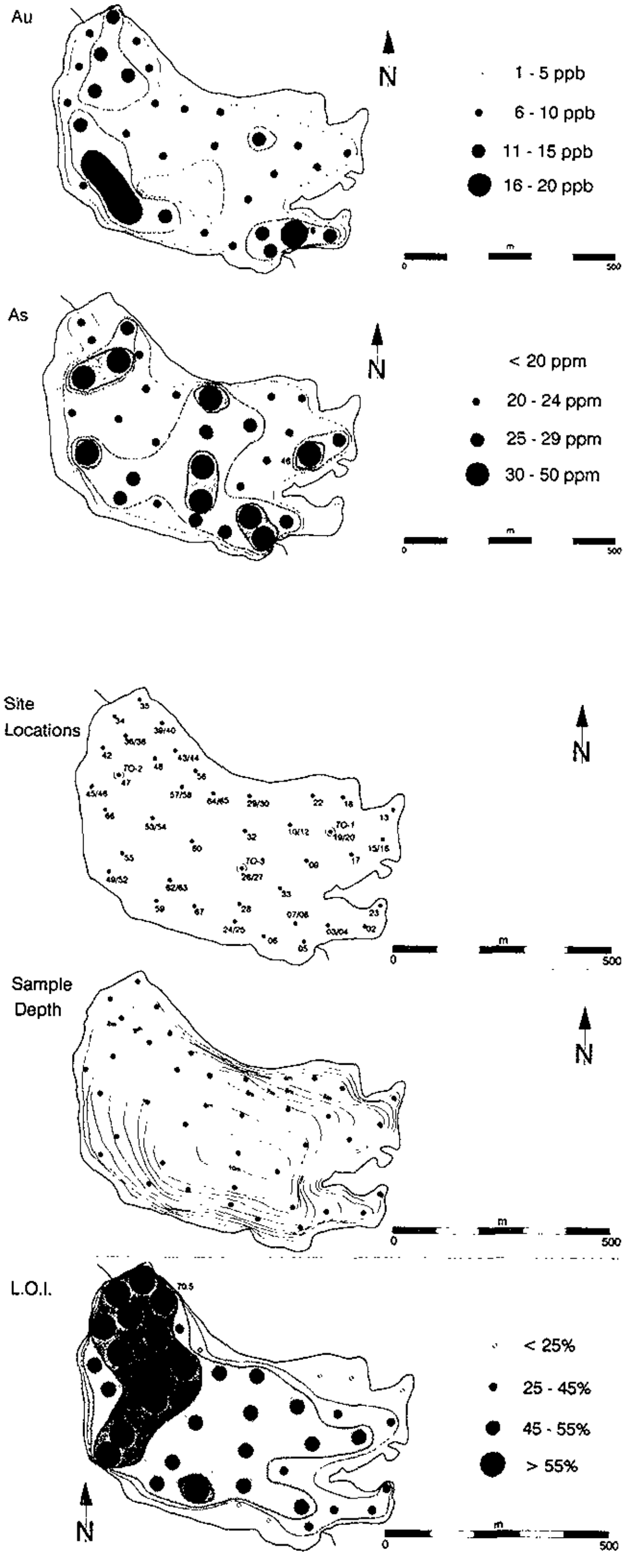

Figure 20-14. Clisbako Lake, showing distribution of gold (ppb), arsenic (ppm) and loss on ignition (%), and site locations and sample depths (m).

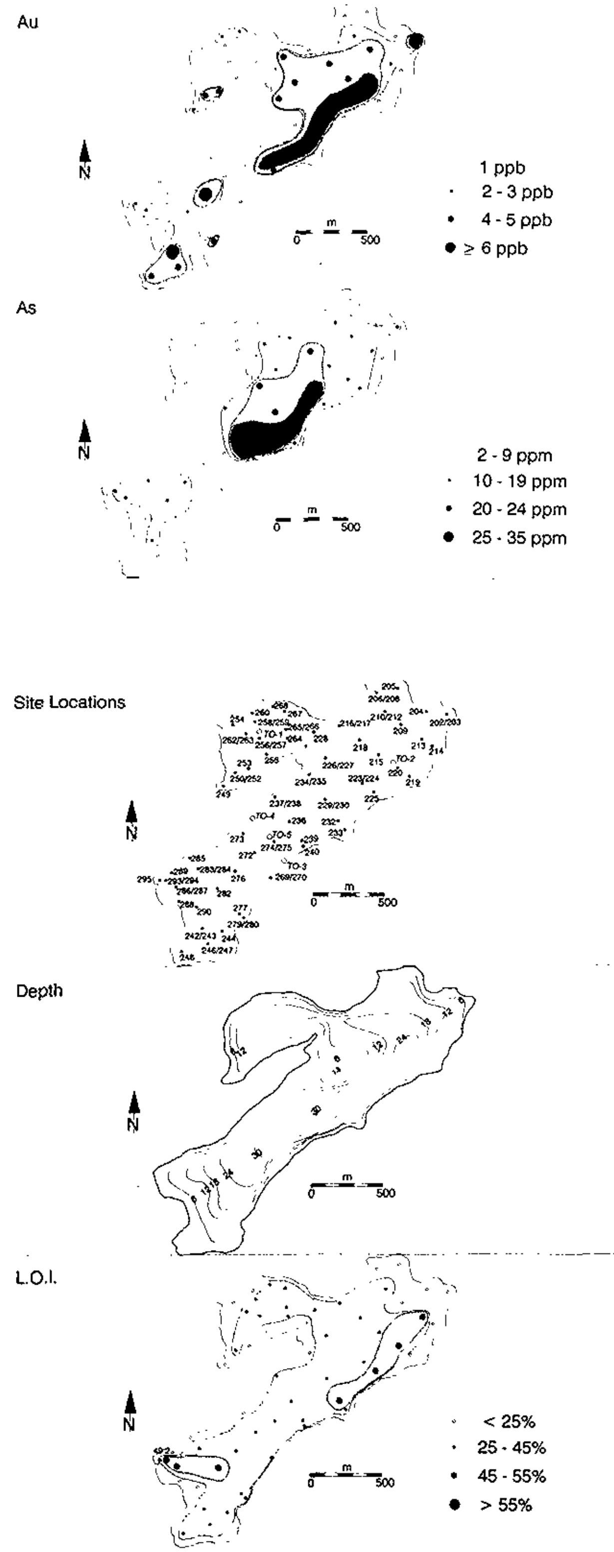

Figure 20-15. Bentzi Lake, showing distribution of gold (ppb), arsenic (ppm) and loss on ignition (%), and site locations and lake depth (m). Depth contours after Walsh and Philip (1977).

tains 12 to 16 ppb gold. A fifth site nearer the shore (depth: 3 metres) contains 10 ppb gold. Sites at greater depths in the profundal basin itself contain less gold. The second group of four sites is located near the stream inflow on the southeast side of the lake, where sediment contains 11 to 16 ppb gold at a depth of 3.5 to 8 metres. Unlike the first group, which are of a typical gyttja composition, the latter samples range in composition from organic to sandy organic. The third group is located near the stream inflow in the northwest corner of the lake. Here, several sites with up to 14 ppb gold occur on a shallow shelf at depths of 1 to 3.5 metres. Sediment from these shallow-water sites contains a large component of poorly decomposed organic matter and has the highest LOI values in the lake. Gold concentrations decrease eastward down the profundal slope and basin. The highest iron concentrations (up to 4.86%) occur in the profundal basin where gold values are low. Although some of the lowest gold concentrations in Clisbako Lake occur in parts of the profundal basin, none of these sites contains less than 4 ppb gold. The few sites containing less than 4 ppb are within a deep, narrow subaqueous channel (24 m) paralleling the southeast side of the lake. However, elevated gold values do not occur at all locations near this channel. With two exceptions, the highest gold values are either in, or on the northwest bank of, the channel at sample depths of 19 to 35 metres. None of the three nearby sites on the southeast side of the channel contain detectible gold concentrations. Elevated gold values (4-5 ppb) also occur in sediment at shallower depths between the channel and the northwestern arm of the lake, but there is no detectible gold at a number of sites in the deepest part of the profundal basin, in the southwest centre of the lake. Interestingly, gold-poor sediments of the deep profundal basin have higher manganese contents (max: 18 752 ppm) and lower LOI values (range: 35-39%) than do sediments from the channel, where manganese and LOI values are (with one exception) in the 1000 to 1400 ppm and 46 to 49% range, respectively. The four channel sites with anomalous gold concentrations, although not the deepest, are those with four of the highest LOI values in Bentzi Lake.

Neither iron nor manganese correlates with gold (Figure 20-9), and only two sediment sites with elevated gold concentrations contain appreciable manganese. Among trace elements, arsenic has a similar distribution pattern to gold, with the highest arsenic concentrations also occurring in the channel. However, elevated arsenic concentrations are somewhat more widely distributed and extend to sediment in deeper parts of the profundal basin, where they are more closely associated with high iron and manganese concentrations than is gold.

DISCUSSION

Lake sediments consist of organic gels, organic sediments and inorganic sediments (Jonasson, 1976). Organic gels, or gyttja, are mixtures of particulate organic matter, inorganic precipitates and mineral matter (Wetzel, 1983), and are mature green-grey to black homogenous sediments characteristic of deep-water basins. Organic sediments are immature mixtures of organic gels, organic debris and mineral matter occurring in shallow water and near drainage inflows (Jonasson, 1976). Inorganic sediments, by contrast, are clastic-rich mixtures of mineral particles with little organic matter. Of the three varieties of lake sediments, organic gels are the most suitable geochemical exploration medium; deep-water basins where they accumulate have been favoured as ideal sites for regional geochemical sampling (Friske, 1991). Sediment composition is influenced by bedrock geology, surficial geology, climate, soils, vegetation, mineral occurrences and limnological factors. Sediment geochemistry in the Nechako Plateau, as in other areas of Canada, generally reflects bedrock variations (Hoffman, 1976; Gintautas, 1984). This study shows that sediment geochemistry also reflects the presence of nearby epithermal gold occurrences, and provides preliminary evidence for the hydromorphic mobility of gold in the Cordillera. Elevated gold concentrations occur in sediments of all three lakes surveyed adjacent to epithermal gold prospects, with differences being primarily related to: the median concentrations of gold present; variations in the gold distribution patterns; and variations in the suite of anomalous elements.

GOLD CONTENT OF LAKE SEDIMENTS

There are no regional lake sediment geochemistry data currently available for the NTS 93F (Nechako River) or 93C (Anahim Lake) map areas with which to compare to element concentrations from Wolf, Clisbako and Bentzi lakes. However, median values of selected elements from RGS centre-lake sediment data (N = 445) for adjacent NTS map areas 93E and 93L (Johnson *et al.*, 1987a,b) to the west provide a useful estimate of regional background levels (Table 20-6). For example, background gold (1 ppb) and arsenic (4 ppm) concentrations are far less than those detected in sediments adjacent to epithermal mineralization in this study. Regionally, sediments in only 22 of 421 sites contain more than 10 ppb gold. Element concentrations reported here are greater than regional background even when underlying bedrock variations are considered. Mean gold (1.8 - 2.6 ppb) and arsenic (4 - 5.1 ppm) concentrations in lake sediments over rhyolite, tuff and volcanic breccia lithologies reported by Earle (1993) are considerably less than those in sediments from this study. More appropriate estimates of regional background concentrations will be available when results of regional lake sediment surveys in parts of NTS map areas 93F/2, 3, 6, 11, 12, 13 and 14 (Cook and Jackaman, 1994) are released.

TABLE 20-6
MEDIAN AND RANGE OF SELECTED ELEMENTS IN RGS CENTRE-LAKE SEDIMENTS (N=445) OF NTS MAP AREA 93E (WHITESAIL LAKE) AND 93L (SMITHERS)

	Au (ppb)	As (ppm)	Cu (ppm)	Mo (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	Fe (%)	Mn (ppm)
Median	1	4	34	1	8	118	0.1	2.52	360
Minimum	1	1	8	1	1	13	0.1	0.2	50
Maximum	55	74	840	70	497	1730	9.2	14.4	20000

DISTRIBUTION AND SOURCE OF GOLD IN LAKE SEDIMENTS

Gold distribution patterns in sediments reflect not only the presence of mineralization, but also the general direction toward its source. The gold distribution in the Wolf Pond basin is very uniform, and the small size of the watershed makes the source area relatively easy to discern. The Clisbako and Bentzi Lake watersheds are considerably larger, but nevertheless the location of alteration and mineralized zones is revealed by gold distribution patterns. For example, gold distribution patterns at stream inflows of Clisbako Lake clearly reflect gold in alteration zones both south and northwest of the lake (Figure 20-3). The source of gold in sediments on the southwest side of the lake is unknown. Interestingly, the area adjacent to and upslope from the lake margin has been mapped as a colluvium veneer over till (Proudfoot and Allison, 1993), suggesting the possibility that its source and composition may differ from that of the underlying till. High gold concentrations in Bentzi Lake do not have such a direct spatial relationship to stream inflows as exists at Clisbako. However, both the shape of the gold pattern and the distribution of gold on the northwest side of the deep channel suggest that gold entered the main basin from the northwest, probably through the Northwest inlet where anomalous gold concentrations occur in stream sediments (Donaldson, 1988), and concomitantly dispersed toward the northeast part of the lake with the regional hydrologic flow. Reasons for the low gold concentrations in sediment of the Northwest arm basin on Bentzi Lake are unknown, but may not involve limnological factors; oxygen and temperature profiles indicate that similar relatively oxygen-rich mesotrophic regimes occur in both basins. The more widespread distribution of other elements, such as arsenic, seems to render these less useful in determining anomaly source.

EVIDENCE FOR HYDROMORPHIC ORIGIN FOR GOLD IN LAKE SEDIMENTS

Preliminary evidence indicates a hydromorphic, rather than clastic, origin for the high gold concentrations in sediments of the three lakes. These include the close association of gold with organic matter, the similarity of gold concentrations in field duplicate samples, the uniformity of gold concentrations at similar sediment depths, and the absence of significant clastic input into the lake basins, particularly at Wolf Pond. Schmitt *et al.* (1993) have recently summarized studies relating to the mobility of gold in surface waters. It may form the hydroxide complex $AuOH(H_2O)^0$ in neutral sulphur-poor lake waters, as well as gold-humic complexes in suspended matter, permiting a limited degree of down-drainage hydromorphic dispersion. Hydromorphic gold dispersion distances of 200 to 300 metres were suggested by Fox *et al.* (1987) for lakes in the Canadian Shield, but results of this study suggest considerably greater distances are likely. Perhaps the most interesting finding is the close association between gold and organic matter, whether in deep-water gyttja (Bentzi Lake) or shallow near-shore organic sediments (Clisbako Lake). At Clisbako, there is a gradual decrease in sediment gold concentrations toward the centre of the profundal basin from three separate sides of the lake: stream inflow areas on the south and northwest side, and the margin sites on the southwest side. Similarly, gold concentrations in Bentzi Lake decrease toward the centre of the profundal basin, where organic matter decreases and iron content increases.

The association of gold and organic matter in lake sediments from Shield regions is well known. Several studies in Saskatchewan and Ontario (Schmitt *et al.*, 1993; Fox *et al.*, 1987; Coker *et al.*, 1982) have reported the presence of elevated gold concentrations in organic-rich sediments. As indicated in this study, near-shore organic sediments may scavenge gold before it disperses to deeper parts of the lake. Both Coker *et al.* (1982) and Fox *et al.* (1987) noted that organic-rich sediments with highest gold values may be near-shore sediments as well as those of the profundal basin. Results are mixed regarding the relationship between gold, and iron and manganese. There is little relation between elevated gold concentrations and those of iron or manganese in either Clisbako or Bentzi Lake, suggesting scavenging of gold by iron or manganese oxides is relatively unimportant. Considerably higher iron concentrations are associated with anomalous concentrations of gold and other elements at eutrophic Wolf Pond, however, indicating the need for additional work in determining the form of iron in this basin.

FACTORS CONTROLLING THE ABUNDANCE AND DISTRIBUTION OF RELATED ELEMENTS

Sediments of lakes adjacent to epithermal precious metal occurrences may exhibit multi-element geochemical signatures. Elevated concentrations of gold, silver, arsenic, zinc, molybdenum and antimony occur in sediments draining the Wolf occurrence. However, lake sediments at the Clisbako and Holy Cross occurrences contain elevated concentrations of only gold, arsenic and, to a lesser extent antimony. Variations in the suite of anomalous elements in the sediments probably reflect the level of the hydrothermal system. Base metal distributions increase with depth in epithermal systems, while near-surface arsenic and antimony may indicate potential precious metal deposits at deeper levels (Panteleyev, 1986). Consequently, elevated levels of gold, arsenic and antimony alone in sediments, such as at Clisbako, may reflect the geochemistry of near-surface systems; a wider variety of precious and base metals, such as the elevated gold, silver, zinc and molybdenum in Wolf Pond sediments, may indicate a deeper position within the system. Molybdenum concentrations of up to 23 ppm in the centre basin of Wolf Pond are, for comparison, equivalent to the highest molybdenum concentrations obtained by the author from sediment of Tatin Lake, adjacent to the Ken porphyry molybdenum-copper occurrence north of Endako (Cook and Jackaman, 1994).

The element content of near-surface hydrothermal alteration zones, as well as limnological factors related to scavenging by iron-manganese oxides, may also affect the suite of anomalous elements in lake sediments. Alteration zones at the Wolf occurrence have a greater areal extent than mineralized stockwork zones, and comprise zones of advanced argillic alteration within broader areas of argillic alteration (Andrew, 1988). Kaolinite is the dominant mineral of the argillic alteration zones, with lesser illite and montmorillonite (Schroeter and Lane, 1994; Andrew, 1988). Such argillic alteration zones commonly contain elevated levels of gold, arsenic and lead, although in lower concentrations than found in silicified zones (Panteleyev, 1986). The clay alteration zones provide larger exploration targets than the auriferous stockworks themselves, but the relative importance of their weathering product contribution to lake sediment metal content is not clear.

EXPLORATION RECOMMENDATIONS

Studies in other parts of Canada (Fox *et al.*, 1987; Davenport and McConnell, 1988; Rogers, 1988) have determined lake sediment geochemistry to be an effective gold exploration method. However, results of some studies in the Canadian Shield (Fox *et al.*, 1987; Coker *et al.*, 1982) concluded reconnaissance-scale (*i.e.* 1 site per 6 to 13 km^2) lake sediment exploration for gold to be inadequate for locating anomalous areas, and suggested that 1 to 3 samples per lake be collected. Results of this study support the detailed sampling (*i.e.* every lake) approach. No site density or field sample size recommendations are given here, as comparative studies of various regional sampling densities (1 to 7.5 km^2 versus 1 to 13 km^2) and sample sizes are currently in progress. The following preliminary recommendations are given for geochemical exploration for epithermal gold deposits in the northern Interior Plateau.

SAMPLE MEDIA AND SAMPLING STRATEGIES

Lake sediment geochemistry is most effective for gold exploration if every lake in the survey area is sampled. The gold content of Wolf Pond sediment illustrates the importance of sampling even very small drainages. This strategy has been applied to regional lake sediment surveys conducted by the Geological Survey Branch in the northern Interior during 1993 (Cook and Jackaman, 1994).

A single centre-lake sample should be collected from the profundal basin in small lakes, and additional samples should be taken from the centres of all other major basins in multi-basin lakes. Although the lakes of this study do not, with the exception of Bentzi Lake, have more than one major basin, a wide range of copper and molybdenum concentrations occurs between different sub-basins of lakes adjacent to porphyry molybdenum-copper occurrences (Cook, 1993a) in the Interior Plateau.

Collection of centre-lake gyttja samples is the most effective sampling method for trace elements such as copper and zinc, but evidence from this and other studies (Coker *et al.*, 1982; Fox *et al.*, 1987) suggests that gold may also be concentrated in near-shore organic-rich sediments, particularly near drainage inflows. Collection of samples from these areas, in addition to centre-lake sediment, is recommended for detailed surveys.

SAMPLE PREPARATION AND ANALYSIS

The low concentrations of gold within lake sediments demand the use of an analytical technique with a low detection limit of 1 or 2 ppb. No comparisons of INAA with either fire assay/GF-AAS or ICP-MS were conducted in this study. If using fire assay techniques, however, low gold detection limits require a greater vigilance about sediment contamination (P.W. Friske, personal communication, 1993).

A rigourous quality control program is a necessity when using lake sediments for gold exploration. Inclusion of abundant standards, field duplicates and analytical duplicates is recommended due to the very low concentrations occurring in lake sediments and the particle sparcity effect.

Analysis for additional elements is recommended. Arsenic and antimony are useful pathfinder elements in this study. Elevated concentrations of base metals such as zinc and molybdenum are more likely to be present in lakes adjacent to the erosional remnants of lower-level hydrothermal systems.

FOLLOW-UP OF ANOMALOUS SITES

Results of this study indicate that gold concentrations of 4 ppb or greater in centre-lake sediments reflect the presence of adjacent gold occurrences. Similar conclusions were reported from Newfoundland by Davenport and McConnell (1988). The very subtle level of gold anomalies in lake sediment cannot be overemphasized. For example, sediment in a lake adjacent to the large Hemlo deposits in northern Ontario was reported by Friske (1991) to contain only 6 ppb gold in an area with a background of less than 1 ppb.

Follow-up of anomalous lakes, involving both verification of the original anomaly and determination of a potential source direction, should include re-sampling of the centre-lake site, as well as sampling of near-shore sediment from all sides of the lake. Organic sediments near inflowing drainages are particularly important to sample. The collection of duplicate field samples is recommended.

CONCLUSIONS

Lake sediments at Wolf Pond, Clisbako and Bentzi lakes reflect the presence of nearby epithermal precious metal occurrences, containing maximum gold concentrations of 56 ppb, 16 ppb and 9 ppb, respectively. These concentrations are far in excess of the regional background of 1 ppb gold in lake sediments of adjacent map areas. Centre-lake sediments may, but do not necessarily, contain the highest gold concentrations. Instead, distinctive gold distribution patterns in Clisbako and Bentzi lakes are more strongly influenced by high organic matter content and bathymetry than by basin depth, and their shapes and locations clearly indicate the positions of stream and groundwater inflows draining upslope epithermal mineralization and alteration zones. Preliminary results indicate a hydromorphic rather than mechanical origin for the gold in the sediments. The suite of anomalous elements in sediment of the three lakes may be related to the level of the adjacent hydrothermal system, with elevated concentrations of a wide variety of base and precious metals in Wolf Pond reflecting the geochemistry of lower level systems. In contrast, anomalous levels of only gold, arsenic and antimony in Clisbako and Bentzi Lakes are probably derived from the weathering of higher level systems. For exploration, sampling of each lake and sub-basin during regional lake sediment surveys is recommended. In follow-up surveys, near-shore organic sediments adjacent to drainage inflows should also be sampled.

ACKNOWLEDGMENTS

The author wishes to acknowledge G. Mowatt, W. Jackaman and T. Giles for assistance in the field, and S.J. Sibbick and P.F. Matysek for their comments and suggestions during development of the project. Staff of the Fisheries Branch, Ministry of Environment, Lands and Parks, especially J. Balkwill, R. Dabrowski and D. Coombes, are thanked for providing equipment, bathymetric maps and useful advice. P.W. Friske of the Geological Survey of Canada, Ottawa, loaned sediment sampling apparatus and some lake sediment standards. S. Tank completed most of the data entry, and discussions with R.E. Lett, R.A. Lane and A. Panteleyev proved most helpful. Rio Algom Exploration Inc. and Metall Mining Corporation are thanked for providing access to information and properties, respectively. The manuscript benefited from reviews by S.J. Sibbick and P.T. Bobrowsky.

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ANALYTICAL METHODS FOR DRIFT

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INTRODUCTION

The evolution of drift sample analysis in Canada reflects the development of improved exploration technology in glaciated regions, largely stimulated by the search for gold in concert with a greater understanding of the character and genesis of glacially transported materials. Before 1970, drift surveys commonly used the same methodology as soil geochemical surveys, where the -80 mesh (<0.177 mm) size fraction of the sample was analyzed for a small number of metals (*e.g.* Cu, Pb and Zn), using a mineral acid digestion and atomic absorption spectrometry or colorimetric methods. This approach was relatively successful in regions of high relief, where the drift cover is relatively shallow, but often failed to detect mineralization in terrain typical of the Canadian Shield because of the greater thickness and stratigraphic complexity of drift. Improved deep overburden sampling methods, the concentration of specific minerals into different density and grain-size fractions and the application of more sensitive analytical methods has enhanced the ability of drift exploration techniques to detect concealed mineralization.

Sample preparation and analytical methods typical of drift prospecting programs in Canada before 1980 are summarized in Table 21-1. Early surveys used potassium pyrosulphate fusion and colorimetric analysis of the -80 mesh fraction to analyze till samples (Ermengen, 1957a). Heavy minerals (>2.9 SG) were recognized by Lee (1963) as an appropriate medium for improving gold anomaly contrast in drift samples collected in the Kirkland Lake area. Reverse-circulation rotary drilling was introduced in 1971 as a more efficient method for obtaining deep overburden material in northern Ontario (Thompson, 1979). In the Kanamack Lake area, Northwest Territories, Shilts (1972) separated till and esker samples into the <0.063-millimetre and <0.002-millimetre grain-size fractions; the >3.3 specific gravity (SG) density fraction of the <0.250-millimetre grain size; the >2.85 SG of the 1 - 0.250-millimetre grain size, a magnetic fraction and a bromoform separate. These fractions were analyzed by an acid digestion and atomic absorption spectrometry for copper, lead, zinc, nickel, cobalt, silver and molybdenum. The sample preparation procedure developed for the Kanamack Lake samples formed the basis for many later regional drift geochemical surveys.

Contemporary work in Sweden compared copper, lead and zinc values produced by aqua regia digestion and atomic absorption analysis, and spectrographic analysis of four different size fractions from till profiles. Results showed that the greatest geochemical background to anomaly contrast was obtained using the finest (<0.053mm) fraction (Eriksson, 1975). In Canada, at the same time, coarser size fractions were found to be effective, as illustrated by the lead and zinc analysis of -10+270 mesh size material from till and fluvial deposits over the Anvil, Yukon base metal deposit (Morton and Fletcher, 1975). Increased interest in exploration for uranium during the late 1970s stimulated further orientation studies, which resulted in the greater use of neutron activation analysis to measure uranium in the clay (<0.002 mm) size fraction of drift samples. Analysis of the clay fraction combined with lower detection limits using neutron activation and were found to dramatically improve uranium anomaly contrast as well as the ability to detect concealed uranium mineralization (DiLabio, 1979). Multi-element analysis using different mineral acid digestions and inductively coupled plasma emission spectroscopy also assisted mineral exploration by providing data for element patterns characteristic of different types of uranium deposits.

Examples of methods commonly used from 1980 to 1989 are summarized in Table 21-2. Much of the information presented is based on data originally gathered by Coker and DiLabio (1987). High gold prices in the 1980s encouraged exploration throughout Canada and especially in the Shield, where the thick drift challenged those seeking new precious metal deposits to improve the existing overburden sampling and analytical methods. Heavy mineral concentrates of drift samples, recovered by reverse-circulation rotary drilling and analyzed by neutron activation, were instrumental in the discovery of significant gold mineralization in Ontario, Québec and Saskatchewan (Routledge *et al.*, 1981; Sauerbrei *et al.*, 1987; Averill and Zimmerman, 1986).

The introduction of non-destructive neutron activation analysis, originally by Lee in 1986, enabled an examination of the sample mineralogy to be made after the analysis, thereby retaining the integrity of original till mineral concentrate (Bloom, 1987; Bird and Coker, 1987). While a small number of drift geochemical surveys (*e.g.* James and Perkins, 1981) continued to use the -80 mesh (<0.177 mm) fraction of the sample for analysis, most of the regional drift sampling programs carried out by the Geological Survey of Canada and provincial counterparts after 1980 employed muti-element analysis of the <0.002-millimetre, <0.063-millimetre and heavy mineral (SG 2.9) fractions (Rogers *et al.*, 1984; Dredge and Nielson, 1986; Hicock, 1986). The analytical methods most commonly used for the fractions were aqua regia digestion:atomic absorption (Cu, Pb, Zn, Mn, Fe, Zn), nitric-perchloric acid digestion - atomic absorption (As), fusion-colorimetric analysis (W) and nitric acid digestion - fluorimetric analysis (U) and neutron activation (U, Au). The extensive application of drift prospecting for gold exploration stimulated several detailed

TABLE 21-1
EXAMPLES OF DRIFT SAMPLE PREPARATION AND ANALYTICAL METHODS USED IN CANADA: PRE-1980

Location	Sample Type	Preparation	Elements Analyzed	Method	Reference
South Mountain Batholith, Nova Scotia	Till	<0.002 mm and heavy mineral fractions	As, Au, B, Cr Ni, Zn, Sb, Sc Ta, U, W Cu, Pb, Zn, Mn	INAA Aqua regia-AAS	Stea and Fowler, 1979
Louvem Deposit, Quebec	Oveburden drill-hole samples	<0.188 mm fraction (basal till and lacustrine clay)	Cu, Zn	potassium pyrosulphate fusion-colorimetry.	Garrett,1971
Val d'Or, Quebec	Piston-type drill core samples	<0.188 mm fraction	Zn, Ag	Not stated	Gleeson and Cormier, 1971
Chibougamau, Quebec	drift profile samples	<0.188 mm fraction	Cu, Zn	Cold and hot extractable metal-colorimetry.	Ermengen, 1957a, b
Kirkland Lake, Onrtario	Till (backhoe auger and RCD samples)	<0.063 mm fraction heavy minerals	Cu, Pb, Zn, Ni, Mo Ag As Au, U	HNO_3-$HClO_3$-FAAS Colorimetry INAA	Thompson and Guindon , 1979
Kirkland Lake, Onrtario	Till excavated using explosives	heavy mineral fraction fraction of 0.5-1.23 mm size fraction	Au Cu, Pb, Zn	Neutron activation Wet chemistry	Lee, 1963
Currie-Bowman Townships, Ontario	Rotary drill RC samples sediments	< 2 mm fraction heavy mineral fraction <0.188 mm fraction	Cu, Pb, Zn, Ag Au Sb, Ba As, W	HCl-HNO3-FAAS Fire assay-FAAS XRF Colorimetry	Thompson,1979
Beardmore-Geraldton Area, Ontario	B-soil horizon Till	<0.188 mm fraction <0.063 mm fraction heavy minerals	Ag, As, Cu, Cr Zn, Pb Sn, B Au	HCl-HNO_3-FAAS Emission spec. FA-AAS	Closs and Sado, 1979
Kaminak Lake, NWT	Till from mudboils and esker-base samples	<0.002 mm <0.063 mm Heavy mineral (>3.35 SG) of 0.25mm-0.125mm Heavy mineral (>2.85 SG) of 1 to 0.25mm fraction. Magnetic 0.25 mm to 0.063 mm fraction. 0.125 mm to 0.25 mm bromoform fraction.	All fractions for Cu, Zn, Pb, Ni Co, Ag, Mo	HNO_3-HCl (2 hr)-FAAS	Shilts, 1972
Anvil Deposit, Yukon	Till and fluvioglacial samples	2 mm to 0.063 mm	Cu, Zn, Pb	HNO_3-$HClO_4$-FAAS	Morton & Fletcher, 1975

Legend
FAA-Flame Atomic Absorption Spectrometry
INAA Neutron Activation

TABLE 21-2
EXAMPLES OF DRIFT SAMPLE PREPARATION AND ANALYTICAL METHODS USED IN CANADA: 1980-1989

Location	Sample Type	Preparation	Elements Analyzed	Method	Reference
Buchans Area, Newfoundland	B-horizon soil and till	<0.188 mm fraction	Cu, Zn	HNO_3-FAAS	James and Perkins, 1981
East-central Labrador	Till	<0.002 mm fraction <0.002 mm fraction >0.002 mm<0.063 mm	Cu, Pb, Zn, Ni, Fe and Mn U Y, Zr, Ce, Sr, Th	Lafort aqua regia- FAAS. INAA XRF	Klassen and Bolduc, 1986
Strange Lake, Labrador	Till from mudboils	<0.063 mm fraction	Cu, Pb, Zn, Cu, Cu, Ni, Cd and Fe F U Sr, Rb, La, Cr, Ce	HNO3-HCl digest- and FAAS . Ion select+electrode. Fluorimetry. XRF	McConnell and Batterson, 1987
Forest Hill, Guysborough County, Nova Scotia	Till profiles	<0.063 mm fraction and heavy minerals	Ag, Cu, Ni, Cr Mn, Fe, Hg, As Pb, Zn, W Au W, As Au	Lefort aqua regia- FAAS Fire assay-AAS Colorimetry Mineral counting	MacEachern and Stea, 1985
Eastern Shore, Nova Scotia	Till and lake sediments	<0.002 mm fraction heavy minerals	Cu, Pb, Zn Ni, Co, Fe, Mn Mg, Ca, Hg, As Mo, Ag, Cd Sn, W U	Lefort aqua regia- FAAS Colorimetry HNO_3-fluorimetry	Rogers and Lombard,1990
Oldham, Nova Scotia	Till C-horizon soils	<0.063 mm fraction	Au, As	Fire assay-FAAS and FAAS (As)	DiLabio , 1982
Nova Scotia (Meguma Zone Drift)	Tills	<0.063 mm fraction <0.002 mm fraction Heavy mineral fraction	Cd, Ag, Cu, Pb Zn, Co, Ni, Fe Mn, Ca, Mg, Mo As U Sn, W	Hot HNO_3-HCl-FAAS HNO_3-$HClO_4$-FAAS HNO_3-fluorimetry Fusion-colorimetry	 Stea and Grant, 1982 Stea and O'Reilly, 1982 Stea 1982
North-Central Nova Scotia	Bedrock and till	<0.002 mm fraction <0.063 mm fraction Heavy mineral fraction	Cd, Ag, Cu, Pb Zn, Co, Ni, Fe Mn, Ca, Mg, Mo As U Sn, W Sr, Cr, Ba	Lafort aqua regia- FAAS Colorimetry. HNO_3 *leach-fluorimetry* Fusion-colorimetry DCP	Stea *et al.*,1986
St George Batholith, New Brunswick	B- horizon C-horizon (till)	-80 mesh ? fraction Heavy mineral fraction	Cu, Pb, Zn, Ag Co, Mo, U, Sb W Sb, Sn U Au	Acid digesion-FAAS Colorimetry. XRF INAA FA-GFAAS	Rampton *et al*., 1986
Sisson Brook, New Brunswick	Till	-10+80 mesh fraction -80+200 mesh fraction -200 mesh fraction -10 mesh ground to -200 mesh fraction Heavy mineral fraction	Cu, Pb, Zn, Ni Ag, Mo, Fe Sn As F W Bi	HNO_3-HCl-FAAS XRF Colorimetry Ion Electrode Fusion-colorimetry HNO_3-FAAS	Snow and Coker , 1987
West-Central New Brunswick	Till	<0.002 mm fraction	Cr, Fe, Co, Ni Mn, Cu, Zn, Mo Ag, Cd, Pb, W Sn As F W U	HNO_3-HCl-FAAS XRF Colorimetry Ion Select. electrode *Fusion-colorimetry* HNO_3-fluorimetry.	Lamothe, 1986

Continued on next page

Table 21-2 continued

Location	Sample Type	Preparation	Elements Analyzed	Method	Reference
West-Central New Brunswick	Till	<0.002 mm fraction	Cr, Fe, Co, Ni Mn, Cu, Zn, Mo Ag, Cd, Pb, W Sn As F W U	HNO_3-HCl-FAAS XRF Colorimetry Ion electrode Fusion-colorimetry HNO_3-Fluorimetry.	
Eastern Townships, Quebec	Till Stream seds.	Heavy mineral fraction	Fe, Ni, Cu, Zn Ag, Pb, Co Co, Sb, As Ta, Cr, Ba, Nb, Sn Au U	Aqua regia-FAAS Colorimetry XRF Fire assay-FAAS HNO_3-fluorimetric	Maurice, 1986
Casa-Berardi Area, Quebec	Till Sand-gravel from RC drill holes	Heavy mineral fraction	Au,As Au grain counts	Not stated	Sauerbrei *et al*., 1987
Bousquet Area Malartic, Quebec	Humus, Till	<0.150 mm fraction Heavy minerals	Cu, Pb, Zn, Ag Au	HCl-HNO_3-FAAS Fire assay-FAAS	Gleeson and Sheehan,1987
Hopetown, Ontario	C-Horizon (Till)	<0.002 and <0.188 mm fractions	Zn, Cd, Hg Zn (partial)	Aqua regia-FAAS Na citrate-FAAS	DiLabio, 1982 Sinclair, 1986
Lanark County, Ontario	Humus, B soil horizon, Till	<0.075 mm fraction Heavy mineral fraction Heavy minerals	Au Au	Aqua regia-GFAAS Fire assay-FAAS	Gleeson et al.,1984 Rampton *et al*. ,1986
Kirkland Lake, Ontario	Till (backhoe auger and RCD samples)	<0.063 mm fraction Heavy mineral fraction	Cu, Pb, Zn, Ni, Mo Ag As Au, U	HNO_3-$HClO_3$-FAAS INAA Colorimetry INAA	Routledge *et al*., 1981 Averill and Thompson, 1981 Fortescue and Lourim, 1982
Kirkland Lake , Ontario	Till	<0.059 mm fraction	Au	Aqua regia-GFAAS Fire assay-FAAS	Gleeson and Rampton,1987
Matheson Lake Abitibi Area, NE Ontario (BRiM)	Till (rotasonic and backhoe samples)	<0.059 mm and heavy mineral fractions Pulverised <2 mm fraction to <0.075 mm	Au, As, Sb, Mo Cr, U, W, REEs Ag, Cu, Pb, Zn, Ni Ti, Zr Au, As, Sb, Mo Cr, U, W, REEs Ag, Cu, Pb, Zn, Ni Ti, Zr Major oxides, S LOI COS	INAA Acid digestion -DCP XRF INAA Acid digestion -DCP XRF XRF Ignition Combustion-IR	Averill *et al*.,1986 Bloom ,1987
Macklem Township, Ontario	RCD Samples of glacial sediments	<2 mm of heavy minerals pulversized to <0.075 mm	Au, Cu, Zn, Ni, As	Aqua regia-FAAS	Gray,1983
Hoyle Township, Ontario	RCD Samples of glacial sediments	< 2 mm fraction heavy minerals	Au	INAA	Bird and Coker, 1987
Hoyle Township, Ontario	RCD Samples of glacial sediments	< 2 mm fraction heavy minerals	Au, Cu, Zn, As	Aqua regia-FAAS	Harron *et al*.,1987
Hemlo Area, Ontario	ercussion-B130d and flow-through samples. B soil horizon.	Heavy mineral fractions and detailed grain size analysis	Cu, Pb, Zn, Ag Fe, Mn, Mo, Sb Ba, W As Au	HCl-HNO_3-FAAS XRF HNO_3-$HClO_4$-FAAS Fire assay-FAAS	Gleeson and Sheehan, 1987
Onaman River, Ontario	Till (C-soil horizon)	< 0.002 mm fraction <0.063 mm fraction Heavy mineral fraction	Cu, Zn, Ag, Bi Ni, Co, Mn, Fe As Au, Carbonate Mineralogy	Acid digest:FASS Leco combustion SEM Analysis	DiLabio, 1982

Table 21-2 continued

Location	Sample Type	Preparation	Elements Analyzed	Method	Reference
NW Manitoba	Till	< 0.002 mm fraction	Cu, Pb, Zn, Ni Cr, Mo, Fe, Mn As	Aqua regia-FAAS Colorimetry	Kaszycki and DiLabio, 1986
Lynn Lake, Manitoba	Till	< 0.002 mm fraction Heavy mineral fraction	Cu, Pb, Zn, Co Ni, Cr, Mn, Fe Hg, Ag As Au	Hot HNO_3-HCl-FAAS HNO_3-$HCLO_4$-FAAS Aqua regia-GFAAS	Fedikow,1984
Farely Lake, Manitoba	Till	< 0.002 mm fraction Heavy mineral fraction	Cu, Pb, Zn, Co Ni, Cr, Mn, Fe Hg, Ag As Au	Hot HNO_3-HCl-FAAS Colorimetry Aqua regia-GFAAS	Nielsen and Graham, 1984
Minton Lake-Nickel Lake (Lynn Lake), Manitoba	Till	< 0.002 mm fraction Heavy mineral fraction	Cu, Pb, Zn, Co Ni, Cr, Mn, Fe Hg, Ag As Au	Hot HNO_3-HCl-FAAS Colorimetry Aqua regia-GFAAS	Nielsen and Fedikow,1986
Waddy Lake, Saskatchewan	Sonic drill till samples	heavy mineral fraction (>3.3SG) <0.188 mm fraction <0.002 mm fraction	Au Au Au	Au grain counts and fire assay-FAAS Fire assay-FAAS Aqua regia-GFAAS	Averill and Zimmerman,1986
Waddy Lake area, Saskatchewan	Till	<0.002 mm fraction <0.188 mm fraction heavy mineral fraction.	Au Au grain counts Au	Aqua regia-GFAAS Fire assay-FAAS	Sopuck *et al.*, 1986a, b
Mahon Lake, Saskatchewan	Precussion flow-through bit collected till samples	<0.188 to>0.059 mm, <0.059 mm , <0.002 mm and heavy mineral fractions. Whole sample	Cu, Ni, Co, Zn Ag, Mg, V, Fe, Mo U As, Se Major oxides	HCl-HNO_3-FAAS HNO_3-fluorimetry Hydride-FAAS Not stated	Simpson and Sopuck, 1983
Buttle Valley, Vancouver Island, BC	Till	<0.002 mm fraction	Cu, Zn, Pb	HF-HNO_3-$HClO_4$-FAAS	Hicock, 1986
St Elias Mountains, BC	Pulverized glacial erratics	<0.059 mm fraction	Co, Cu, Zn, Pb Ni, Cd, Mo, Ag	HF-HNO_3-$HClO_4$-FAAS	Day *et al.*, 1987

Legend
GFAAS-Graphite furnace atomic absorption spectrometry
XRF-X-ray fluorescence
DCP-DC Plasma emission spectroscopy

orientation studies to assess the distribution of metals in till (Shelp and Nichol, 1987; DiLabio, 1985).

Examples of methods used in recent drift sampling programs are summarized in Table 21-3. Regional drift sampling surveys in eastern Canada continued to use acid digestion - atomic absorption analysis of the <0.002 and <0.063-millimetre fractions (Kettles, 1993). However, other studies and geochemical orientation work have employed a more rigorous hydrofluoric acid digestion of the heavy mineral fraction combined with inductively coupled plasma emission spectroscopy for determining the elements (MacDonald and Bonar, 1993), or have examined the distribution of other metals such as platinum in till samples (Cook and Fletcher, 1993). Most recently, mineralogical examination of heavy mineral concentrates from drift samples for diagnostic minerals has become extremely important in diamond exploration in northern Canada.

This paper reviews the different methods used for drift sample preparation and analysis in Canada, with an emphasis on mineral exploration applications. Questions commonly raised about the reliability of various techniques are discussed and the direction for future research is considered.

SAMPLE PREPARATION

The aims of preparing a drift sample for analysis are to:

- reduce a large amount of material to a small but representative sample by a process which minimizes the 'nugget effect' commonly observed when minerals and native metals are present as rare grains;

TABLE 21-3
EXAMPLES OF DRIFT SAMPLE PREPARATION AND ANALYTICAL METHODS USED IN CANADA: POST- 1990

Location	Sample Type	Preparation	Elements Analyzed	Method	Reference
Cape Breton, Nova Scotia	Shallow drift	<0.063 mm fraction <0.063 mm non-magnetic heavy mineral fraction	38 elements 25 elements	Lefort aqua regia-ICP $HClO_4$-HCl-HNO_3-ICP	MacDonald and Boner, 1993
Manitouwadge, Ontario	Shallow drift	<0.002 and <0.063 mm fractions <0.063 mm fraction	Ag, Al, As, Ba, Bi Ca, Cd, Co, Cr, Cu Fe, K, La, Mg, Mn Mo, Na, Ni, Pb, Sb Sc, Sr, Sn, Te, V W, Y, Zn Au, Pt, Pd	Aqua regia-ICP Fire assay-DCP	Kettles, 1993
Clyde Forks - Westport, Ontario	Shallow drift	<0.002 and <0.063 mm fractions <0.063 mm fraction	Cu, Pb, Zn, Co Ni, Ag, Cr, Mo Mn, Fe, Cd, Hg U As Au, Pt, Pd	Aqua regia-FAAS Fluorimetry. Colorimetry Fire assay-DCP	Kettles, 1992
South-central Canadian Shield County, Ontario	Shallow drift	<0.002 mm and <0.063 fractions	Cu, Pb, Zn, Co Ni, Ag, Cr, Cd Mn, Fe U As Carbonate	Hot HCl-HNO_3-FAAS Fluorimetry. Colorimetry Leco Combustion	Kettles *et al.*, 1991
Tulameen Complex British Columbia	C soil horizon sediments	Wet sieve to <0.212 mm and pulverize to <0.075 mm	Pt, Pd Major oxides Fe Fe	Fire assay-ICP $LiBO_4$ fusion-ICP HNO_3-$HClO_4$-HF- HNO_3-$HClO_4$-HF-	Cook and Fletcher, 1993
Nickel Plate Mine, British Columbia	Till profiles	0.212-0.420 mm 0.106-0.212 mm 0.053-0.106 mm and heavy (>3.3 SG) fractions	Au	Fire assay-FAAS	Sibbick and Fletcher,1993

- concentrate metal and/or indicator mineral grains into specific density fractions to improve the reliability of microscopic identification and to provide an accurate estimation of abundance; and
- concentrate metals into specific grain-size fractions, thereby reducing the effects of dilution and increasing the geochemical background to anomaly contrast.

One of the problems of devising a "standard method" for processing drift samples is that the behaviour of metals, especially gold in glacial deposits, can vary considerably depending on the mechanism of transport from bedrock source, style of sediment deposition and post-depositional weathering of the transported materials. Consequently, different schemes have generally been specifically developed for exploration in different glaciated terrains or to detect specific metals. In Canada, Lee (1963) developed one of the first drift-sample treatment schemes for gold exploration by separating minerals from till samples in the Kirkland Lake area of Ontario. The aims of his study were to identify and count the mineral grains, including gold, determine the size of down-ice glacial dispersion fans and seek evidence of altered bedrock associated with gold in the till. The sample treatment scheme designed to assess these factors comprised simple and mobile equipment capable of processing up to 0.2 cubic metre of material daily. Two grain-size fractions (1.23-3.35 mm and 0.5-1.23 mm) and a heavy mineral concentrate were recovered using sieves and a sluice box. Samples were analyzed for gold and other metals by a combination of neutron activation, emission spectroscopy and wet chemical methods.

Elements of Lee's procedure were used for processing reverse-circulation rotary-drill samples, also collected in the Kirkland lake area, by major mining companies during the early 1970s (Thompson, 1979). The sample recovery scheme, shown in Figure 21-1, involved separating the -10-mesh size fraction of the reverse circulation discharge into <0.0177-millimetre grain-size and SG >3.28 density fraction, which were then analyzed for a range of metals, including gold. The original scheme was refined for application to regional deep-overburden sampling programs forming part of the Kirkland Lake Initiatives Program (KLIP; Routledge *et al.*, 1981; Averill and Thompson, 1981). Preparation (Figure 21-2) involved treating a 4 to 8-kilogram bulk reverse-circulation drill-discharge sample by a combination of sieving, shaking (Wiffley) table and heavy liquid separation to produce a <0.063-millimetre fraction, SG>3.3 and SG 2.8 to 3.3 density concentrates. The density fractions were further separated into >0.125-millimetre and <0.125-millimetre size, magnetic heavy mineral concentrates. The purpose of separating sediment into these fractions was to determine the existence of postglacial hydromorphic anomalies (analysis of the <0.063-millimetre grain-size fraction); establish transport distance (mineralogy and chemistry of the >0.125-millimetre and <0.125-millimetre size heavy mineral concentrates) and determine the presence of gangue

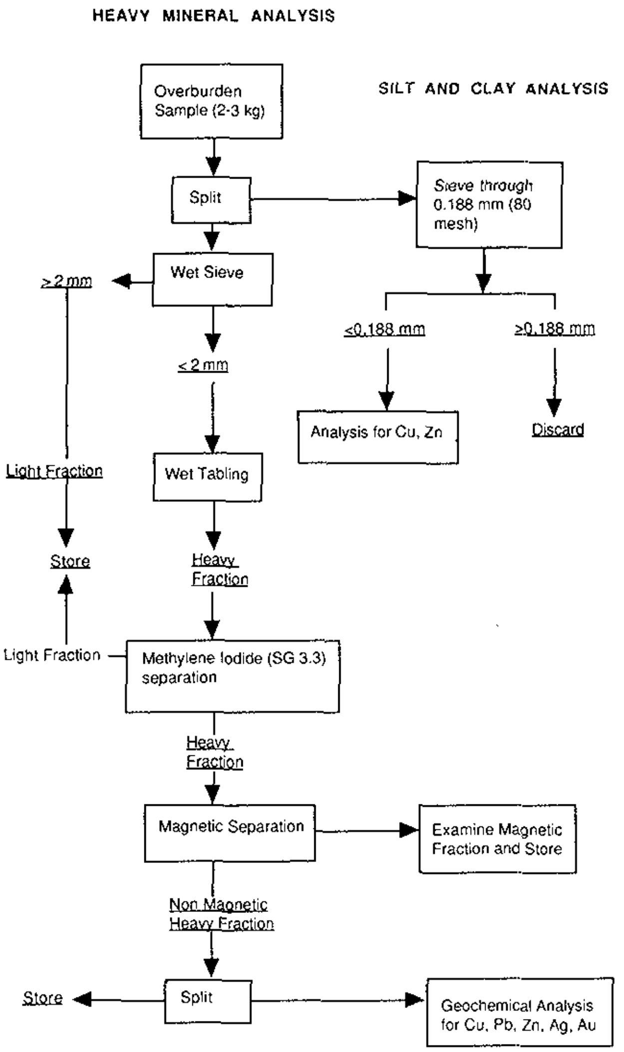

Figure 21-1. Processing and analysis of overburden samples from Ontario (Thompson, 1979).

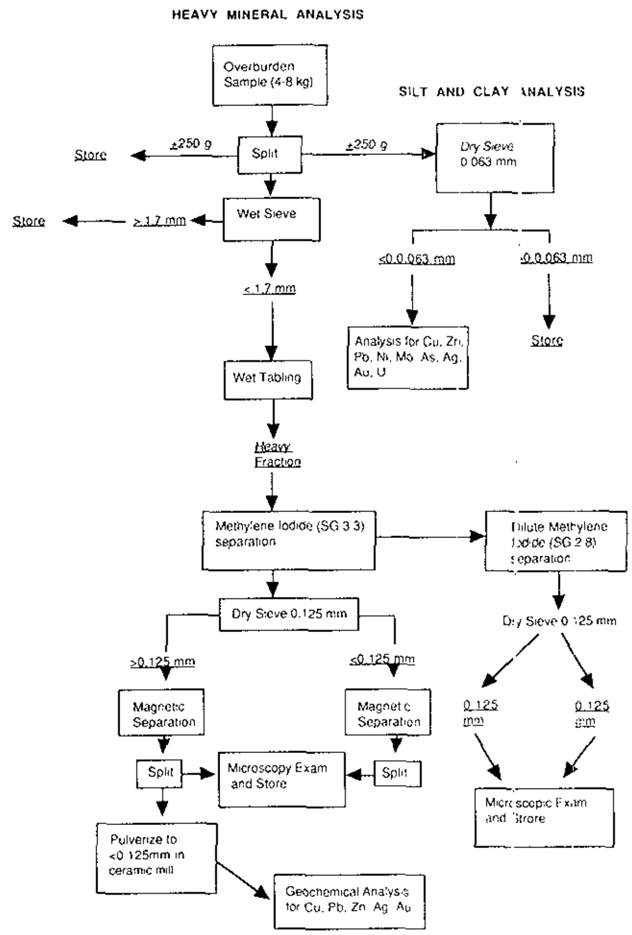

Figure 21-2. Processing and analysis of KLIP overburden samples (Routledge *et al.*, 1979).

minerals in the glacial material (mineralogy of the SG 2.8 to 3.3 density concentrate).

Modified versions of the sample preparation method have been used extensively across the Canadian Shield. A similar procedure to that used for the KLIP program was employed in the BRiM regional overburden surveys in the Matheson area (Averill *et al.*, 1986). Averill and Zimmerman (1986) carried out till orientation surveys over gold zones in the Waddy Lake area in Saskatchewan (Figure 21-3) splitting the original bulk till into a sample processed for heavy minerals (SG>3.3), a sample wet sieved to <0.180-millimetre grain size and a sample centrifuged to recover the <0.002-millimetre (clay) fraction. Analysis of the fractions revealed that gold content of the <0.180-millimetre and clay-sized fractions was not a reliable guide to the source of gold. However, gold grain counts in the heavy mineral fraction provided a direct indication of the bedrock source of the gold and its size. The success of overburden drilling and the careful interpretation of mineralogical data for heavy mineral concentrations is emphasized by successful exploration through thick drift in Casa-Berardi Township, Québec which resulted in the discovery a new major gold deposit (Sauerbrei *et al.*, 1987).

Early overburden sampling schemes used in Ontario resemble the procedure developed by the Geological Survey of Sweden (Brundin and Bergstrom, 1977). The first stage of the mineral separation (Figure 21-4) was carried out in the field using a suction dredge and sluice box, followed by heavy liquid concentration of the <0.5-millimetre size fraction to produce SG 2.95 to 3.31 and SG 3.31 density fractions. The density fractions were then separated into weakly magnetic and nonmagnetic fractions for chemical and mineralogical analysis. However, no grain-size fractions were separated from the drift samples. Differences between the Canadian and Scandanavian approach to drift exploration and till sample processing are discussed in detail by Shilts, 1984.

A major disadvantage of overburden samples collected by reverse-circulation rotary drilling is that the fine fraction of the material is dispersed in the return water flow and may be lost during sample recovery. This may not be a severe limitation for the reliable detection of mineralization when gold is present in the till predominantly as coarse grains. However, orientation studies by DiLabio (1985) in Nova Scotia and Shelp and Nichol (1987), have revealed that the gold in drift does not necessarily reside in the heavy mineral

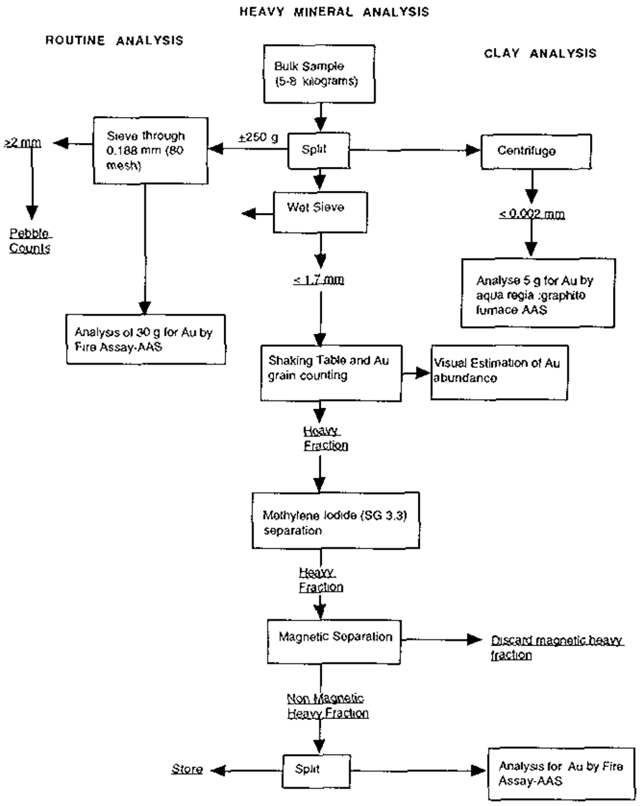

Figure 21-3. Processing and analysis of overburden samples from Waddy Lake, Saskatchewan (Averill and Zimmerman, 1986).

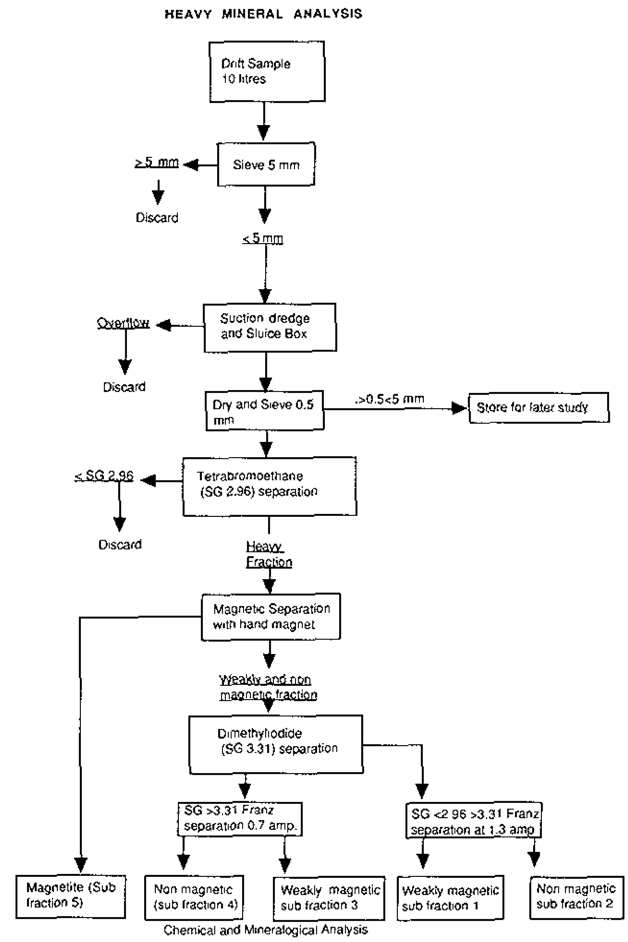

Figure 21-4. Processing and analytical scheme of drift samples from Sweden (Brundin and Bergstom, 1981).

concentrate, but in fact, may be abundant in the fine (<0.063 mm) fraction. Consequently, other schemes have been developed to detect gold, uranium and other metals in whole drift samples rather than in material recovered by rotary drilling. For example, the preparation technique introduced by Shilts (1972) involved separating the <0.002-millimetre size fraction from bulk drift samples for analysis. This approach has been used extensively for regional drift geochemical surveys, where the aim of the survey has been to detect a range of metals. The rationale for analyzing the clay-size fraction, which has been found to consist predominantly of phyllosilicate minerals, is that the more geochemically mobile metals (*e.g.* Cu, Zn, Fe, Mn, U) are released by oxidation of sulphide and other mineral grains in weathered till and are adsorbed onto the phyllosilicates. This process explains the large background to anomaly contrast for metals in the clay-sized fraction, compared to that for coarser fractions,and the relatively strong association of the metals as revealed by results of partial extraction analysis of clay samples (Shilts, 1984). Another advantage of the clay-sized fraction is that the distribution of the metals within the fraction is most uniform (hence sampling variations are minimal) and the chemistry of the phylosilicate minerals may vary comparably to that of the source material. However, a practical limitation of using the clay-sized fraction is the comparatively slow and costly preparation involving the dispersion of the sample in Calgon and recovery of the fraction by repeated centrifuging. Alternatively, the <0.063-millimetre fraction can be economically recovered by dry sieving the sample. The background to geochemical anomaly contrast for mobile metals is still sufficiently enhanced by analysis of this fraction. Also, the geochemical patterns it reveals are consistent in samples collected over large areas, provided that the proportion of the <0.063 to <0.002-millimetre fractions remains relatively constant (Shilts, 1975).

A typical scheme for processing regional drift samples (Figure 21-5) consists of splitting the original material into two components which are then processed to a <0.002-millimetre fraction and a heavy mineral (>SG 2.96) fraction. The heavy mineral separation is typically performed on the <0.3 to >0.063-millimetre fraction, because orientation studies have demonstrated that during glacial comminution of till the more dense minerals are concentrated into smaller grain-size fractions (Thompson and Guindon, 1979). Examples of regional surveys where the <0.002-millimetre and <0.3 to >0.063-millimetre heavy mineral and/or the <0.063-

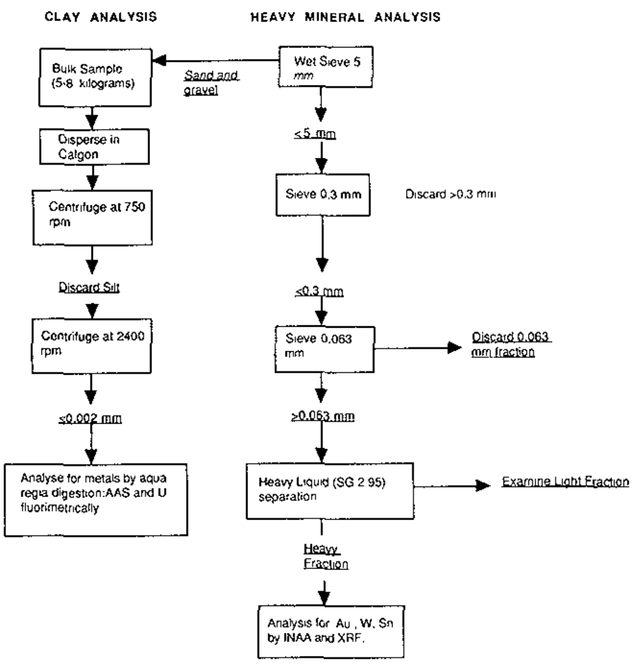

Figure 21-5. Processing and analysis for reversed drift samples from Eastern and Central Canada (Stea *et al.*, 1986).

millimetre grain-size fraction were used are Labrador (Klassen and Bolduc, 1986), Nova Scotia (MacEachern and Stea, 1985) and Ontario (Kettles, 1993). Efforts have been made to improve the efficiency of heavy mineral separations by reducing the dependency of the process on expensive and highly toxic heavy liquids such as bromoform and methylene iodide. A device to concentrate minerals based on elutriation in a water stream has been developed and used for drift sampling in Nova Scotia (Smith and Rogers, 1993). This system can be used in the field and in the laboratory to separate a single mineral grain or multiple grains. The effective separation into density fractions depends on material of uniform grain-size; therefore samples must be screened into a number of size fractions before elutriation.

SAMPLE ANALYSIS

Drift samples may be analyzed physically (*e.g.* using mineralogical identification, X-ray diffraction) to establish the mineralogy of the sample, or chemically to measure concentrations of economic or pathfinder elements.

A summary of the different methods and their particular application is shown in Table 21-4. Aqua regia digestion followed by flame atomic absorption spectrometry, fire assay - flame atomic absorption spectrometry (Au) and instrumental neutron activation (Au, U) are the most commonly used techniques for determining trace and minor element concentrations in density and grain-size fractions of drift

TABLE 21-4
SUMMARY OF METHODS USED FOR DRIFT SAMPLE ANALYSIS

Digestion/Fusion method	Analytical Technique	Elements commonly determined	Examples of Applications
Lefort aqua regia	*Flame atomic absorption spectometry*	*Cu, Pb, Zn, Ag, Mo Mn, Cr, Ni, Co, Mg Ca, Cd*	*Rogers and Lombard, 1990. Maurice, 1986*
Nitric-perchloric acids	*Flame atomic absorption spectometry*	*Cu, Pb, Zn, Ni, Mo As, Ag*	*Averill and Thompson, 1981*
Prepared sample	*Thermal neutron activation*	*Au, As, Sb, Mo, Cr, Co, U, W, Hf, La, Lu, Sc, Sm, Ta, Ba Th, Se, Yb, Eu, Ce.*	*Bloom, 1987*
Hydrofluoric-sulphuric-nitric acids	*Direct current plasma emission spectroscopy*	*Mo, Cu, Pb, Zn,Ni*	*Bloom, 1987*
Aqua regia	*Direct current plasma emission spectroscopy*	*Ag, Cu, Pb, Ni*	*Bloom, 1987*
Pressed pellets	*X-ray fluorescence*	*Sn, W, Y, Zr, Ce, Sr Th, La, Cr, Rb*	*Klassen and Bolduc, 1986 Snow and Coker, 1987 Bloom, 1987*
Fusion	*Ion selective electrode*	*F*	
Fire assay	*Flame atomic absorption apectometry*	*Au*	*DiLabio , 1982 Gleeson and Sheehan, 1987*
Aqua regia	*Graphite furnace atomic absorption spectrometry*	*Au*	*Sopuck, et al., 1986*
Fused disc	*X-ray fluorescence*	*Major oxides*	*Bloom, 1987*
Fire assay	*Direct current plasma emission spectroscopy*	*Au, Pt, Pd*	*Cook and Fletcher, 1993*
Nitric acid digestion	*Fluorimetry*	*U*	*Stea et al., 1986*
Lithium metaborate fusion	*Inductively coupled plasma emission spectroscopy*	*Major oxides, minor and trace elements*	

samples. Visual examination of gold grain shape (to establish distance from source), counting the gold grains and neutron activation analysis of the sample have been found to be the most effective combination for overburden drilling programs. Other instrumental methods which have been used include graphite furnace atomic absorption spectrometry for gold, inductively coupled plasma emission spectroscopy for minor and trace elements and X-ray fluorescence for minor elements and major oxides. Methods for drift analysis have recently been reviewed in detail by Kauranne *et al.* (1992).

While the methods have been applied to the analysis of different geochemical sample media questions are often raised regarding the reliability of specific techniques for drift prospecting. Several points of concern are discussed below.

THE RELIABILITY OF NEUTRON ACTIVATION ANALYSIS FOR GOLD IN HEAVY MINERAL CONCENTRATES

Neutron activation analysis involves irradiating a sample in a high neutron flux and measuring the induced gamma radiation. Depending on the energy, the incident neutrons are either thermal (<0.5keV), epithermal (0.5 to 10^3KeV) or fast (>10^3KeV). Neutron activation gold values for heavy mineral concentrates may be lower than the abundance estimated from gold grain counts or measured by fire assay because of self-shielding. This effect is due to absorption of neutrons by the outer layer of the gold particle so that the inner core is not irradiated. Self-shielding is most significant using epithermal neutrons because of the higher effective absorption cross-section of the gold in this energy range. There is evidence that epithermal irradiation of a 0.2-millimetre diameter gold sphere is 50% less effective than thermal irradiation (Hoffman, 1992). The self-shielding problem can be avoided by using thermal irradiation for neutron activation and by sieving the sample before analysis so that the grain-size of the heavy mineral concentrate is less than 0.2 millimetre.

Advantages of neutron activation for determining gold in prepared drift samples are the ability of the method to cover a wide concentration range, the simultaneous determination of gold pathfinder elements such as arsenic, and the ability of the method to accept relatively coarse, unground samples. The last advantage reduces gold loss from the sample due to smearing of the metal onto the surface of the pulverizing equipment. Although the whole sample can be examined for minerals after neutron activiation analysis, one disadvantage is that a lengthy delay time may elapse before the secondary gamma radiation from the sample falls to levels where the material can be safely handled. Also, irradiated samples can only be stored in a facility approved and licensed by the Atomic Energy Control Board of Canada. Certain elements such as copper and lead cannot be determined by neutron activation, and other alternative techniques must be used to generate the data. Instead of neutron activation, samples can be analyzed for gold by fire assay - atomic absorption spectrometry finish, fire assay - direct current plasma emission spectroscopy, and aqua regia digestion - graphite furnace - atomic absorption spectrometry. However, these techniques destroy the sample during the process of analysis. Aqua regia digestion - graphite furnace - atomic absorption spectrometry has an advantage of being able to detect gold in a small sample (*e.g.* clay-sized fraction) because of the greater sensitivity of the method. Unfortunately, the aqua regia digestion may not release all of the gold from the material (Hall *et al.*, 1989).

THE APPLICATION OF PARTIAL EXTRACTION ANALYSIS FOR DETERMINING THE DISTRIBUTION OF METALS IN DRIFT SAMPLES

Partial and sequential partial extraction analyses are commonly used to measure the distribution of metals in geochemical samples and, in particular, to establish the mineral association(s). Previous examples generally describe the results of partial and sequential extraction analysis for stream sediment, lake sediment and soils rather than for drift samples. Shilts (1984) describes the extraction of manganese, iron and zinc from the clay-sized fraction (0.001 mm to 0.004 mm) of till using ammonium citrate, sodium dithionite extraction and hydrofluoric acid digestion. Very little of the metals was extracted by the ammonium citrate and sodium dithionite compared to that liberated by hydrofluoric acid, indicating that metals are strongly retained in phyllosilcate minerals during the weathering of drift. Bradshaw *et al.* (1974) described the use of ethylene diamine tetra-acetate (EDTA) as a partial extract for copper in thin till overlying the Cariboo-Bell copper deposit in central British Columbia.

MAJOR OXIDE GEOCHEMISTRY IN DRIFT PROSPECTING

Major oxides are commonly measured in rock samples for petrochemical classification purposes, but are used less often in drift prospecting despite applications for discriminating between different till sheets and determining the bedrock source of the drift. In Finland, the distribution of potassium, sodium and calcium, measured by optical emission spectrometry in the <0.06-millimetre fraction of till samples, has been found to reflect bedrock chemistry (Hartikainen and Damsten, 1991). In Canada, major oxide data for the pulverised <2-millimetre fraction of till samples collected during the BRiM program strengthened the discrimination between felsic and mafic till sheets (McClenaghan *et al.*,1992). Drift samples from northern Vancouver Island, British Columbia were separated into several grain-size fractions and analyzed for major oxides by lithium metaborate fusion - inductively coupled plasma emission spectroscopy (S. Sibbick, personal communication, 1993). Analytical precision, shown in Table 21-5, is similar to that obtained by X-ray fluorescence analysis.

THE QUALITY OF DRIFT GEOCHEMICAL DATA

While most published drift geochemical studies describe the analytical methods used, very few authors comment on the quality of the data produced. Can it be assumed that all published data passed set quality control criteria and,

TABLE 21-5
ANALYTICAL PRECISION OF MAJOR OXIDE ANALYSES

Oxide	SO_2 Mean (%)	SO_2 %RSD	Reference Value (%)	SO_3 Mean (%)	SO_3 %RSD	Reference Value (%)
SiO_2	34.61	1.9	33.92	52.43	0.5	53.51
Al_2O_3	5.92	1.1	5.75	14.67	1.9	15.26
Fe_2O_3	2.14	1.4	2.16	7.73	1.4	7.95
MgO	8.4	1.6	8.25	0.86	1.3	0.9
CaO	20.14	0.2	20.45	2.68	1.6	2.74
Na_2O	0.99	1.7	1	2.42	0.2	2.56
K_2O	1.46	10.3	1.94	2.71	2.3	2.95
TiO_2	0.32	0.1	0.03	1.29	0.8	1.43
Ba	309 ppm	1.7	296 ppm	1120 ppm	2.3	966 ppm
Sr	210 ppm	1.6	217 ppm	314 ppm	1.8	340 ppm
Zr	161ppm	11.6	No value	656 ppm	2.9	No value
LOI	25.8	1	No value	14.6	0.8	No value

TABLE 21-6
ANALYTICAL PRECISION (95% CONFIDENCE LEVEL)
FROM DUPLICATE HEAVY MINERAL CONCENTRATES
FROM THE KLIP PROGRAM)

Element	Detection Limit	Method	Precision (%)
Cu	2 ppm	FAAS	5.01
Pb	2 ppm	FAAS	15.12
Zn	2 ppm	FAAS	9.16
Ni	2 ppm	FAAS	10.88
Mo	2 ppm	FAAS	17.17
As	2 ppm	COL	13.03
Au	20 ppb	FAAS	67.54
U	0.2 ppm	INAA	8.44

Routledge *et al.*, 1981

if so, what were the criteria? Drift geochemical data produced by Federal and Provincial surveys are subjected to a rigorous quality evaluation through the careful scrutiny of a reference standard, blind field duplicate sample and blind analytical duplicate sample inserted into every batch of 20 samples analyzed. The precision determined from blind replicate data for heavy mineral fractions (<0.125 mm) collected during the KLIP is shown in Table 21-6. Acceptance limits for results are ±15%. The poor precision for gold can be explained by the small weight (1 g) of the sample taken for analysis. A careful examination of the quality control data for the BRiM program indicates that the precision and accuracy for all elements, except lead and titanium, fell within acceptable limits. Ideally, quality control should be incorporated into the design of drift geochemical surveys and the sample identification scheme should be sufficiently flexible to allow for the insertion of standards and duplicates when submitting samples for analysis.

CONCLUSIONS

Geochemical data produced from drift geochemical orientation studies have helped to explain the behaviour of metals in glacially transported material. In weathered drift, the mobile metals such as copper, lead, zinc, cobalt, nickel, molybdenum, arsenic and uranium are primarily concentrated in the <0.002-millimetre grain-size fraction.

Gold in glacially transported material may be present as coarse detrital grains or concentrated into the finer grain-size fractions. Because of this varying distribution, no single "standard" sample preparation method is reliable and sample preparation schemes should be designed based on an assessment of the aim of the drift prospecting program, the terrain and the character of glacigenic sediments. Geochemical orientation studies, guided by the results of surficial mapping, are therefore essential before major drift geochemical programs are undertaken in new areas, to establish the optimum size and density fractions for ensuring the maximum background to anomaly contrast.

Currently the analytical methods most commonly used for analysis of prepared drift samples are aqua regia digestion - atomic absorption spectrometry, aqua regia digestion - inductively coupled plasma emission spectroscopy and neutron activation. X-ray fluorescence is often used to determine concentrations of major oxides and minor elements. Major oxide analysis by lithium metaborate fusion - coupled plasma emission spectroscopy can be used as an alternative method to X-ray fluorescence for determining drift bulk chemistry.

Possible growth areas for analytical research to aid drift prospecting are partial extraction analysis for major and minor elements to determine the degree of overburden weathering and the relationship between soil and drift, the application of inductively coupled plasma mass spectroscopy for rare earth analysis and the development of new standard reference materials.

ACKNOWLEDGMENTS

The author would like to thank P.T. Bobrowsky, B. Bhagwanani, S.J. Sibbick and J.M. Newell for constructive criticism of the manuscript.

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BIOGEOCHEMICAL PROSPECTING IN DRIFT-COVERED TERRAIN OF BRITISH COLUMBIA

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FIRST CONSIDERATIONS

The glacial drift that covers much of western Canada presents a problem to the prospector and exploration geologist searching for mineral deposits. The problem is further compounded by the presence of a thick cover of forest and shrubs. Often the vegetative cover is regarded as an additional frustration to hinder exploration. However, both trees and shrubs can be used productively to characterize overburden and bedrock, and thereby provide a focus for more detailed exploration.

Trees and shrubs can be considered as the subaerial extension of the chemistry of the underlying geology. They contain elements drawn from soils, sediments, rocks and groundwater. Commonly, if there is enrichment of metals in the ground, there is a concomitant enrichment of these metals in the vegetation. However, each plant species has its particular requirements and tolerances to metals, and before conducting a biogeochemical survey, it is necessary to know which plant, and which part of a plant, to collect in order to best detect the associated mineralization.

There are great differences in the uptake of metals by different species of plant. Table 22-1 shows the variations that occur in trees rooted in the thin drift cover that overlies gold mineralization at Doctor's Point, on the west side of Harrison Lake, British Columbia. Note in particular the wide range in concentrations of arsenic.

Table 22-2 illustrates the variation in gold that occurs within single jack pine and black spruce trees, both species common to the northern Cordillera.

An example near the Sullivan lead-zinc mine at Kimberley, British Columbia shows that this variation in a single tree is typical of most elements (Table 22-3). Clearly, there are very marked differences, and when conducting a biogeochemical survey it would be misleading to mix different types of tissue.

Large deciduous trees may have deep and extensive root systems, such as the fig tree shown in Photo 22-1. Although the conifers that predominate in the forests of British

TABLE 22-2
GOLD IN VARIOUS TISSUES OF A SINGLE JACK PINE AND A SINGLE BLACK SPRUCE

	Au (ppb) in:	
	Dry Tissue	Ash
Jack Pine		
Outer Bark	2.10	140
Inner Bark	0.61	32
Needles	0.36	15
Young Twigs	0.36	24
Old Twigs	0.15	17
Outer Trunk Wood	0.08	32
Inner Trunk Wood	0.04	14
Black Spruce		
Outer Bark	0.90	50
Twigs	0.62	28
Trunk Wood	0.09	19
Needles	<0.16	<5

Near gold mineralization in the boreal forest

TABLE 22-1
DISTRIBUTION OF ELEMENTS AMONG TISSUES OF COMMON SPECIES FROM A SINGLE LOCATION

		Au ppb	As ppm	Mo ppm	Sb ppm
Douglas Fir	Twig	35	1600	<1	1
Douglas Fir	Needle	23	130	<1	2
Douglas Fir	Bark	53	250	<1	8
Western Hemlock	Twig	200	710	<1	8
Western Cedar	Twig	7	11	4	1
Western Cedar	Needle	5	6	<1	1
Western Cedar	Bark (all)	8	12	<1	1
Western Cedar	Bark (outer)	31	46	<1	11
Red Alder	Twig	14	4	57	0.5
Red Alder	Bark	<5	4	4	0.3
Douglas Maple	Twig	12	6	4	1

Near gold mineralization at Doctor's Point, Harrison Lake, southern B.C.

TABLE 22-3
METAL CONCENTRATIONS OF SEVERAL ELEMENTS IN THE ASH OF DIFFERENT TISSUES (IN ppm, EXCEPT Au IN ppb) FROM A SINGLE LODGEPOLE PINE

	Top Stem	Lower Twigs	Outer Bark	Roots
Ag	1	3	13	77
As	9	9	52	190
Au	<5	<5	20	19
B	1150	400	260	580
Ba	48	310	1000	500
Cd	52	95	143	135
Cr	6	18	18	10
Cs	110	9	5	38
Mn	13000	27000	4230	53000
Ni	180	22	14	24
Pb	150	2950	4900	16400
Sb	2	3	13	5
Zn	6100	7350	5700	12800

Above tourmalinite near the Sullivan lead-zinc mine, Kimberley, southern B.C.

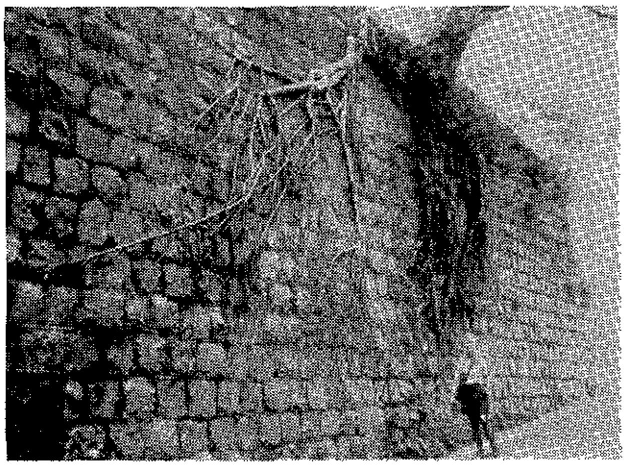


Photo 22-1. Extensive root system of a fig tree (*Ficus*) - Victoria Park, Hong Kong.

Photo 22-2. Root system of fallen Engelmann spruce, near Quesnel, B.C.

Columbia have relatively shallow roots, the volume of soil and groundwater from which they extract elements is very large (Photo 22-2).

In addition to major element requirements, each species of tree requires certain trace elements in order to survive (*e.g.* Zn, Cu, B). Other elements may not be essential, but get drawn into the tree and deposited where they can cause little harm: by analogy with the human body, toxic elements such as lead and arsenic are concentrated in our extremities (hair and fingernails), whereas a tree moves non-essential elements to outer bark, ends of twigs and tree tops. Fortunately for exploration, many of these 'toxic' elements are heavy metals that are of potential economic value (notably gold, platinum-group metals and base metals) or pathfinder elements, which have been transported through the tree to some of the easiest parts to sample.

THE FORESTS OF BRITISH COLUMBIA

In the temperate forests that cover much of British Columbia there are several 'biogeoclimatic' zones, controlled mostly by the north-south trending mountain ranges and valleys, where rainfall, altitude and aspect determine the occurrence and distribution of different tree and shrub assemblages. In general, the conifers are the most useful biogeochemical sample media, especially lodgepole pine, Pacific silver fir, sub-alpine fir, hemlock (western and mountain), Engelmann spruce, Douglas fir, and red cedar. Locally, other species of pine, spruce, fir, larch, yew and cedar occur which may be used for a survey. Of the many deciduous species, alder, birch, maple, willow and poplar are the most common. The choice of sample medium depends very much on the elevation and in which part of the province the survey is taking place. The map entitled 'Biogeoclimatic Zones of British Columbia, 1988', published by the B.C. Ministry of Forests gives a good idea of what species might be expected at any locality. Tree identification books (*e.g.* Petrides and Petrides, 1992), and booklets (*e.g.* Watts, 1973) are also useful sources of information relevant to biogeochemical sampling.

SAMPLING

Rings or metal jewellery should not be worn when handling biogeochemical samples, because they will contaminate the samples and generate false anomalies. Sampling procedures are mostly very simple, but before conducting a survey a number of precautions need to be taken. The basic rule is to 'be consistent'; one should collect the same type of plant tissue, the same amount of growth, all from the same species, and from trees of similar appearance and state of health.

FIELD ACCESSORIES

The only additions to the usual field equipment of the geologist are:

- a pair of anvil-type pruning snips, preferably Teflon coated;
- a paint scraper or hunting knife for scraping bark, and either a dustpan or paper bag for collecting the flakes of bark (a hatchet is useful for surveys involving collection of thick bark, such as that of Douglas fir);
- standard 'kraft' soil bags for bark samples; for twigs use fairly large bags - about 20 by 30 centimetres - made either of heavy duty coarse brown paper if conditions are dry (*e.g.* 7 kg hardware bags), or cloth if conditions are wet; or the slightly smaller "Hubco" plasticized, aerated bags with drawstrings, which are tough, light, and very convenient, but samples should not be left in these bags for several weeks or they will grow mould;
- a roll of masking tape or stapler to close paper bags;
- a large back-pack; if twigs are the chosen sample medium the volume of material collected soon becomes quite large (but not heavy). For large surveys use heavy duty orange garbage bags which can be left at the ends of cut lines to be picked up at the end of the day; and
- a 10x hand lens which helps in species identification and in counting growth rings in twigs.

TABLE 22-4
CONCENTRATIONS (IN ASH) OF ELEMENTS IN INNER AND OUTER BARK FROM TWO SPRUCE TREES

	Tree A (Bark)		Tree B (Bark)	
	Inner	Outer	Inner	Outer
Au ppb	<5	51	9	126
As ppm	2	56	93	300
Sb ppm	0.1	10	0.7	3.5
Cr ppm	1	41	7	18
Fe ppm	500	16000	2200	16000
La ppm	0.5	16	3	18
Ba ppm	3600	1500	5100	2500
Zn ppm	3300	1600	9200	3900
Ca %	30	18	32	28

TABLE 22-5
ELEMENT DISTRIBUTION ALONG BRANCHES OF WESTERN HEMLOCK (CAROLIN MINE, B.C.)

	Thick (>10 mm dia.)	Medium (5-10 mm dia.)	Thin (<5 mm dia.)
Au (ppb)	530	650	1590
As (ppm)	22	31	82
Cr (ppm)	32	26	84
Co (ppm)	11	12	21
Ca (%)	29	24	14
Fe (%)	0.8	1.1	2.3
Na (%)	0.4	0.4	1.1
La (ppm)	2	3	6
Br (ppm)	19	18	18
Cs (ppm)	2	2	2
Sr (ppm)	430	480	450
Zn (ppm)	1500	1400	1900

TABLE 22-6
PERCENTAGE ASH YIELDCOMMONLY OBTAINED FROM VARIOUS PLANT TISSUES

Plant	Organ	% Ash Yield (to 470°C)
Coniferous Trees	Twigs	2-3
	Needles	3-5
	Bark (outer)	1-3
	Bark (inner)	2-4
	Trunk Wood	0.2-0.5
	Cones	0.5-1
Deciduous Trees and Shrubs	Twigs	3-4
	Leaves	5-8
	Bark (all)	4-6
	Trunk Wood	0.4-0.8

TABLE 22-7
AVERAGE CONCENTRATIONS OF GOLD IN THE ASH OF ALDER TWIGS

	Gold (ppb)
Early June	28
Early August	10
Mid-September	17
Mid-April	69

Collected from the same 19 shrubs at different times of the year

BARK

It is important to appreciate that inner bark is very different in composition from outer bark (Table 22-4): therefore, for most surveys, do not include chunks of inner bark. Collect about 50 grams of the loose outer scales characteristic of many conifers, by scraping with either a hunting knife or a paint scraper (a very effective tool). A dustpan or large paper bag can be used to collect the scales, which can then be poured into kraft soil bags. Not all conifers (especially the firs) have scaly bark; fir bark is usually not very informative nor is it a practical sample medium because several species have many sticky sap blisters which hamper collection. In an area dominated by fir, twigs are the preferred sample medium.

TWIGS

There is substantial variation in chemical composition along a twig. Table 22-5 shows an example of western hemlock sampled close to gold mineralization at the Carolin mine. The differences in gold, arsenic and chromium distribution are particularly striking, with each being most concentrated toward the twig ends. Note, too, that not all elements follow the same trend: calcium is more enriched in the thick part of the branch, whereas strontium and zinc are homogeneously distributed.

From Table 22-5 it is clear that in surveys using twigs, each sample should comprise a similar number of years of growth. A 30 to 50-centimetre length is a practical amount. The age of the twigs is readily determined by counting the growth nodes along the twig, or by counting the number of growth rings in a cut cross-section (using a 10x hand lens). Commonly, twigs of similar length and diameter are similar in age. Exceptions occur where there are significant changes in environmental conditions, such as traverses that move from dry to boggy areas, or if there is a major change in lithology. Under such conditions, a compromise has to be taken. For example, if 10 years of twig growth is being collected in a survey, and a tree is encountered with scrawny growth, it would be better to collect 12 years' growth. By collecting 10 years one is already integrating annual changes in chemistry throughout the growth period; but by taking two more years of growth the period of integration is not affected by much, yet twigs of similar diameter will be obtained, and therefore, similar twig bark to twig 'wood' ratios will result. It is this ratio of bark to wood which is important, as many of the heavy metals are located in the bark. If this ratio is varied substantially, then variations in element content may be attributable entirely to mixing thick with thin twigs; hence, false anomalies.

In general, seven to ten twigs should be collected, as the total weight of fresh twig and needles obtained at each sample station should be about 200 grams. About half this weight is moisture, leaving 100 grams of dry twig and needle. Of this about 70% is needle, leaving only 30 grams of dry twig. This is sufficient for neutron activation analysis of a dry briquette, or for providing about 0.6 gram of ash. If a proposed analytical program is to involve more than one technique, 1 gram of ash is the preferred amount and the original sample size must be adjusted accordingly. The typical ash yield of tree tissues is given in Table 22-6.

Unless dead tissue (such as bark) is to be sampled, seasonal changes in plant chemistry must be considered. Table 22-7 shows the substantial changes of gold in alder that can occur during the year. Each plant species exhibits its own variations in different elements throughout the year, so a survey using live tissues should be conducted in as short a time as possible (*e.g.* within a 2 to 3-week period); metal concentrations in a tree sampled in the spring will be different from those in the same tree during the summer. During the growing season, cuticle is shed from the plant (Photo 22-3), and salts containing trace metals crystallize on plant surfaces and get washed away during rains.

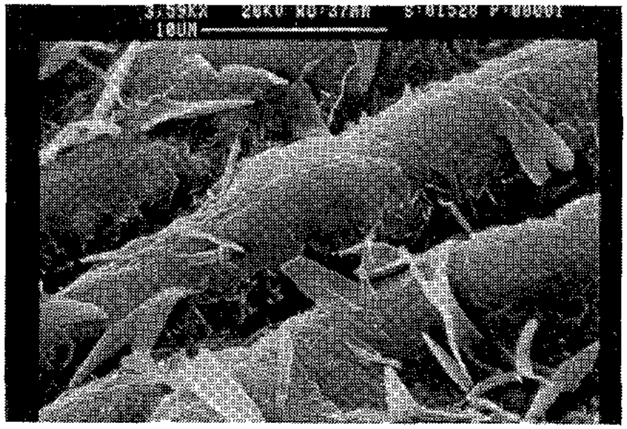


Photo 22-3. Scanning electron micrograph of cuticle spalling from spruce twig.

AN EXPEDIENT SURVEY METHOD USING A SINGLE CONIFER TWIG

So far discussion has centred upon twigs and bark, and it has been shown that each tissue type has a different concentration of elements. However, the ratio of an element in twigs to that in needles usually remains quite consistent. Therefore, if the density of needles on twigs is similar throughout a survey area, it is possible to identify those areas of relative element enrichment by collecting a single twig at each sample station (ensuring that you have a similar amount of growth and diameter of twig) and analyzing it all (twig and needles). Figure 22-1 shows a comparison of data from a single twig plus needles, with data from a bulk twig-sample from the same tree.

When using the above method, it is important to remember that:

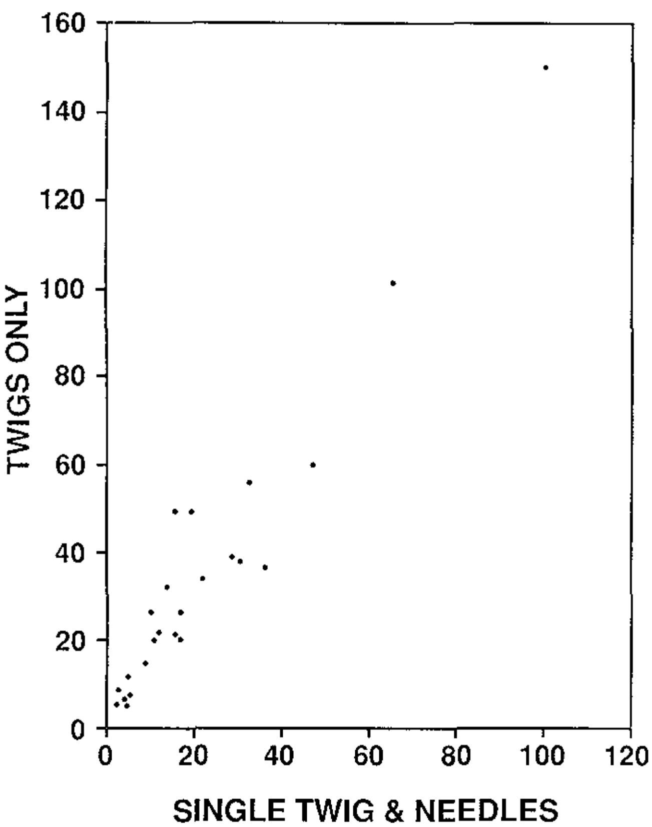


Figure 22-1. Arsenic in Pacific silver fir (*Abies amabilis*) - concentrations in a single twig with needles versus a bulk sample of twigs (less needles) from the same tree.

TABLE 22-8
BASIC RULES TO BE APPLIED AT EACH SAMPLING STATION WHEN CONDUCTING A BIOGEOHEMICAL SURVEY

Basic Rules	Reason
1 Collect same species.	Every species has a different chemical composition, and trace element requirements and tolerances.
2 Collect same plant organ.	Each plant organ has a different capacity to store trace elements.
3 Collect same amount (*i.e.* age) of growth, from same area of tree (*e.g.* chest height), preferably from all sides.	There are chemical variations along a twig (*see* Table 22-5). Heterogeneity in bark scales can be minimized by scraping from around the tree.
4 Try to collect samples from plants of similar age and appearance.	This is the basic inter-site consistency that is required for any geochemical sample medium.
5 If living tissue is the selected medium, collect at same time of year (*i.e.* conduct survey in 2 to 3-week period).	There are significant seasonal changes in plant chemistry.
[Dead tissue (*e.g.* outer bark) can be collected at any time	No appreciable seasonal change]
6. Do not return to a previously sampled tree and expect to obtain exactly the same analyses.	This is unrealistic in view of the heterogeneity of element distributions and seasonal variations in composition (and to a lesser extent annual variations). Be satisfied if an anomaly is the same order of magnitude.

- the composition of twigs is different from needles; as most trace elements are more strongly concentrated in twigs than needles, the needles will 'dilute' the twig concentrations (perhaps to below detection levels);
- the ratio of twig to needles must be similar at all sample stations;
- the single twig plus needles will provide a less representative sample of the tree than the preferred bulk sample of seven to ten twigs; and
- this procedure can be adopted for fir, pine, cedar and hemlock samples, but it is not well suited to spruce, because spruce needles contain only about 10% of the concentrations of heavy metals that occur in twigs, therefore, the dilution factor may be too great and too many values may be below detection levels.

Table 22-8 summarizes the sampling procedures and precautions that must be taken during a biogeochemical sampling program.

SAMPLE PREPARATION

WASHING

Samples from dusty areas should be washed. Rinsing in a stream or lake, or under a tap is usually sufficient, although more thorough washing in a laboratory may be needed if samples are very dusty, and particles are lodged in the plant tissues. Samples from many areas of British Columbia need not be washed because they are regularly rinsed by rain. Furthermore, in most cases the dust is mostly silicates which are unlikely to be enriched in precious and base metals. Table 22-9 shows data from washed and unwashed portions of three samples from near the Nickel Plate mine at Hedley, and affirms that there is insignificant loss of elements (except K) after even the most rigorous washing.

DRYING

Samples should be spread out to dry, if possible on the day of collection. If samples in paper bags are left in a backpack or box, moisture released from the vegetation will soon cause disintegration of the bags. If they are stored in plastic bags they will soon grow mould and begin to rot, making sample handling very unpleasant. Furthermore, redistribution of chemical elements among tissue types may occur. Mould can also grow on cloth bags. The samples need not be removed from the bags in which they were collected, provided the bags are sufficiently porous to allow a free passage of air. If plastic bags are used, samples must be removed on the day of collection. This is not necessary for the 'Hubco' bags, but they should not be left sealed in a damp place for several weeks or mould will grow.

It takes several weeks for samples to dry fully in a warm, dry atmosphere. Faster methods are to dry them in an oven for 24 hours at just over 100°C, or place them in a microwave oven for 10 to 40 minutes, depending upon wetness. Microwaving must be carefully monitored, as samples should not be overheated. If mercury is to be determined, do not use a microwave, and keep the drying temperature to less than 40°C.

TABLE 22-9
EFFECTS OF THOROUGH WASHING IN DISTILLED WATER ON THE CHEMICAL COMPOSITION OF DIFFERENT PLANT TISSUES

	Sagebrush Twig		Sagebrush Leaf		Lodgepole Pine Bark	
	Unwashed	Washed*	Unwashed	Washed*	Unwashed	Washed*
Au (ppb)	270	294	279	267	293	298
As (ppm)	100	95	50	64	150	160
Ba (ppm)	330	300	140	150	590	590
Co (ppm)	4	4	2	2	11	10
Fe (ppm)	6300	5500	2500	2800	17600	17200
K (%)	26.3	24.3	17.4	13.2	3.2	1.5
Mo (ppm)	11	10	9	11	2	3
Sb (ppm)	1.7	1.5	0.7	1.1	4.2	4.3
Zn (ppm)	570	550	530	610	1300	1400

* One hour in ultrasonic bath

SEPARATION

Once the moisture has been removed it is a simple process (for most species) to remove the foliage from the twigs by pummelling the bag, then rubbing one's hands (clean and no rings) through the sample to remove the brittle leaves. This separation procedure is always advisable, because as noted above, the chemistry of the different tissue types is not the same, and the density of foliage may vary from one sample to the next (therefore the ratio of twig to foliage will vary, providing the potential for false anomalies).

Bark, of course, needs no further separation, as any separation of inner from outer bark will have been done in the field; it is much easier to do this separation when the samples are moist. Drying bakes the layers together. The dried and separated material is then ready for either:

- maceration and direct analysis by instrumental neutron activation analysis (INAA), or
- ashing to preconcentrate the metals prior to analysis by atomic absorption spectrometry (AAS) or inductively coupled plasma emission spectrometry (ICP-ES). Ashing is particularly useful if you want to determine concentrations of elements not readily determined by INAA (*e.g.* Pb, Ni, Cu, Cd, V, Sn, Li, B, Bi, Se, Te, Ga, Tl, F, Mg, Mn, Al and low levels of Ag).

MACERATION

If a decision has been made to analyze the dry tissue, the material should next be homogenized by macerating (chopping) the sample in an appropriate blender or mill. The most commonly used apparatus is a 'Wylie mill' which contains steel blades that rapidly reduce the material to small fragments that are then forced through a sieve to provide 'sawdust' powder of moderately uniform size. The material can then be pressed into pellets for trace element analysis by INAA. The pellets for INAA are obtained by pressing 8, 15 or 30-gram aliquots of material in an XRF press (this service and the maceration are provided by most commercial laboratories). Commonly the 15-gram sample size is adequate. Wet chemical analysis can be performed on the dry powder, but most procedures are tedious and detection limits are commonly inadequate.

ASHING

Preconcentration of the vegetation by ashing (available from commercial laboratories) brings the levels of many metals to concentrations that are easily detectable by ICP-ES, AAS, or even simple colorimetry. Maceration is not usually necessary, as the entire 50 to 100 grams of dry material that comprises the sample can be placed in an aluminum tray and, after bringing the temperature slowly up to 470°C, it can be ashed for 12 to 24 hours until all charcoal has disappeared. It is important that the material should just smoulder; if it actually ignites some elements will volatilize.

The ash is then ready for analysis by whatever chemical method is available and appropriate. Tests performed on the analysis of ashed and unashed tissues of the same sample indicate that a few elements (*e.g.* Br) volatilize during this controlled ashing procedure. There may be loss of a small portion of other elements, but data indicate that loss is a fairly consistent percentage. Figure 22-2 shows that for zinc there is no loss.

A word of caution: a few species (not commonly used in biogeochemical surveys), especially those belonging to the rose family, contain cyanogenic glycosides. These combine with gold in the plant, causing volatilization long before the usual ashing temperature is reached. Therefore, the ash yields little or no gold. Conversely, palladium forms a very stable monoxide during ashing to 470°C, requiring that the temperature be raised to 870°C to fully break this bond prior to wet chemical analysis. Only a portion of the palladium is released upon acid digestion after ashing at a lower temperature.

ANALYSIS

The two methods most commonly used in the analysis of plant material for exploration are INAA and ICP-ES, both of which have been discussed briefly in the previous section. In summary, the pros and cons of the two techniques are:

INAA is a 'total' analysis which measures the total content of elements in the sample, regardless of how they are bound with other elements. It is particularly appropriate for measuring small traces of elements in dry or ashed vegetation. The only drawbacks to the method are that it cannot be used to measure certain elements (*e.g.* Pb, Bi, Tl), and it has either high detection limits or requires a separate irradiation for some other elements (*e.g.* Ag, Cd, Cu, Ni, Mg, Mn, V).

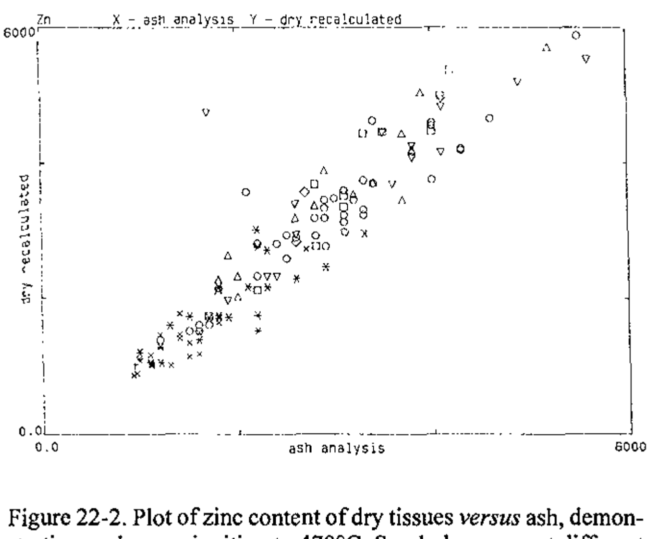


Figure 22-2. Plot of zinc content of dry tissues *versus* ash, demonstrating no loss on ignition to 470°C. Symbols represent different tissues from boreal species.

If the analytical program requires mainly gold, arsenic, antimony, cobalt, chromium and any of the other 30 elements available in commercial packages, INAA is the best method.

ICP-ES following an aqua regia digestion of ash samples is total for most elements, although on occasion some elements may be bound with others such that the aqua regia digestion does not release them all into solution, or there may be spectral interference among high levels of some elements. Such situations are rare. Data for some elements, especially barium and strontium, are only partial, and detection levels are usually too high to be of use for gold, uranium and a few elements of lesser importance. The generation of arsenic, antimony, selenium, tellurium bismuth and germanium by hydride evolution can be obtained for an additional cost, providing useful data on these 'pathfinder' elements. ICP-ES on dry vegetation provides data of only limited value because of the low levels of elements present.

A method that is becoming increasingly important is ICP-MS (mass spectrometry) as it can detect very low levels of elements. At this time it is not widely used by commercial laboratories, and where available the cost is not competitive with INAA or ICP-ES. It does hold, however, great potential for biogeochemical analysis.

STANDARDS

Whichever method is used, it is essential that for adequate quality control, at least one standard sample of known composition (and similar matrix) and one duplicate pair are inserted in every batch of 20 'regular' field samples. Without this control one has no idea of the accuracy (using standards) and precision (determined from your duplicates) of the data.

EXAMPLES FROM SURVEYS IN BRITISH COLUMBIA, USING DIFFERENT SAMPLE MEDIA

NICKEL PLATE MINE, HEDLEY

At the Nickel Plate mine, near Hedley, skarn-hosted low-grade gold mineralization occurs mostly in conglomerate within a sequence of Triassic volcanic and impure carbonate rocks (Figure 22-3). The hill above the large open pit (Lookout Mountain) has a thin mantle of glacial drift covered with forest dominated by lodgepole pine, which was the main sample medium selected for this survey (outer bark). Samples were collected along picketed cut lines at 130-metre spacing on an evenly spaced grid. Figure 22-3 shows the distribution of gold in the ash of the bark. Remarkably high gold concentrations are present and the patterns show an even zonation northward from the deposit. As airborne contamination from the pit could not be ruled out, several trees were dissected to determine the metal content of inner tissues. Results show that the trunk wood is enriched in gold and arsenic (Table 22-10), confirming that the metals are in fact being taken up from the ground through the root systems. The biogeochemical survey revealed strong enrichment of many metals in several vegetation species, but especially the outer bark of lodgepole pine (Au, As, Bi). There is a large area (>100 km^2) within which gold and

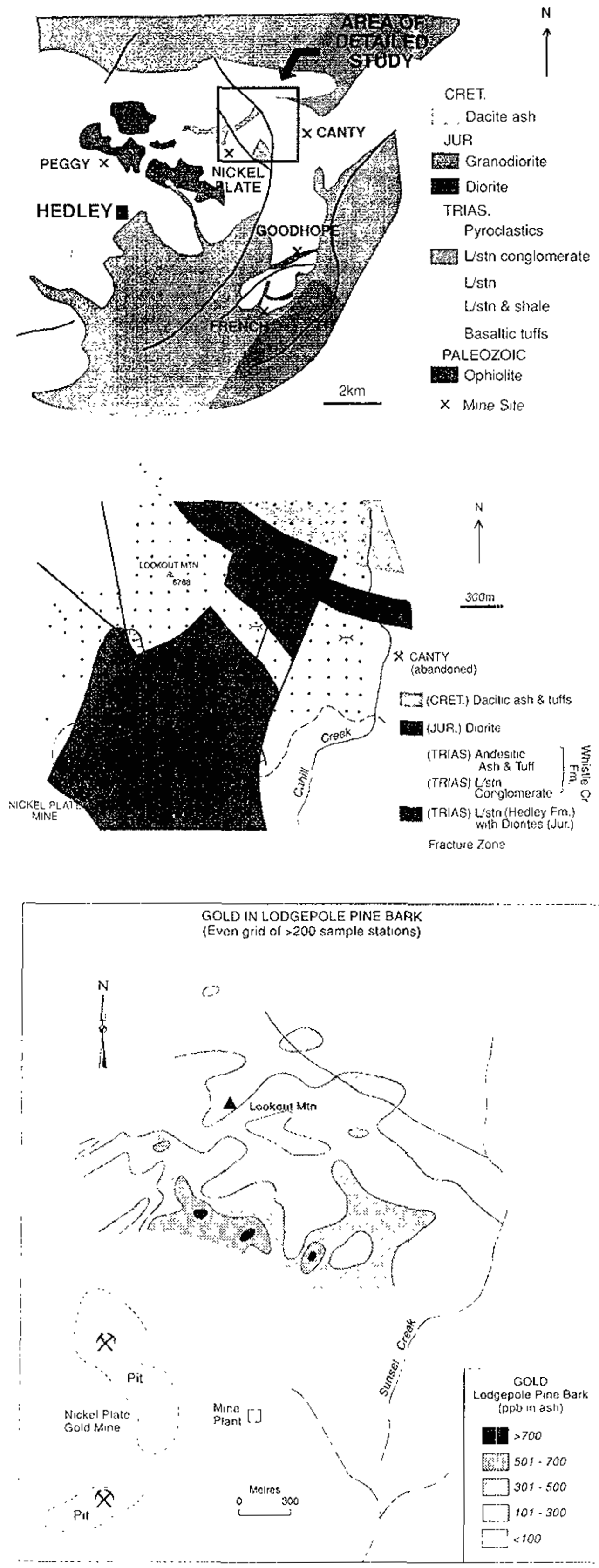


Figure 22-3. Nickel Plate mine, Hedley: a) Location map; b) Geology and sample sites; c) Gold (ppb in ash) of lodgepole pine bark (*Pinus contorta*).

TABLE 22-10
CONCENTRATIONS OF GOLD AND ARSENIC IN LODGEPOLE PINE FROM THE VICINITY OF THE NICKEL PLATE MINE, HEDLEY, SOUTHERN B.C.

	Outer Bark	Inner Bark	Trunk Wood
Gold (ppb) in ash			
Pine #1	420	114	128
Pine #2	308	28	56
Pine #3	238	32	36
Arsenic (ppm) in ash			
Pine #1	220	25	59
Pine #2	160	22	41
Pine #3	150	20	33

Data demonstrate unusual enrichment of metals on the outside and inside of the trees, indicating absorption through the roots rather than airborne contamination. Typical background levels are < 10 ppb Au and < 5 ppm As.

arsenic are enriched in the trees, such that by sampling just one tree per 10 square kilometres the gold-rich system could be identified.

CAROLIN MINE, NEAR HOPE

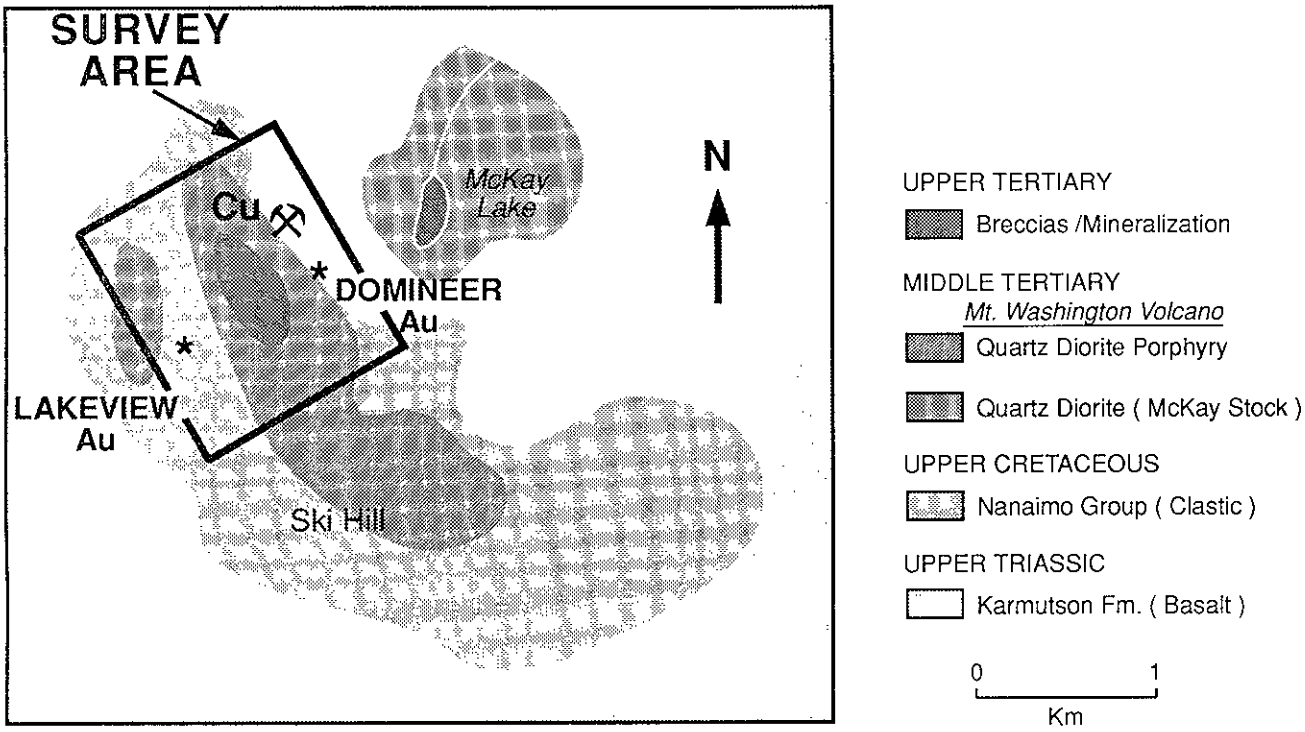
Gold at the Carolin mine occurs in a coarse-grained turbidite of the Jurassic Ladner Group (Ray, 1990). The cover of glacial material on the steep slope is irregular in thickness, but mostly less than 1 metre. Pacific silver fir and western hemlock are the dominant species, both of which are strongly enriched in gold, arsenic and sodium near the zones of mineralization. There are broad areas of biogeochemical enrichment down slope, caused by some mechanical dispersion, but mostly by dispersion of metals dissolved in ground water. The implication for exploration in this rugged moist terrain is that heavily wooded valleys can be screened for surrounding mineral potential by collecting a few tree tissues to provide focus for more detailed exploration.

MOUNT WASHINGTON, VANCOUVER ISLAND

Mount Washington, located 15 kilometres northwest of Courtenay on Vancouver Island, is in the mountain hemlock biogeoclimatic zone. Gold-quartz veins, carrying silver, copper and arsenic are associated with dacitic tuff, breccia, and diorite of Tertiary age (Muller, 1989; Figure 22-4). The forest is dominated by mountain hemlock and yellow cedar, with some Pacific silver fir and subalpine fir, and an understory of rhododendron. The chemistry of the hemlock and rhododendron both clearly outlined the zones of mineralization. Distribution patterns of gold, arsenic, cobalt and cesium (Figure 22-5) show a spatial relationship to the mineralization. Of particular importance in biogeochemical studies is the recognition of metal zonation patterns in the vegetation; in this area, and others where biogeochemical exploration is applied, it is important to look for multi-element patterns that may relate to different styles of concealed mineralization.

QR DEPOSIT, QUESNEL TROUGH

The Quesnel River (QR) gold deposit is situated in forested terrain 140 kilometres southeast of Prince George (Figure 22-6). Compact, single-event lodgement till, 3 to 5



(after Carson, 1972)

Figure 22-4. Mount Washington, Vancouver Island - location map with geology.

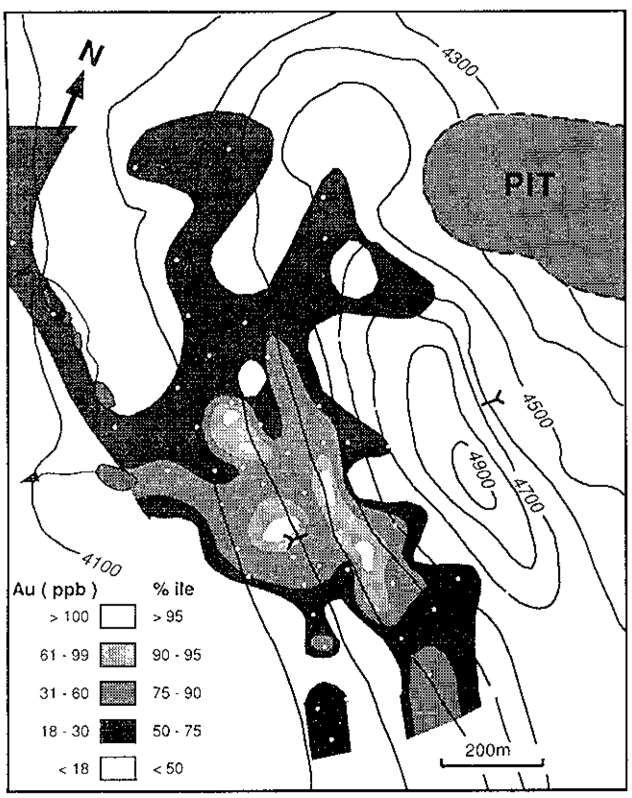


Figure 22-5a. Gold (ppb in ash) of rhododendron twigs (*Rhododendron albiflorum*). Mount Washington.

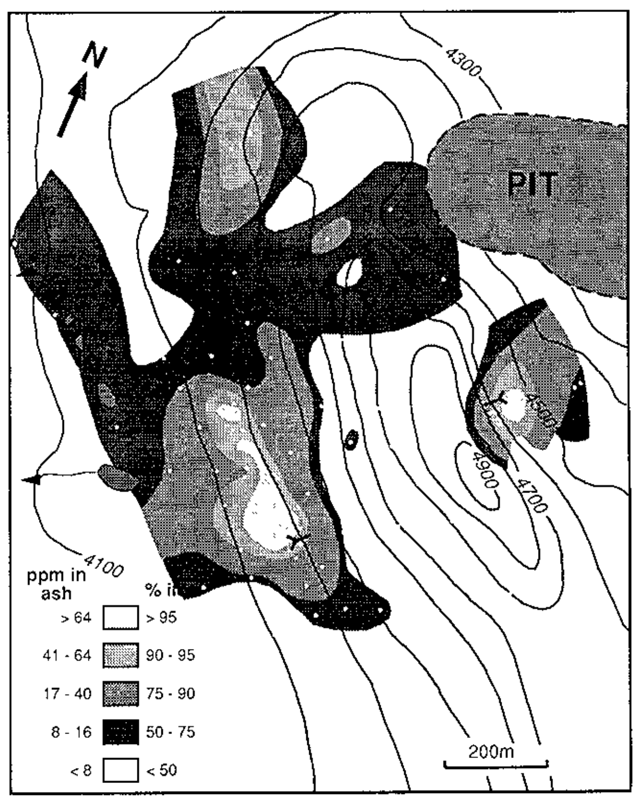


Figure 22-5b. Arsenic in Rhododendron twigs. Mount Washington.

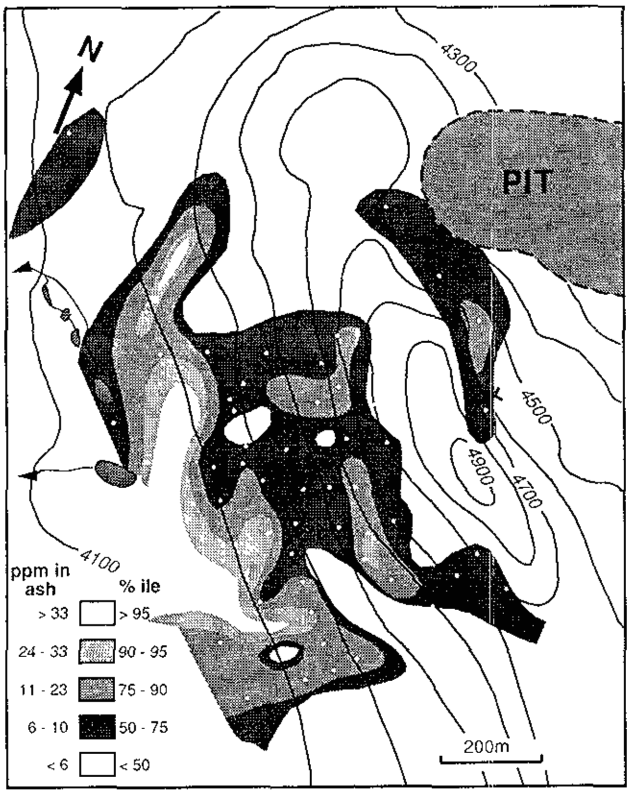


Figure 22-5c. Cobalt in Rhododendron twigs.

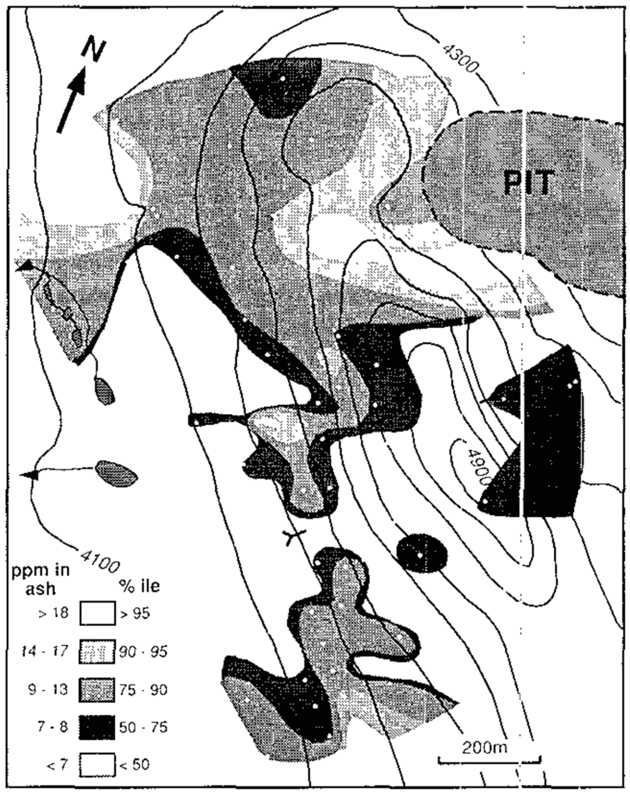
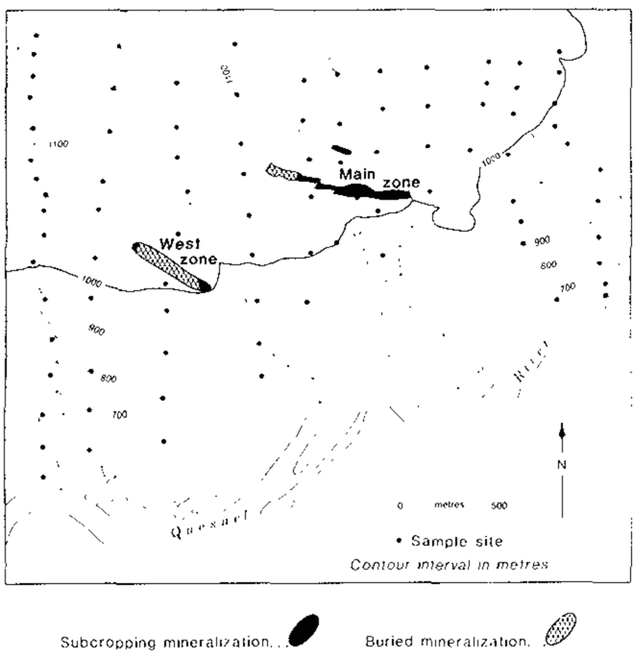


Figure 22-5d. Cesium in Rhododendron twigs.



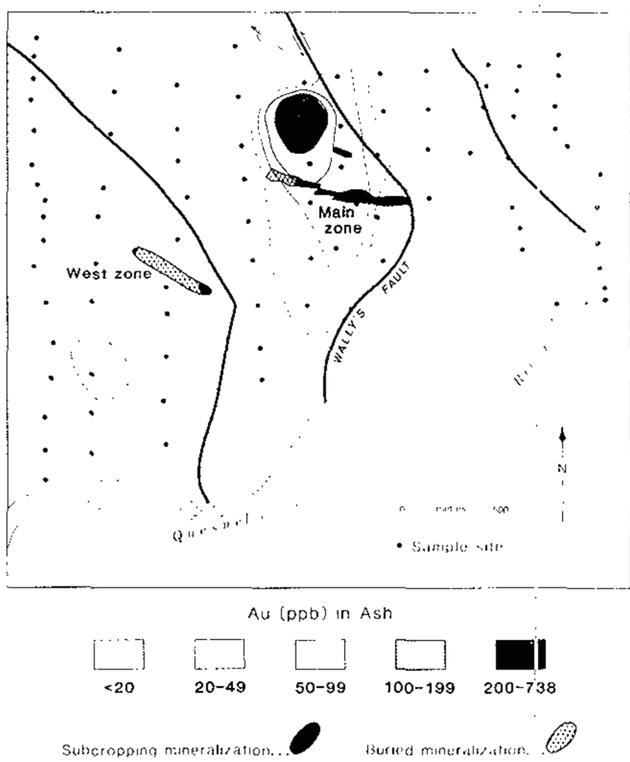


Figure 22-6. QR deposit, central British Columbia: a) Topography and zones of concealed gold mineralization; b) Gold (ppb in ash) in top stems of Douglas fir (*Pseudotsuga menziesii*).

metres thick, covers propylitized basalt and sediments hosting pyrite and chalcopyrite with micron-sized gold along grain boundaries. Within an area of 6 square kilometres, 94 Douglas fir trees were sampled by removing the top 0.5 metre while leaning out of a hovering helicopter (Dunn and Scagel, 1989). INAA analysis of the tree tops (stripped of their needles) revealed high concentrations of gold, suggesting a northwestward (down-ice) dispersion train of gold extending uphill for at least 500 metres from the deposit, coupled with a zone of hydromorphic dispersion downhill.

CONCLUDING REMARKS

It is important to remember that the biogeochemical method of exploration is just another tool that explorationists have at their disposal, and it should be used in conjunction with all other available geological, geochemical and geophysical information. It is not a panacea, and in some environments it may not be the best tool to use. The case histories selected show unusually high concentrations of metals in the vegetation. Such high numbers are rarely found, but this should not be cause for dismay or concern as the identification of mineralization zones is based on the patterns of elements and their spatial relationships, rather than the absolute numbers.

We now have sufficient knowledge of the application and usefulness of biogeochemical methods for the thoughtful explorationist to consider using biogeochemistry as part of a mineral exploration program. It should no longer be considered a 'when all else fails' technique, as vegetation chemistry frequently can provide information on the substrate that can not be obtained by other means.

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SHALLOW SEISMIC METHODS: APPLICATION TO DRIFT PROSPECTING

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INTRODUCTION

Seismic methods are geophysical techniques which use measurements of the time taken for acoustic energy to travel from a source on the surface through the subsurface and back to a series of receivers on the ground. Energy is refracted or reflected at boundaries where there is a change in acoustic impedance (the product of material density and seismic velocity), and because contrasts in acoustic impedance are generally associated with lithological boundaries, seismic techniques can be used to obtain subsurface structural information.

Seismic reflection methods have been the primary geophysical tool used in oil and gas exploration for over 60 years. Because of the tremendous commercial importance of oil, much industrial research and development has been invested in this branch of geophysics. By the 1960s, specialized field procedures, digital magnetic tape recording, and computer processing of the data had become standard in the industry. Over the last couple of decades, the need for more accurate and detailed subsurface structural information for petroleum exploration was one of the driving forces behind the development of supercomputers. Conventional seismic reflection techniques are highly sophisticated, but require considerable investment in both data acquisition and processing.

In contrast, the application of seismic methods to shallow problems related to groundwater or engineering concerns have had to be cost-effective in relation to the drilling of shallow holes, and until the 1980s, refraction rather than reflection methods were used almost exclusively when shallow subsurface structural information was required. Refraction methods depend on the measurement of only the time of first arrival of seismic energy at each receiver location, and so did not require digitization of the seismic wave train or computer processing of the data. Thus, refraction surveys could be carried out with relatively simple and inexpensive equipment, and for many decades were the only shallow seismic method used to obtain estimates of the depth to bedrock, and if possible, to determine the major lithologic boundaries within the overburden.

In the early 1980s, the development of digital enhancement engineering seismographs with high-pass filtering capabilities, together with the proliferation of increasingly powerful microcomputers, made the application of seismic reflection methods to "shallow" problems a viable alternative. Over the last decade, much experience and expertise in the application of shallow high-resolution reflection techniques has been gained, and today these methods are accepted and proven shallow geophysical tools.

Both refraction and reflection techniques have potential applications in drift prospecting, where information on the depth to bedrock, the bedrock topography or the overburden stratigraphy would be useful. The use of seismic methods and the choice of refraction or reflection surveys depends on the particular geological setting, the desired information, and the range of depths that are of interest. In this paper both these techniques will be briefly discussed, together with some examples of survey data. The objective is to describe the type of information that can be obtained with these methods and the conditions under which the best results might be expected, as well as the limitations of shallow seismic refraction and reflection techniques.

SEISMIC REFRACTION METHODS

Seismic refraction methods involve the measurement of the time of first arrival of seismic energy at a series of source-receiver separations. Energy is radiated downwards into the ground from a seismic source (hammer striking a plate, weight drop, shotgun source, explosives *etc.*) and critically refracted according to Snell's law along interfaces across which there is an increase in seismic velocity. As the energy travels along the interface, it is radiated back to the surface where it is detected by geophones (Figure 23-1). Refraction methods are based on the assumption that velocity increases with depth, as energy is refracted away from the surface at an interface where velocity decreases. As the source-receiver separations increase, energy that has been refracted from deeper horizons will overtake the shallower refractions and become the first arrivals. The arrival times and source-receiver distances are used to determine layer velocities and depths to the refracting horizons.

The theory and various methods of collecting and interpreting seismic refraction measurements can be found in basic textbooks on exploration geophysics (*e.g.* Dobrin, 1976; Telford *et al.*, 1976), and in a more recent paper by Lankston (1990). With the development of digital engineering seismographs and the advent of the microcomputer age, seismic refraction records can be interactively picked and analyzed using software developed for personal computers. Techniques such as delay time methods and the generalized reciprocal method (Palmer, 1981; *see also* Lankston, 1990), which potentially yield more detailed information on subsurface structure than the simple dipping layer interpretation, can now be applied more easily and cost effectively.

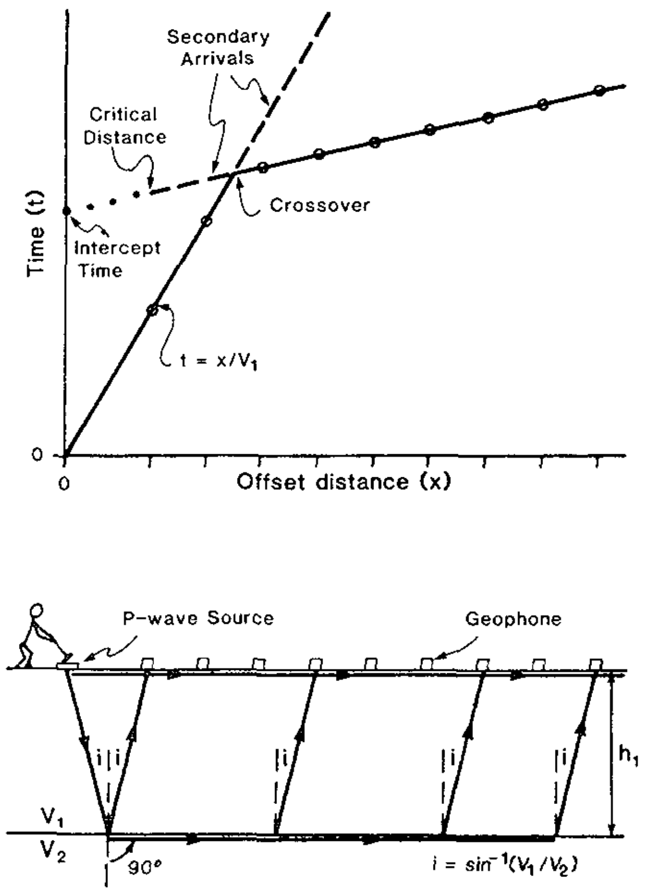

Figure 23-1. Time-distance graph (top), and direct and critically refracted raypaths (bottom) in the ideal two-layer case. First break times are noted by large circles on the time-distance graph. Solid lines are defined by first breaks. Dashed lines on the time-distance graph are secondary arrivals that might not be visible on the field record or might be difficult to time accurately. The dotted line is the projection to the intercept time based on critically refracted arrival times. (Lankston, 1990).

TABLE 23-1
COMPRESSIONAL SEISMIC WAVE VELOCITIES

Velocity (metres/second)	Sediment/Rock Description
200 - 400	Soft, unconsolidated, dry surface deposits.
400 - 1500	Unconsolidated clays and silts, unsaturated sands and gravels.
1500 - 2000	Saturated sands and gravels; compacted clays and silts; tills; completely weathered rocks.
2000 - 2500	Partially consolidated sediments, probably water saturated; compacted tills; strongly weathered/fractured metamorphic and igneous rocks; weathered and/or jointed sandstones and shales.
2500 - 3700	Partially weathered to fresh shales and sandstones; weathered and/or sheared metamorphic, igneous or limestone rocks.
3700 - 4500	Slightly weathered and/or fractured metamorphic or igneous rocks or limestones; some very hard or indurated sandstones and shales.
4500 - 6000	Unweathered metamorphic and igneous rocks; some limestones and dolomites.

Adapted from Whitely, personal communication, 1989.

In general, refraction methods are very useful for determining the depth to bedrock (especially when this interface is characterized by a large velocity increase, *see* Table 23-1), where bedrock is within approximately 30 metres of the surface. As the depth to bedrock increases, and/or the velocity contrast at this horizon decreases, longer spread lengths (series of source-receiver separations) and larger sources are required to measure refracted energy from this surface.

Because velocity contrasts within water-saturated sediments are usually relatively small, refraction methods are not particularly suited to providing detailed information on overburden stratigraphy. Exceptions to this may be found in areas where a till unit (typical velocity of 1700-1800 m/sec) is overlain by a fine-grained unit such as silt or clay (typical velocity of 1500-1600 m/sec). However, there is also the possibility of a "hidden layer" problem, where refracted energy from a layer sandwiched between lower and higher velocity units may never appear as first arrivals.

Given a model of overburden stratigraphy, velocities for each major stratigraphic unit can be estimated (*see* Table 23-1). These velocities and estimated unit thicknesses can be input to simple modelling programs to help design the recording parameters (*e.g.* spread lengths and geophone spacings) for a refraction survey, and indicate potential problems such as a hidden layer. Geophysicists should be able and willing to provide such modelled results prior to setting up a survey.

The limitations of refraction techniques are: the basic assumption that velocity increases with depth; the possibility of "hidden layers" which may lead to significant errors in depth estimates to underlying units; the large source-energies and long spread-lengths required to obtain refractions from horizons deeper than 20 or 30 metres below surface; and the difficulty in resolving detailed structure on the target horizon. However, refraction surveys are relatively inexpensive, and can be used very effectively to provide estimates of the drift thickness, and in some cases, estimates of the depth to the top of a buried till unit.

EXAMPLE: INTERPRETATION OF REFRACTION DATA FROM SHUBENACADIE, NOVA SCOTIA

Figure 23-2 shows the time-distance plot and interpreted depth section for a refraction spread in the Shubenacadie basin in Nova Scotia. The survey was one of a series of test spreads shot to delineate the extent and depth of the Carboniferous basin, and to map the stratigraphy of the overlying Cretaceous and Quaternary sediments.

The data were acquired by laying out 24 geophones at 5-metre spacings, and shooting 5 metres off each end as well as in the centre of the spread. The 120-metre spread-length was sufficient to observe refracted arrivals from high velocity bedrock (unit 4) at a depth of approximately 30 metres. Overlying bedrock is a layer, 15 to 20 metres thick (unit 3), with a velocity of approximately 2200 metres per second, which could be either Cretaceous sediments or a Quaternary till sequence. Tills with velocities in this range are widespread in the area. The interface between units 2 and 3 is not well defined by the data, and therefore the topography

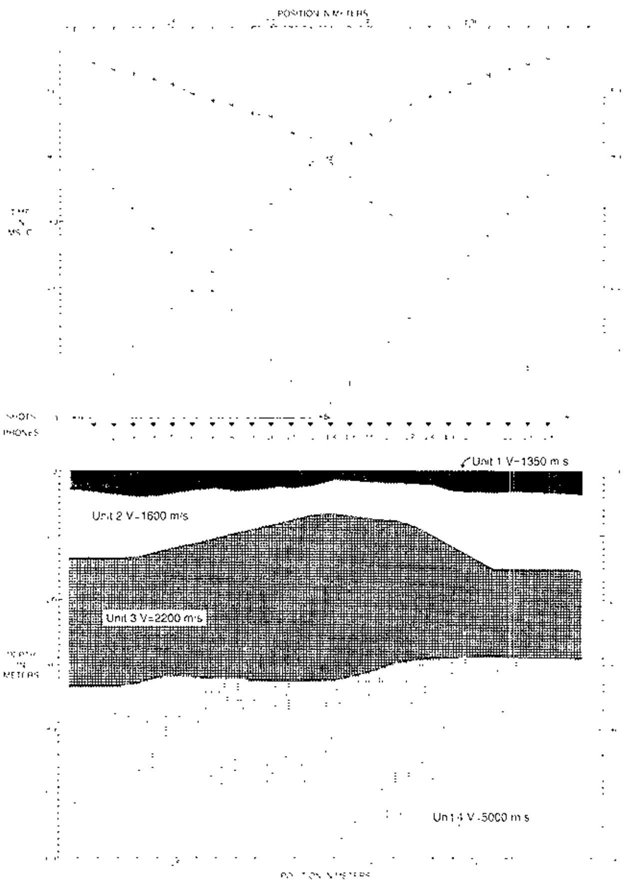

Figure 23-2. Time-distance plot (top) showing the layer assignments for each of the first arrivals. The lower half of the figure is the depth section that was interpreted from the time-distance data using a refraction analysis program (SIPQC) from Rimrock Geophysics Inc.

shown on this interface in the depth section of Figure 23-2 may not be realistic. The upper two units (units 1 and 2) are interpreted to be Quaternary sediments, with unit 1 representing the weathered or unsaturated zone. A drill hole would be required to determine the lithologies of the units identified in the section.

Refraction surveys such as the simple one discussed in this example can be carried out quickly and are relatively inexpensive. The estimate of the depth to bedrock and gross stratigraphy of the overburden materials generated is very useful information for planning a drift prospecting program.

SEISMIC REFLECTION METHODS

Seismic reflection methods involve measurement of the time taken for seismic energy to travel from the source at or near the surface, down into the ground to an acoustical discontinuity, and back up to a receiver or series of receivers on the ground surface. These methods require digitization of the seismic wave train and at least some degree of computer processing of the data. Data are usually acquired continuously along a survey line, and processed to produce a seismic section which is a two-way travel time cross-section of the subsurface. Velocity-depth functions calculated from

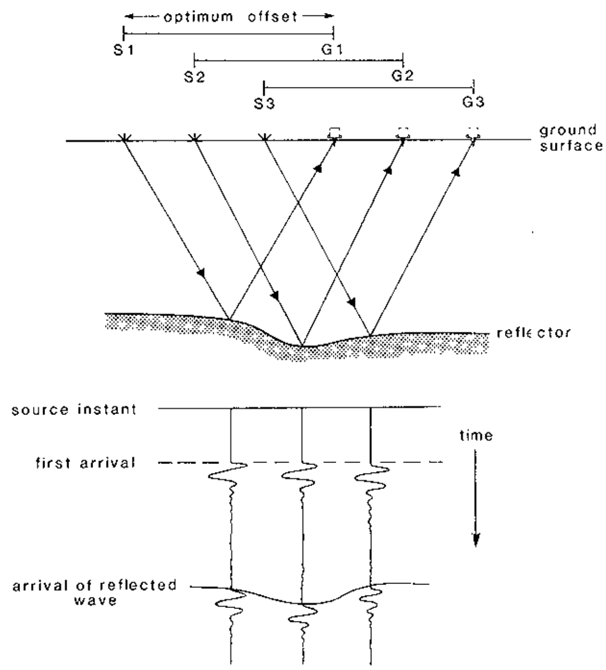

Figure 23-3. The schematic optimum-offset section shown at the bottom of the figure was produced by shooting first from S1 (source position 1) and recording the output at G1 (geophone 1), then from S2 to G2, and finally from S3 to G3.

the data are used to translate the two-way travel time into depth.

Details on the application and methods used in shallow seismic reflection surveys can be found in Hunter *et al.* (1989), Pullan and Hunter (1990) and Steeples and Miller (1990). These papers summarize the development of two different shallow seismic reflection methods - the "optimum offset" technique, which in its simplest form is a single-channel, constant-offset profiling technique requiring a minimum of data processing (Figure 23-3), and the common depth point (CDP) method which is an adaptation of the methods used by the petroleum industry. The optimum offset method evolved in the early 1980s, in part to avoid the dependence of CDP methods on mainframe computer processing, and in part to avoid the costs and time associated with the storage and processing of large amounts of data. In CDP surveys, multi-channel (12, 24, or more) data are recorded for each shotpoint. During processing, these data are sorted according to their common midpoints or common depth points (Figure 23-4), and all data from each CDP are corrected for offset and then stacked (summed) in order to enhance reflection signals. The potential improvement in the signal to noise ratio can be significant, but the survey will be more expensive because substantially more processing time and computer power are required. The technological improvements in engineering seismographs, personal computers and data storage capabilities over the last few years have overcome many of the limiting factors that led to the development of the "optimum offset" technique. It is now recommended that CDP data be collected in the field, allowing common offset panels to be pulled from the data

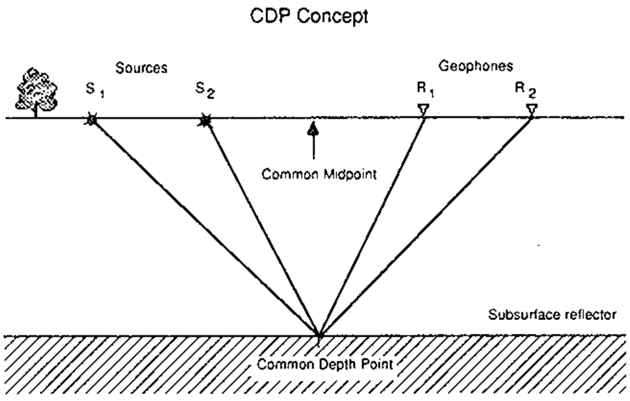

Figure 23-4. Illustration of the common depth point (CDP) concept. When 24-channel records are recorded at each shotpoint, and shotpoints coincide with every geophone location, the subsurface reflection points will be sampled 12 times, resulting in 12-fold CDP data after processing. (Steeples and Miller, 1990).

set and examined before a final decision on the requirement for CDP processing is made (Pullan *et al.*, 1991). This procedure gives the interpreter the flexibility to exploit the advantages of either technique, depending on the particular problem and site conditions involved.

Reflection methods overcome many of the limitations associated with refraction methods. Firstly, energy will be reflected back to the surface from any interface across which there is a change in the acoustic impedance, whether it is associated with an increase or a decrease in seismic velocity. Thus, even though no energy will be refracted from the top of a low-velocity layer, a reflection does exist. Another advantage of reflection methods is the large amplitude of a reflection in comparison to the refracted signal from the same interface. There may be as much as an order of magnitude between the amplitudes of the reflected and refracted waves. This means that smaller, non-destructive sources can be effectively used to obtain reflections from depths of several tens or hundreds of metres, while it might require the use of explosives or heavy, truck-mounted seismic sources to obtain refractions from the same horizons. Finally, reflection techniques have the potential to provide considerable detail on the overburden structure and bedrock topography, depending on the frequencies of the reflection signals that are recorded. For example, small bedrock depressions or rugged bedrock topography are difficult to resolve with refraction techniques, but may be well delineated by a reflection survey.

Shallow seismic reflection methods do, however, have their own limitations. Firstly, the successful application of any shallow reflection survey depends on the detection of high-frequency energy reflected from velocity discontinuities within the subsurface. Unfortunately, earth materials, and especially unconsolidated overburden sediments, are strong attenuators of high-frequency energy. Thus, seismic waves in the 10 to 90 hertz range commonly used in petroleum exploration may be reflected from depths of thousands of metres, but energy with frequencies above 100 hertz normally only have travel paths on the order of tens or hundreds of metres. The ability of a particular site to transmit high-frequency energy is a major factor in determining the quality and the ultimate resolution of a shallow reflection survey.

Much of the attenuation of high-frequency energy occurs in the near-surface materials where the seismic energy is produced. The optimum conditions for shallow reflection surveys are usually present when the surface materials are fine grained and water saturated; reflections with dominant frequencies of 300 to 500 hertz can be obtained in such field situations. These frequencies correspond to seismic wavelengths in unconsolidated overburden sediments on the order of 3 to 5 metres, with a potential subsurface structural resolution of 1 to 2 metres. However, when the surface materials are coarse grained and dry, the dominant frequencies of reflection data can be less than 100 hertz. In such areas, seismic wavelengths may exceed 15 metres, and the resolution of the data may not be sufficient to obtain the desired subsurface information.

The ability to produce and record high-frequency energy for shallow seismic reflection surveys has improved significantly over the years with the development and testing of various seismic sources (Pullan and MacAulay, 1987; Miller *et al.*, 1986, 1992) and with the technological improvements in engineering seismographs. Today, state-of-the-art engineering seismographs use instantaneous floating point analog to digital converters, reducing or even removing the necessity to use high-frequency geophones and pre A/D analog low-cut filters in the field in order to enhance the high-frequency components of the seismic signal. This has substantially improved the potential of shallow seismic reflection surveys, but site characteristics are still crucial in determining the suitability and ultimate success of the survey.

Reflections from very shallow interfaces arrive at times that are close to the arrival times for energy that has travelled directly along the surface of the ground or been refracted from shallow interfaces such as the water table. For this reason, it is often not possible to separate shallow reflection signals from other interfering events. The depth to the first separable reflection horizon depends on the frequency of the signals and the source-receiver offsets, but in general, horizons within 10 to 15 metres of the surface cannot be delineated using the shallow seismic reflection method.

Shallow seismic reflection surveys are recommended for detailed mapping of overburden stratigraphy and bedrock topography below depths of 15 to 20 metres. The quality and resolution of the results are critically dependent on the surface conditions, with the best results usually associated with fine-grained, water-saturated surface materials, and the poorest with coarse-grained, dry surface sediments. Large variations in surface topography along a survey line can be corrected for during the processing sequence; however, surface conditions and the depth to water table are likely to vary with the topography and these changes may affect the frequency characteristics and the resolution of the data. High-resolution seismic reflection surveys should not be attempted in areas where the surface sediments are gas charged (*e.g.* on fill, peat, swamps), as the attenuation of high-frequency energy in such areas is extreme.

Shallow seismic reflection surveys are expensive ($5000+ per line-km depending on the site location, type of data collection and processing, and density of shot/receiver locations). For this reason, such surveys are suited to problems where detailed knowledge of the subsurface structure could lead to substantial savings in drilling costs (*i.e.* drift prospecting, identification of buried valleys in groundwater investigations, and site characterizations for environmental assessments). It is strongly recommended that a test survey be carried out prior to any major reflection survey, to establish whether or not shallow seismic reflection methods can provide the desired resolution of the target horizon at that particular site.

EXAMPLE: OPTIMUM OFFSET SHALLOW SEISMIC REFLECTION PROFILE FROM VAL GAGNÉ, ONTARIO

In the Matheson/Val Gagné area, east of Timmins, Ontario, gold prospecting has been inhibited by thick overburden cover, consisting of clay, silt, and/or sand overlying pockets of till above bedrock. The average depth to bedrock in 42 holes drilled by the Ontario Geological Survey (OGS) in 1984 was 35 metres. Ideally, till sampling programs would position drill holes in the glacial lee of buried bedrock highs where thick occurrences of the oldest till are likely to be found. However, without any prior knowledge of the subsurface structure, much of the initial exploratory drilling is carried out blindly, and it is estimated that 25% of such holes do not encounter till.

In 1985 and 1986 approximately 10 line-kilometres of optimum offset shallow seismic profiles were shot at a test site near Val Gagné, Ontario, to demonstrate the potential usefulness of this technique in a drift prospecting program in the area (Pullan *et al.*, 1987). Line 1 was obtained using a source-receiver offset of 30 metres, and a geophone spacing of 2.5 metres. Data were recorded on a Nimbus 1210F engineering seismograph, using a 12-gauge shotgun source (Pullan and MacAulay, 1987), and processed on an Apple IIe microcomputer.

The most significant bedrock depression discovered on the Val Gagné test site by the seismic program is along Line 1, shown in Figure 23-5. The section is 660 metres in length, and bedrock varies from a depth of 37 metres at the south end of the line to 65 metres at the drill hole (OGS sonic drill hole 85-01). The essentially flat-lying overburden consists of clay grading into a thick sand unit. The contact between massive and varved clay occurs at a depth of 17 metres, and this interface is clearly visible on the seismic section at a time of approximately 30 milliseconds. This unit grades into a poorly laminated sand from 40 to 50 metres in depth. The

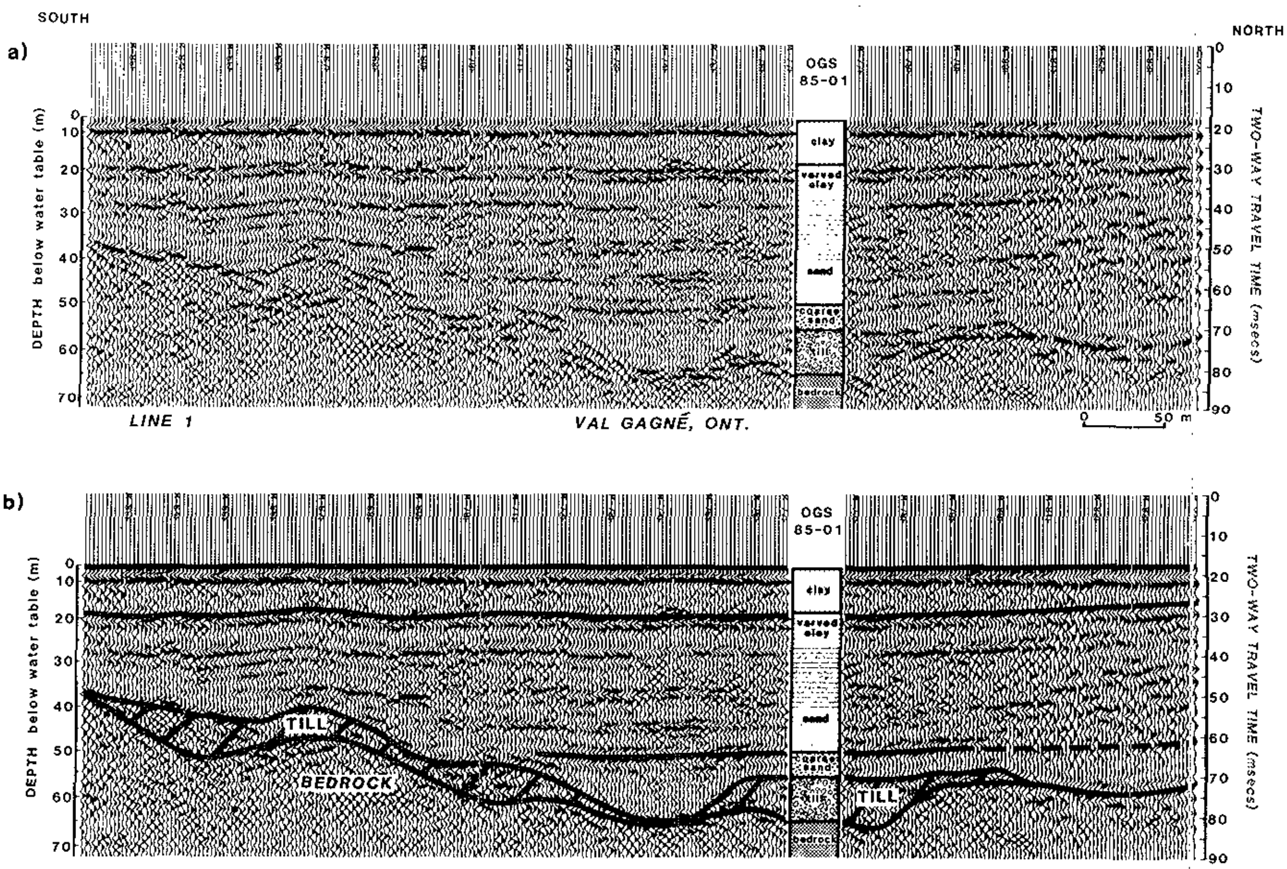

Figure 23-5. (a) Line 1 from Val Gagné, Ontario, with a simplified drill log shown at the location of OGS sonic-drill hole 85-01. (b) An interpretation of Figure 23-5a, indicating the extension of lithological units north and south of the borehole, and probable occurrences of till (from Pullan *et al.*, 1987).

top of the sand is an indistinct boundary and is not easy to define on the seismic section; however, there is a weak reflector visible at a depth of approximately 40 metres. Horizontal layering is clearly indicated throughout the clay/sand units with a small amount of draping visible.

At the drill hole, 15 metres of sandy till overlies bedrock. This pocket of till was identified on the seismic section prior to drilling, and the drill site was selected specifically to sample this unit. Figure 23-5b shows another pocket of till south of the drill hole. The section clearly demonstrates the value of seismic profiling prior to drilling; had the borehole been sited 100 metres to the north of its location, only a minor occurrence of till would have been encountered in the hole.

EXAMPLE: CDP SHALLOW SEISMIC REFLECTION PROFILE FROM SOUTHEASTERN MANITOBA

In 1992, several shallow seismic reflection CDP surveys were carried out in conjunction with a major drilling program conducted as part of a Mineral Development Agreement with Manitoba. Some of these surveys were conducted in support of drift prospecting interests, and an example is shown in Figure 23-6.

The seismic profile in Figure 23-6 is a six-fold CDP section that is 350 metres long with a trace spacing of 1.5 metres. It was obtained by recording 12-channel records with 3-metre geophone intervals, using a 12-gauge in-hole shotgun as a seismic source, a 3-metre source-to-nearest-receiver offset, and a 3-metre shot interval. The data were recorded on an ES-2401 engineering seismograph and processed on an IBM-compatible personal computer.

The borehole showed 4.5 metres of till on surface, underlain by a sand sequence 20 metres thick coarsening upward. The top of the sand unit is at too shallow a depth to be seen on the seismic section, but the lower contact with a sand diamicton is characterized by a distinct large-amplitude reflection that dips slightly to the east (from 25 to 32 ms across the section).

Above bedrock, there are several till units, separated by thin sand layers. This sequence may account for the series of reflections observed on the seismic section in the range of 30 to 45 milliseconds. The till sequence thickens to the west across the section by an estimated 6 to 7 metres. The top of the lowermost till, described as a stiff clayey silt to silt diamict, is characterized by a large-amplitude reflection (at approximately 40 ms), and appears to be of relatively uniform thickness across the section.

The reflection from bedrock is sometimes difficult to follow beneath the thick sequence of tills, particularly on the western part of the line. However, the seismic data indicate that the bedrock surface is essentially flat lying with the exception of a small incised channel (at CDP 180, borehole position) and perhaps a larger valley (CDP 225-280, estimated depth of 7 m, width of 75 m). The definition of bedrock in the vicinity of this postulated valley is poor, but the till sequence above it appears to have been displaced vertically downwards in a graben structure. This feature may have been produced by the melting of buried debris-rich ice during glacial retreat.

The information provided by this seismic section could be used cost effectively in a drift prospecting program by, at the very least, eliminating the need to sample within the upper sand. Estimates of the depth to bedrock and the bedrock topography, and some information on the stratigraphy within the till sequence, are also important factors in siting boreholes and determining the depth range in which to sample.

SUMMARY

Shallow seismic methods are geophysical tools that are capable of mapping bedrock topography and overburden stratigraphy, but which have not yet been applied extensively in drift prospecting programs. Both refraction and reflection methods can be used, with the choice of method being dependent on the target horizon and the depth of interest. This paper has provided a simple description of these methods, outlining both potential and limitations. It must be

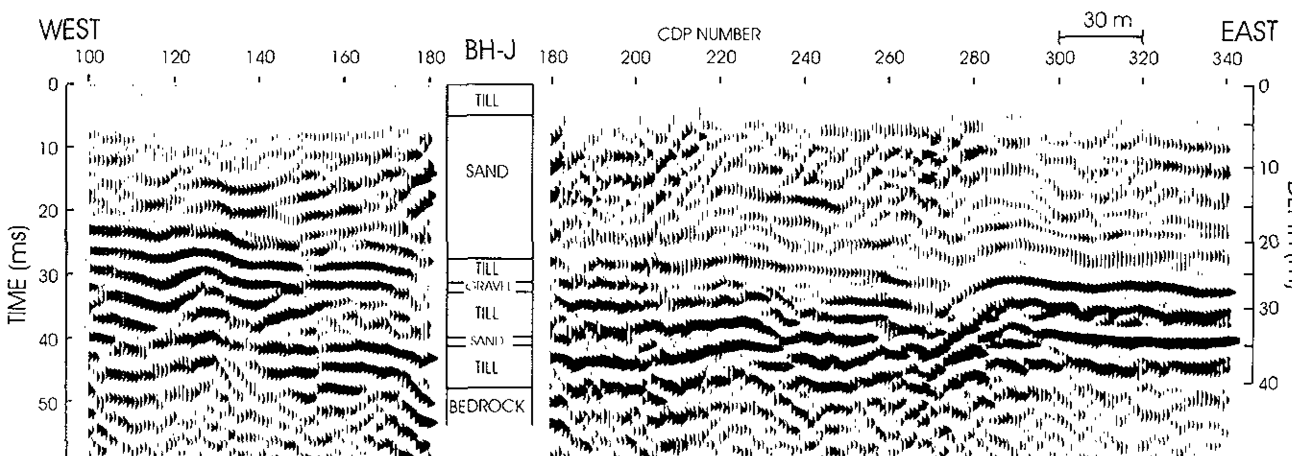

Figure 23-6. A six-fold CDP section approximately centred on borehole J. A simplified lithological log has been inserted in the section at the bore-hole location. The section clearly delineated the top of the till sequence at a depth of approximately 25 metres, and suggests the existence of a small bedrock valley between CDP numbers 225 and 280.

emphasized that the quality of seismic data (especially of shallow reflection data) is site dependent, and it is always prudent to conduct a small test survey before embarking on a major seismic program.

The availability of the subsurface structural information provided by a seismic survey prior to a drift prospecting program could (i) minimize the requirement for sampling by providing an estimate of the depth to buried till sequences, (ii) provide estimates of the depth to bedrock and the total thickness of overlying till, and (iii) allow the siting of boreholes to sample material in favourable structural relationships with respect to bedrock. These factors could result in substantial savings in drilling costs as well as a means of optimizing till sampling locations.

ACKNOWLEDGMENTS

The author would like to thank Harvey Thorleifson of the Geological Survey of Canada for helpful discussions on the Manitoba data, and for providing the borehole log, Jim Hunter for his constructive reviews of the manuscript and Marten Douma for help in drafting figures.

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CHARACTERIZATION OF OVERBURDEN STRATIGRAPHY WITH THE GEONICS EM-39 BOREHOLE LOGGING INSTRUMENT

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INTRODUCTION

This paper presents geophysical borehole logs and sample descriptions compiled from several overburden drilling operations in differing geological environments. These case histories are intended to illustrate how geophysical logs respond to some of the physical characteristics of strata intersected by the drill. The logging equipment is portable, and the small diameter of the tools (3.6 cm, 1 3/8 inches) allows casing as small as 2 inches (inside diameter) to be logged. Only holes cased with plastic tubing can be logged with the conductivity and magnetic susceptibility tools, but the gamma tool is able to log through steel casing, thereby permitting a qualitative evaluation of parameters such as grain size.

METHODS

The Geonics EM-39 borehole logging tool consists of eight major sub-assemblies, contained in two shipping boxes. In a typical application, the electronics console and portable data logger (or laptop logging computer) are attached to the top of the winch assembly, all of which is placed on the ground near the borehole. A tripod is erected over the borehole, and the logging cable, attached to the appropriate logging sonde, is passed over the pulley of the opto-electric counter at the pulley head, and down into the casing. The logging software provides the option of logging down or up the hole. However, logs are usually recorded downward, after allowing the tool to equilibrate with the borehole temperature part-way down the hole.

The conductivity tool uses an inductive electromagnetic principle which is unaffected by the presence of conductive borehole fluid or plastic casing. The source of the primary electromagnetic field is a dipole antenna coil, mounted coaxially 50 centimetres away from the dipole receiving antenna. Effective measurement radius of the conductivity probe is estimated to be 1 to 1.5 metres, and the apparent conductivity measured by the instrument is taken to be that of the surrounding formation and associated ground water.

The magnetic susceptibility probe, also an inductive electromagnetic tool, measures the degree to which a material is magnetized. In general terms, the overall susceptibility of a lithology is dependent only on the amount of ferrimagnetic minerals, such as magnetite, pyrrhotite, and ilmenite, present in the material. The gamma tool detects the decay of uranium, thorium and potassium in the environment, although for practical purposes the tool provides a qualitative measurement of the abundance of clay (because of the potassium). Low gamma readings are an indication of coarse-grained sediments, and high gamma readings are attributable to fine-grained materials; although it is important to consider the provenance and post-depositional history of the strata when interpreting the results.

RESULTS AND DISCUSSION

KIRKLAND LAKE KIMBERLITE PROSPECT

Figures 24-1 and 24-2 present results of logging in two plastic-cased boreholes near Kirkland Lake, Ontario. The distance between the boreholes is about 200 metres. Tills and glaciolacustrine clays, silts, and sands overlie kimberlite bedrock. In general, the gamma tool is unable to effectively discriminate between the various overburden strata, but does record an increase in the count rate at the top of the kimberlite, even though the transition recorded in the sample logs shows a gradual boundary through a strongly weathered zone. Geochemical analyses of samples taken above and across the bedrock boundary show the appropriate correlation between the concentration of radioactive elements in samples and the gamma count in the interval from which the sample was obtained.

Two graded sand units in borehole B-30-03 (Figure 24-1) appear as zones of upward decreasing conductivity. This is due partly to a response to the increasing proportion of silt in the graded units, but also implies a change in the mineralogy. The gamma log, which usually can be relied upon to show graded bedding, is relatively smooth through this zone. The magnetic susceptibility log indicates slightly more magnetic material at the top of the sand units. The conductivity and magnetic susceptibility logs show more variation than the gamma log through the overburden section in the B-30-03 hole, and could be used in conjunction with the sample log to further refine the lithologic boundaries in the core.

The reason for the smooth conductivity response in the B-30-10 (Figure 24-2) borehole is not apparent. Although it shows the same trends in conductivity as the B-30-03 hole, its shows higher values in each respective material. Geochemical data match what might have been predicted from the magnetic susceptibility log, but the response through the basal till unit is noteworthy. In the B-30-10 hole, the two silty sand, poorly sorted till layers immediately overlying the kimberlite are separated from each other by a sand unit,

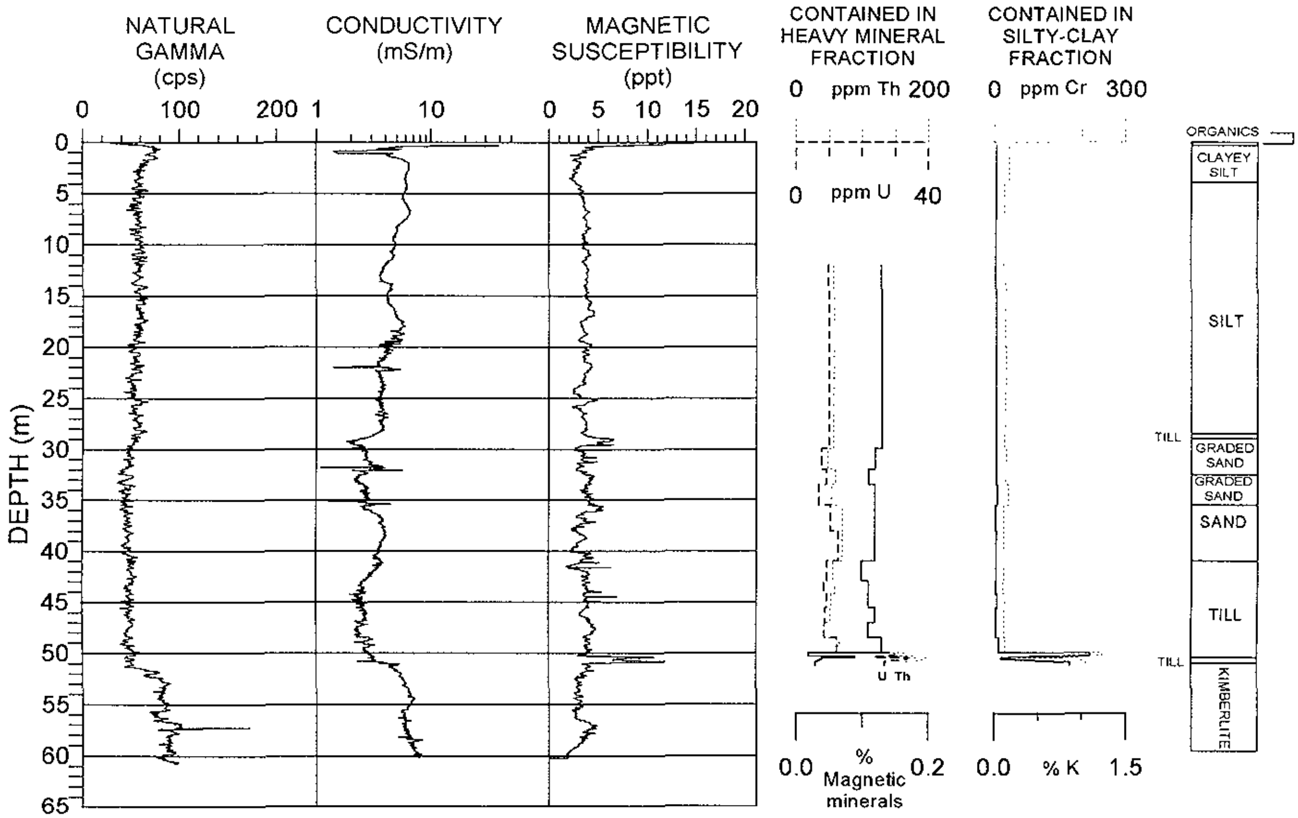

Figure 24-1: EM-39 borehole logs and selected geochemical results from hole B-30-03, a kimberlite prospect near Kirkland Lake, Ontario. U = uranium, Th = thorium, K = potassium, Cr = chromium.

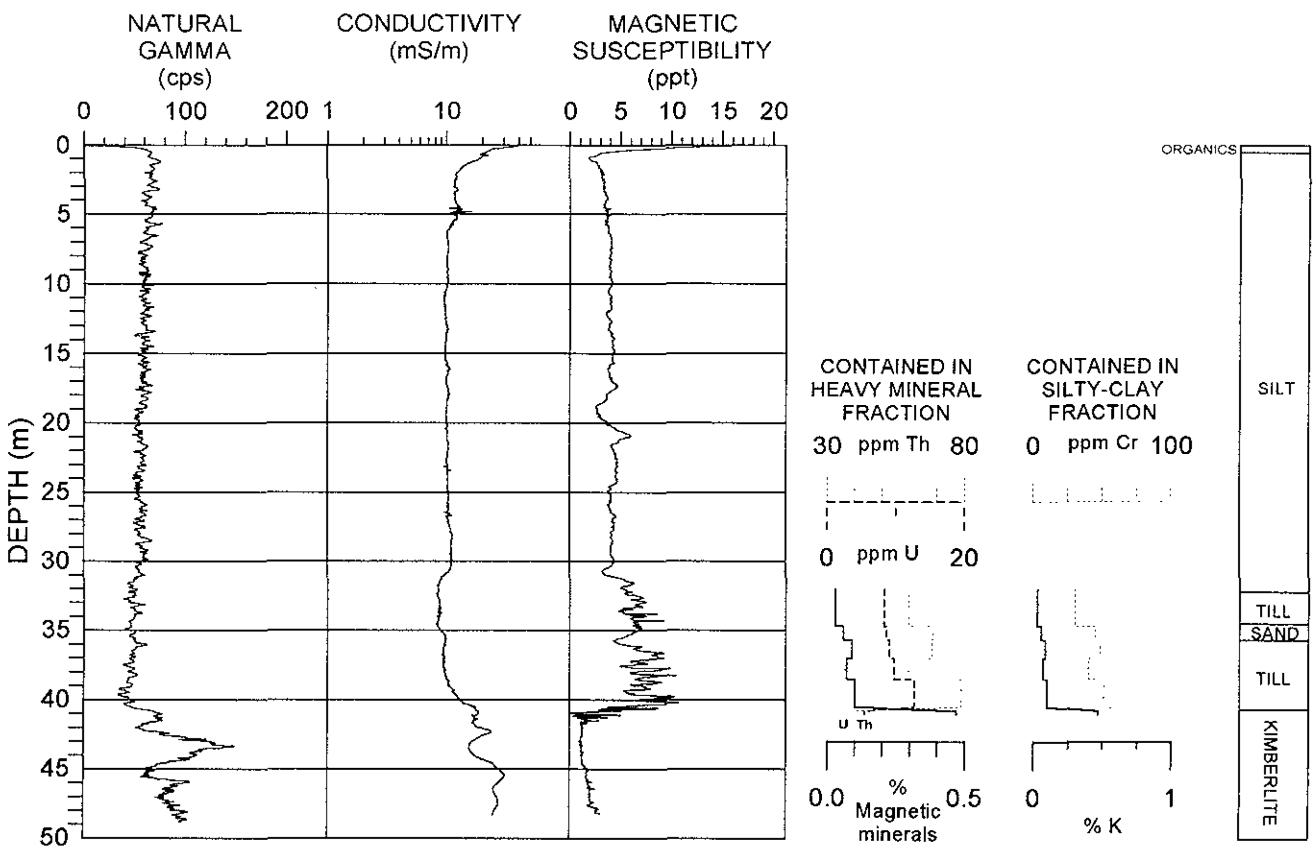

Figure 24-2: EM-39 borehole logs and selected geochemical results from hole B-30-10, a kimberlite prospect near Kirkland Lake, Ontario. This borehole is located approximately 200 metres south of B30-03. U = uranium, Th = thorium, K = potassium, Cr = chromium

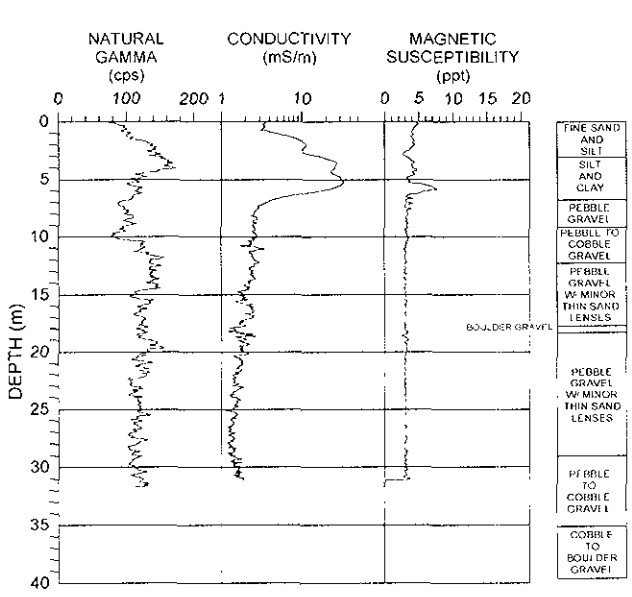

Figure 24-3. EM-39 borehole logs and generalized sample descriotions from hole VL H92-1, Lightning Creek, east of Quesnel, B.C.

and show variable but relatively high values of magnetic susceptibility. In the B-30-03 hole, a similar response is found only in the 1 metre thick, well sorted sandy till directly above bedrock.

CARIBOO GOLD DISTRICT

Figure 24-3 shows the geophysical logs run in the Lightning Creek, VL H92-1 borehole at the Gallery Resources mine east of Quesnel, British Columbia. The logs are part of a multiparameter study designed to test models of placer deposition and preservation (Levson *et al.*,1993). This example illustrates how a cross check between logs can filter out anomalous results. The gamma log shows relatively high count rates throughout the borehole, suggesting the presence of fine-grained sediments. The conductivity log contradicts this interpretation, showing very low conductivity in all but the upper 7 metres. This log would be consistent with a fine-grained unit, conductive because of irreducible interstitial water, overlying a coarse-grained, permeable and well-drained unit. The magnetic susceptibility log shows a minor response at a bed boundary in the upper conductive zone, and a response at its base, but otherwise indicates very little magnetic material.

The sample descriptions reveal that, to a depth of 6.7 metres, the lithologies are fine-grained, well sorted, and composed of silt and clay, overlain by fine sand and silt. Below 6.7 metres, the units are composed mainly of gravel, primarily in a sandy matrix, and most with sand lenses. The reason for the high gamma counts lies in the gravel clasts, a proportion of which are composed of argillite, phyllite and biotite schist which contain high-potassium clay minerals to which the gamma probe responds. Even the overlying fine-grained units show gamma counts greater than would be expected from silts and clays. The explanation lies in the provenance of the detrital minerals, which would include high-potassium clays derived from local bedrock sources.

ANDERSON ROAD DEMONSTRATION BOREHOLE

Located southeast of Ottawa, the site of the Anderson Road demonstration borehole was chosen on the basis of a well-constrained geological setting that could be used as a demonstration and testing site for geophysical equipment (Douma and Nixon, 1993). Figure 24-4 shows the EM-39 logs, generalized sample descriptions, lithofacies (interpreted from a nearby borehole by Gadd, 1986), and a portion of a high-resolution seismic line that intersects the borehole. Approximately 58 metres of subglacial, proglacial, glaciolacustrine, marine, and fluvial sediments overlie Ordovician Carlsbad Formation dolomitic shale. Seismic data show a series of nearly horizontal, parallel reflection events separating units displaying various internal characteristics. The borehole geophysical logs reveal subtle attributes of the strata that are not immediately evident from the seismic or sample data.

The gamma log shows a good correlation with the sample log, and reveals that the slightly radioactive bedrock is overlain by about 5 metres of radioactive till, then 50 metres of Leda clay, which in turn is capped by 3 metres of sand and disturbed fill. The gamma log shows subtle differences within the clay units, probably attributable to shifts in the depositional environment. These changes show up on the seismic reflection line as minor reflectors at 31, 36, 41 and 49 milliseconds two-way travel time from the surface. The magnetic susceptibility log shows a uniform response, except for anomalies at 7, 10 and 15 metres, which are probably due to metallic debris from drilling operations. The anomaly from 47 to 53 metres shows that the soft, varved clay at the base of the Leda clay sequence probably has a different mineralogy, and possibly a different source, than subsequently deposited sediments of the Champlain Sea.

It is the conductivity log that is of primary interest in this borehole, because it measures a parameter that cannot be related to seismic sections, or to casual sample examination. It shows that the sediments at the base of the clay section are either strongly conductive, or contain conductive pore water. Studies of fossil assemblages in the Leda clay indicate deposition in highly saline waters of the Champlain Sea early in its history (Rodrigues, 1987). The conductivity log probably reflects saline pore water trapped in the clay. Decline of the conductivity may be due to flushing of trapped pore water, or to a change in the salinity of the depositional environment. In this case, the latter interpretation is probably correct.

The gamma log through the basal till unit shows relatively high count rates, with magnetic susceptibility log record values similar to those in the bedrock, suggesting that the till is derived, in large measure, from the Carlsbad Formation. Presence of bedrock clasts in the till serves to confirm this interpretation.

CONCLUSIONS

These examples demonstrate that the geophysical logging of boreholes in overburden can be used to augment the value of the sample descriptions. The logs reveal subtleties

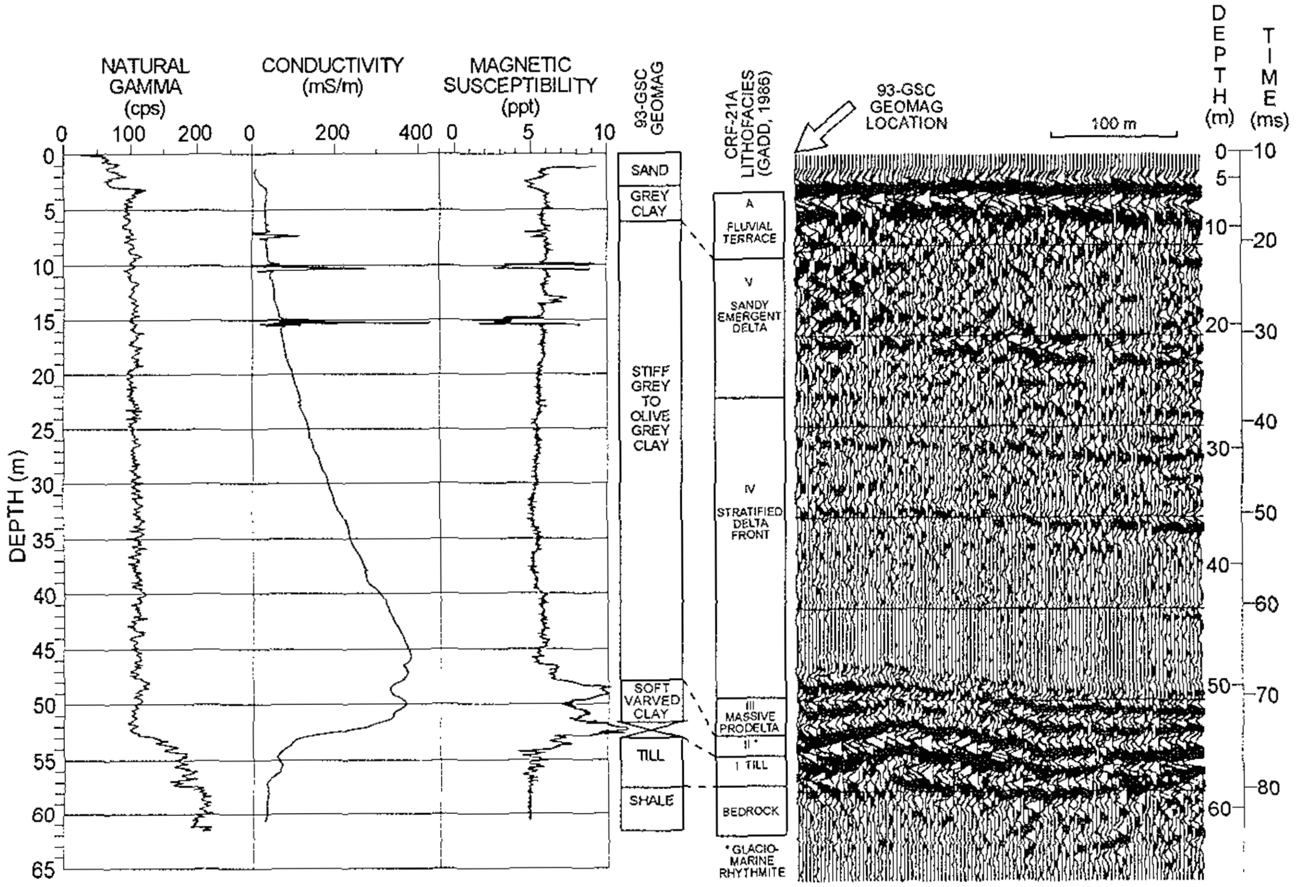

Figure 23-4: EM-39 borehole logs and high-resolution seismic section at the Anderson Road borehole, 93-GSC GEOMAG. Time, shown to the right of the seismic section, is measured as two-way travel time in milliseconds, and is converted to depth (on the adjacent scale) with interval velocity corrections.

of grain size, mineralogy and pore water content that are not always apparent from normal specimen examination in the field. Stratigraphy of the borehole may be more accurately constrained, and hole-to-hole correlations more easily visualized with the aid of the geophysical logs.

Including set-up time, a 30-metre, plastic-cased hole can be logged with the three tools in less than two hours. A preliminary graphic plot of the gamma, conductivity, and magnetic susceptibility logs can be created in the field in 20 minutes, regardless of the length of the borehole.

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RESISTIVITY MAPPING USING ELECTROMAGNETIC TECHNIQUES

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INTRODUCTION

Electromagnetic (EM) resistivity mapping can be an effective method for investigating a wide range of geological conditions. In particular, it can map thickness and lithology of drift (overburden) as well as bedrock conductors beneath the drift. Electromagnetic resistivity mapping can be carried out either on the ground or in the air. Both these techniques will be discussed in this chapter using examples from the Timmins clay belt region of northern Ontario.

We begin with a brief historical overview of airborne electromagnetic (AEM) systems. In the early days of AEM surveys, interpretation consisted of eyeballing anomalous features on analog profiles and plotting these on flight-path recovery maps. Geological and geophysical empirical rules of thumb were developed to prioritize the multitude of anomalies found. These subjective methods were successfully used to find a significant number of massive sulphide orebodies in Canada and northern Europe. Pemberton (1962), Paterson (1967), Best (1985), and the references therein, provide a review of AEM systems and interpretation schemes.

Airborne electromagnetic hardware became more versatile during the period from 1960 to the mid-1970s. Shorter signal averaging times, multi-frequency transmitters and receivers, time-domain systems and multi-coil configurations were developed (Barringer, 1965; Fraser, 1972; Stemp, 1972). These hardware advances brought about the need for better interpretation methods. Nomograms for free-space dikes and spheres, as well as for multi-layer earth models, were developed using analytic and analog modelling (Grant and West, 1965; Keller and Frischknecht, 1966). Time-domain modelling of free-space dikes (Palacky, 1976) provided type curves for the Input system, a towed bird, fixed-wing system with a large loop around the aircraft as a transmitter. The transmitter emits half sine-wave current pulses. During the off time of the transmitter, the received signal is measured in a number of discrete time windows. Screening and classifying algorithms for prioritizing the large number of anomalies found in a typical survey were still mostly empirical, although more rigorous rules of thumb were being developed.

During the 1970s, two and three-dimensional numerical modelling programs were developed (Ward *et al.*, 1973; Hohmann, 1975; Lee *et al.*, 1981; Best *et al.*, 1985). Results from numerical modelling, together with field investigations, showed that current channelling and gathering (Spies and Parker, 1983) in conductive terrains could explain the resistivity section obtained from drilling.

In this same period, airborne resistivity mapping for surficial geology, bedrock geology in tropical environments, and ground water became more common. Indeed, resistivity mapping began to play an important role in traditional massive sulphide exploration. Understanding the nature of near-surface resistivity features provided an effective method for screening out anomalies not associated with bedrock conductors (Fraser; 1978, 1979).

Similar developments occurred for ground EM systems as well. Time domain systems were developed in the late 1970s and 1980s that improved the depth of exploration and resolution of electromagnetic methods. Better processing, interpretation and display capabilities have been developed and are still in the process of being developed. The interested reader can obtain further details on electromagnetic systems from the recent publication by Nabighian (1991) and the references therein.

In these notes, the role of non-linear inversion for resistivity mapping will be discussed. In addition, field examples are given that illustrate the range of expected resistivities for massive sulphide bodies and the volcanic and metasedimentary rocks that host them. Examples of the resistivity and variability of Quaternary sediments follow.

INVERSION

Several of the newer AEM systems (Barringer, 1976; Zandee *et al.*, 1985, Annan, 1986) use complex transmitter pulses and wide-band receivers. Some even use correlation methods to increase the signal-to-noise ratio. Digital signal processing methods are frequently applied to enhance and extract the earth's response from the signal. The digital data provide interesting opportunities for interpretation. They can be transformed from time to frequency and vice-versa if the bandwidth is sufficiently broad and the digitization interval sufficiently small. Interpretation and display can be carried out either in the frequency domain or the time domain, depending on the interpreter's preference and the geological situation.

Digital data sets lend themselves naturally to the use of automated interpretation schemes. In particular, automated inversion can be an effective interpretation tool when the data are in digital form. Forward and inverse models are defined in the following way.

- Forward model: given a model and the values of the physical parameters for the model, compute the response.
- Inverse model: given a model, compute the physical parameters for that model that best fit the observed response.

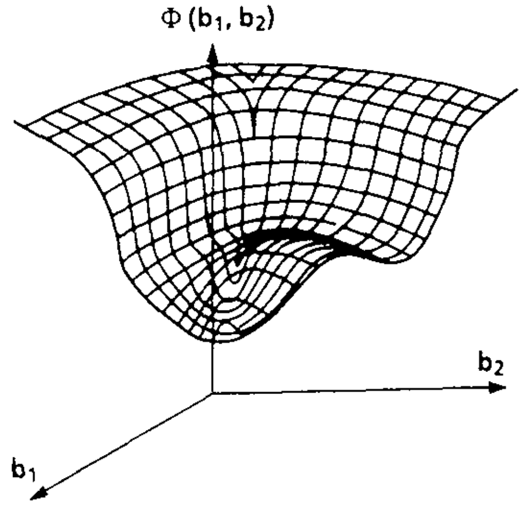

Figure 25-1. Objective function for two-dimensional parameter space.

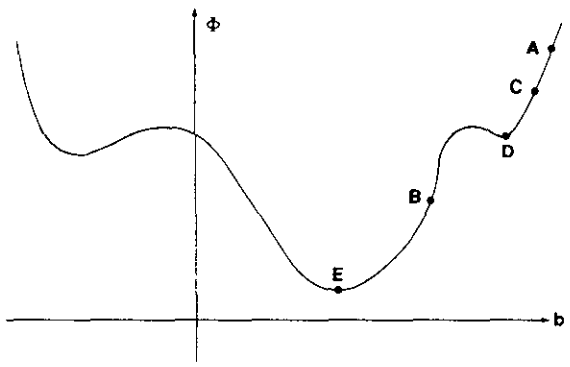

Figure 25-2. Objective function for a one-dimensional parameter space.

Numerical inversion methods have been in existence for many years (Marquardt, 1963; Jackson, 1979; Powell, 1964, 1965). All inversion methods try to minimize the difference between an observed data set and the data obtained from a (hopefully) realistic model that represents the physical observations. More specifically, let y_i, $i = 1,\ldots,N$ be the observed data. Let the mathematical representation of the physical process be

$$F_i = F(x_{1i},\ldots,x_{ni}; b_1,\ldots,b_m);\ i = 1,\ldots,N \qquad (1)$$

where $x_{1i},\ldots,x_{ni}$ are known model parameters (for example frequencies of the EM system) and $b_1,\ldots,b_m$ are unknown parameters (for example conductivity and thickness of the drift layer) that are used to fit the observed and model data. The function f, the objective function,

$$\phi = \sum_{i=1}^{N} w_i[y_i - F(x_{1i},\ldots,x_{ni}; b_1,\ldots,b_m)]^2 \qquad (2)$$

represents the sum of the square of the difference between the observed and calculated values with w_i a weighting value that can be applied to each of the observed values.

The function ϕ is a surface in the multi-dimensional parameter space $b_1,\ldots,b_m$. Figure 25-1 is an example of a two-dimensional surface. Note the surface can have local maxima and minima as well as a global minimum. The minimum, for a given set of observations y_i and known model parameters x [$x=(x_{1i},\ldots,x_{ni})$] represents the best fit, in a least squares sense, of the model to the observations. The values of b [$b=(b_1,\ldots,b_m)$] at this minimum are by definition the parameters of the best fit.

If F is a linear function of the unknown parameters b, then ϕ has at most one minimum which can be computed using standard least squares methods. Indeed the function ϕ is a quadratic function of the parameters b, that is the surface generated by ϕ is a parabola of revolution.

This is not the case when F depends non-linearly on the b parameters. A number of methods have been developed to locate the minimum when the parameters are non-linear. The most common methods compute the gradient of ϕ with respect to each of the parameters b_j. Figure 25-2 represents a hypothetical ϕ surface when F is a function of a single non-linear parameter b. The procedure to find the minimum is roughly as follows: an initial value (guess) of the parameter b (b^0) is made and the function computed, that is (b^0). In Figure 25-2, the initial guess for b^0 is at point A where the gradient is large and positive. To obtain a value of ϕ that is closer to the minimum at E a new value of b (b^1) is determined by computing an incremental change of the parameter b (Δb) from the gradient ($d\phi/db$) and algebraically adding it to b^0 ($b^1 = b^0 + \Delta b$).

If Δb is large enough, it will bypass the local minimum at D to end up at point B on the curve. If b is small, it will end up at point C. One can imagine a succession of small values of Δb that converges to the point D. Consequently, judicious choice of Δb is required in order for this method to converge to the correct minimum at E. The size and algebraic sign of Δb for each successive iteration are determined from the size and direction of the gradient. Although the procedures are simplified in this example, they graphically illustrate how the method works.

The algorithm used for inversion throughout the remainder of this paper is the Marquardt algorithm (Marquardt, 1963; Tabat and Ito, 1973; Anderson, 1979). It determines the best fit using the above gradient concepts. The Marquardt algorithm also incorporates a Taylor expansion to linearize the non-linear parameters. A Taylor series is a power series expansion of a function in terms of the change in the parameters b_j (Δb_j). It reduces to the linear terms, in other words all terms higher than first order are negligible, when the Δb_j are sufficiently small. The Marquardt algorithm was chosen simply because it has proved to be robust, that is it converges to the same point for any reasonable initial guess, and is relatively easy to use. The interested reader can read further on inversion methods in

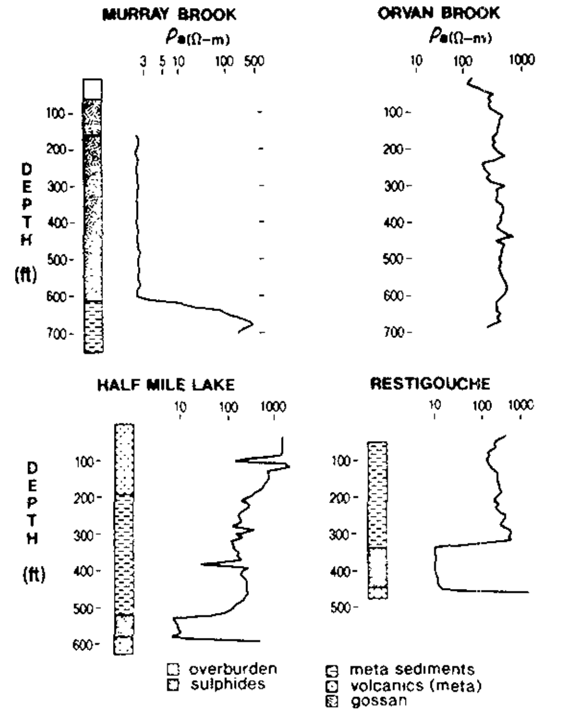

Figure 25-3. Resistivity logs from four massive sulphide deposits in New Brunswick.

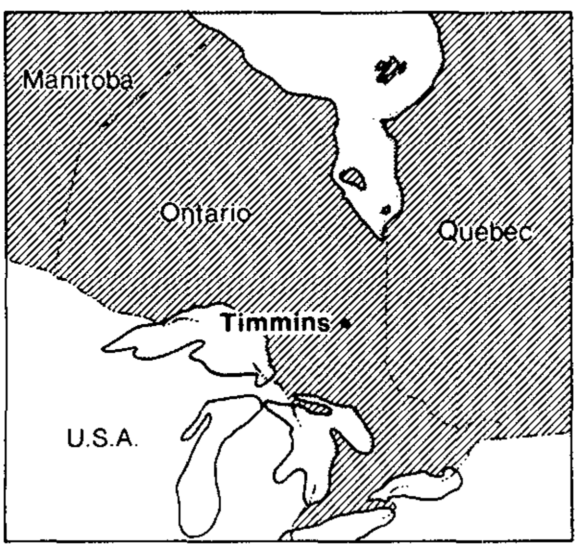

Figure 25-4. Location of Timmins clay belt region.

Rosenbrock (1960), Powell (1964, 1965), Jackson (1979) and the references therein.

RESISTIVITY CHARACTERISTICS OF MASSIVE SULPHIDES AND HOSTROCKS

Massive sulphide orebodies are found in a wide range of geological environments of varying ages. Their resistivity varies from a few ohm-metres to parts of an ohm-metre, depending on the connectivity of the sulphides. Resistivity logs were run through a number of volcanogenic massive sulphide deposits from the Bathurst mining camp in northern New Brunswick, Canada and their associated hostrocks (Figure 25-3). These logs were obtained using the mise-a-la-mass technique (Grant and West, 1965).

Some important results, typical of most volcanogenic environments, can be observed on the logs. The massive sulphide resistivities are between 1 and 10 ohm-metres. This can be related to the scale of connectivity of the sulphides. Most sulphide bodies are not continuously massive but consist of interconnected sulphide stringers and zones. Different scales of connectivity exist from microscopic to macroscopic. For example, the resistivity of a core may be significantly different than the bulk resistivity of a sample that includes several tens of cubic metres of the sulphide zone. This scaling relationship is related to fractals and nonlinear dynamics and is an intrinsic property of a particular sulphide zone. See the recent paper by Ruffet *et al.*(1991) for an example.

The resistivity of the volcanic rocks in Figure 25-3 is greater than 1000 ohm-metres while the resistivity of the metasedimentary rocks is between 100 and 1000 ohm-metres, results which are consistent with other volcanic environments throughout the world.

The large contrast between sulphide and hostrock conductivities is precisely why EM prospecting systems were successful in locating massive sulphide deposits in the past. Good sulphide conductors generate an EM anomaly easy to distinguish from background. Many of these anomalies have been located and drilled. No doubt there are still massive sulphide orebodies to be found, although opportunities to find the easy ones close to surface are decreasing.

Many potential massive sulphide volcanogenic environments are covered with overburden. For example, the overburden in the Timmins clay belt in Ontario, Canada (Figure 25-4) consists of clay, till, sand and gravel with thicknesses ranging from a few metres to several hundreds of metres. They cover known greenstone (volcanogenic) belts that contain economic massive sulphide deposits. Indeed, one of the largest massive sulphide orebodies in Canada (Kidd Creek) is in this region. In general, overburden-covered environments have not been as extensively explored as areas of exposed volcanic rocks.

In 1973, Shell Canada Limited evaluated the effectiveness of a number of AEM systems on the market at that time (Best, 1985). The bedrock conductors associated with targets 16 to 23 (Figure 25-5) were used in the evaluation to investigate the effects of thick and variable overburden on bedrock conductor responses. The sulphide and graphite conductors were drilled based on the original ground EM (Turam) surveys. Shell supplemented these data with resistivity soundings and ground EM surveys.

Figure 25-6 is a detailed map of the region surrounding targets 16 to 20. The location of the resistivity soundings, labelled ES, and an interpreted resistivity section (Figure 25-8) going from ES-09 to ES-11, based on the soundings and drilling, are shown on the map. Figure 25-7(a) is one of

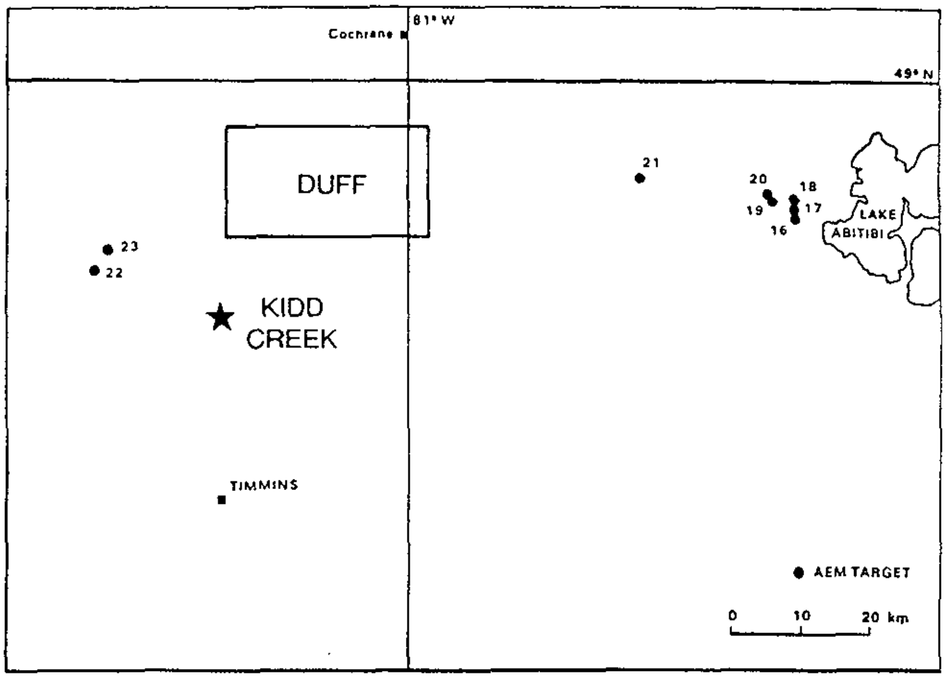

Figure 25-5. Location of targets 16 to 23, Kidd Creek mine and Duff project area.

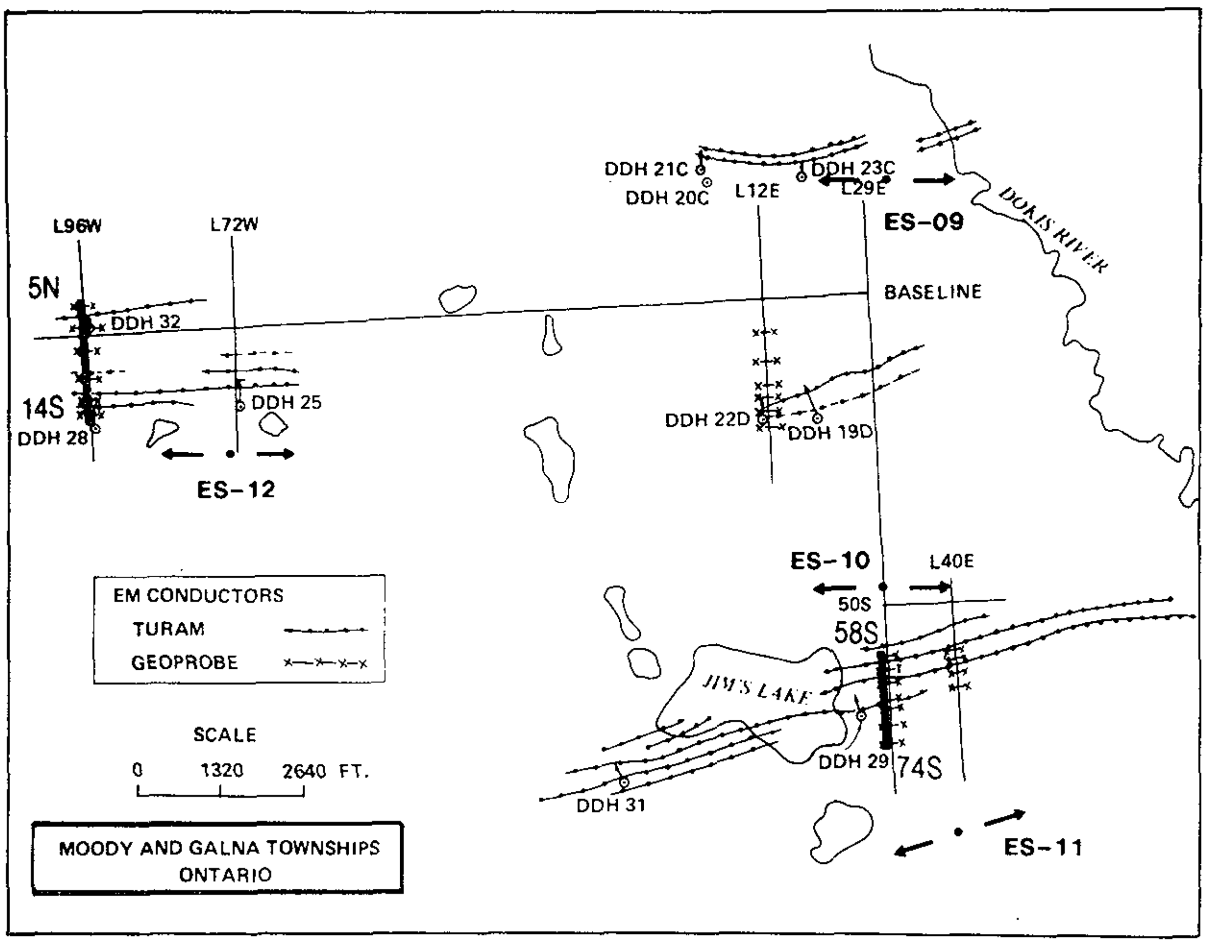

Figure 25-6. Detailed location of targets 16 to 20.

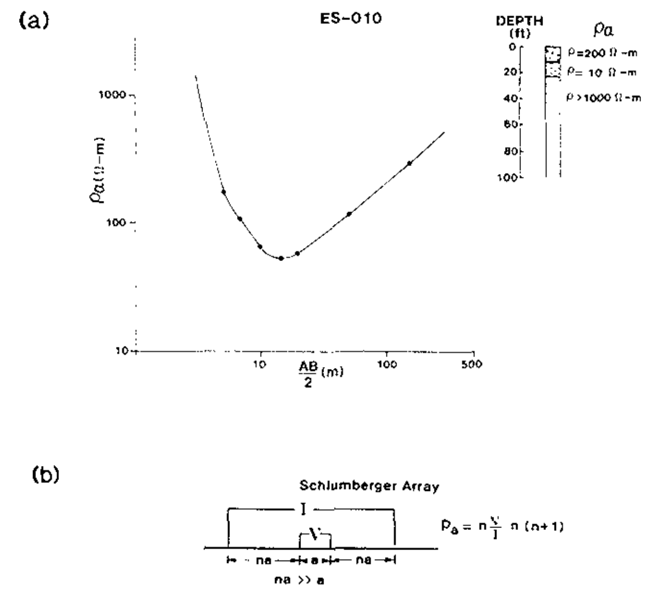

Figure 25-7. (a) Schlumberger resistivity sounding (ES-010)
(b) Geometry of Schlumberger array.

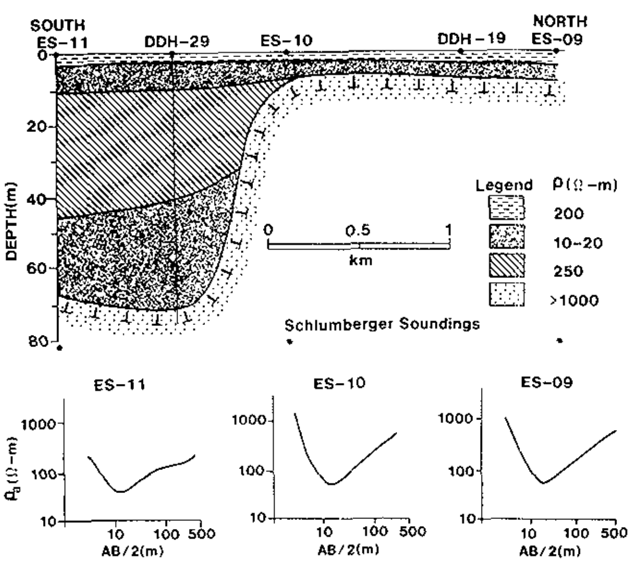

Figure 25-8. Resistivity section along line with drill hole 29 and sounding ES-010.

the Schlumberger resistivity soundings (ES-10) and the corresponding three-layer interpretation. The geometry of the Schlumberger array is illustrated in Figure 25-7(b). The bedrock resistivity is greater than 1000 ohm-metres indicating it is volcanic in origin. Indeed, the two drill holes along the section confirm this observation. The overburden consists of a 10-foot (3-metre) resistive layer of 200 ohm-metre material at the surface with a 4-metre conductive layer of 10 ohm-metre material above the bedrock. The resistivity section is not unusual in the Timmins area.

The first few metres of overburden are resistive along the entire section. A 10 ohm-metre conductive layer, varying in thickness between 3 and 10 metres, underlies this resistive layer. In the northern portion of the section, the overburden is about 10 metres thick increasing to 60 metres or more to the south. The change in thickness occurs abruptly near drill hole 29. In the southern part of the section, two additional layers occur beneath the two layers described above. Although the geological logs for the drill holes on this section do not describe the overburden lithology, they do confirm the total thickness of overburden is close to that predicted from the resistivity data.

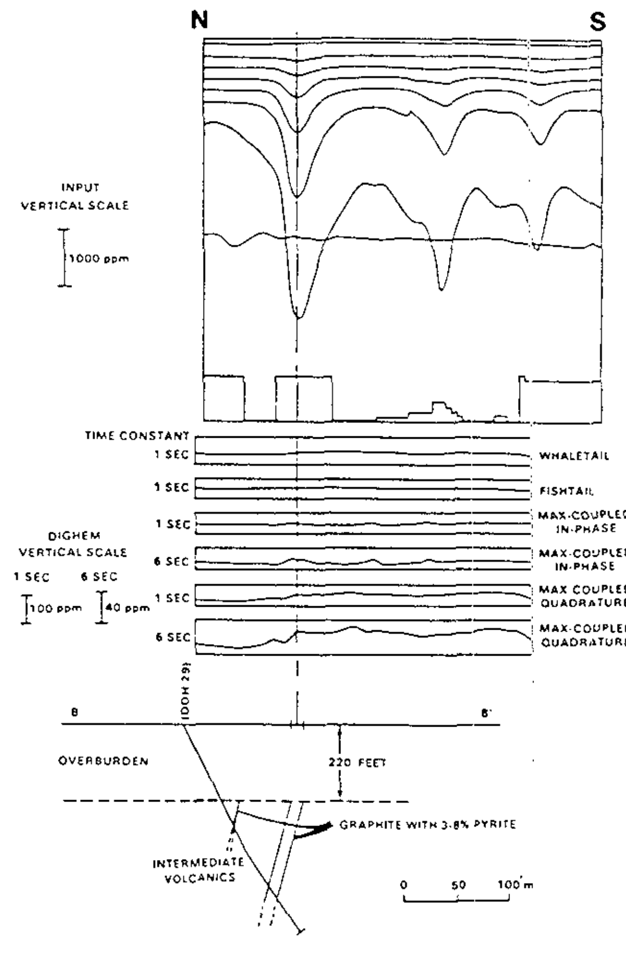

Figure 25-9. Input and Dighem responses over drill hole 29.

Input and Dighem AEM responses along the same section are presented in Figure 25-9. The short-time channel of the Input system and the maximum coupled quadrature response of the Dighem system both increase in amplitude south of drill hole 29, consistent with the thicker overburden. The bedrock conductor appears to be associated with the abrupt change in basement depth which is most likely associated with different basement lithologies.

A ground EM survey using the Geoprobe system (Figure 25-10) was conducted over that portion of the section in Figure 25-9 near drill hole 29. The Geoprobe system's transmitter consists of a circular loop on the ground approximately 10 metres in diameter. In this survey the in-line horizontal and the vertical magnetic fields were measured at twelve frequencies from 20.9 hertz to 30.1 kilohertz. A transmitter-receiver separation of 100 metres or more was

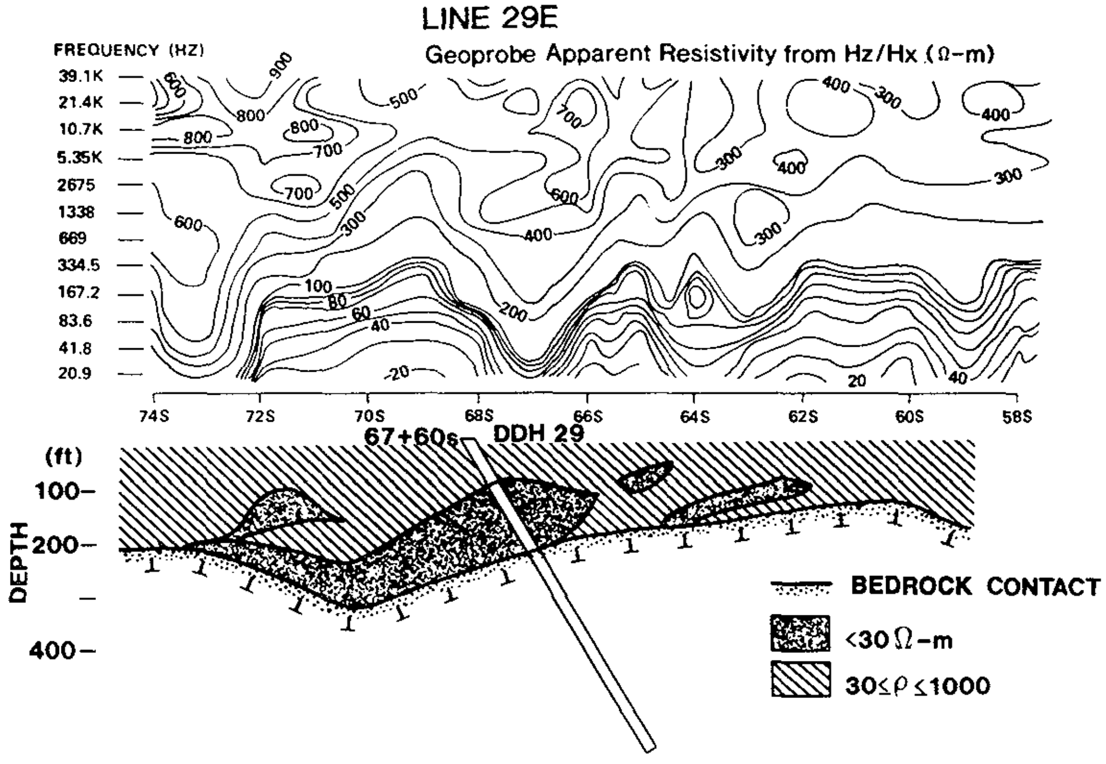

Figure 25-10. Geoprobe response over drill hole 29 and a rough interpretation using a layered earth model.

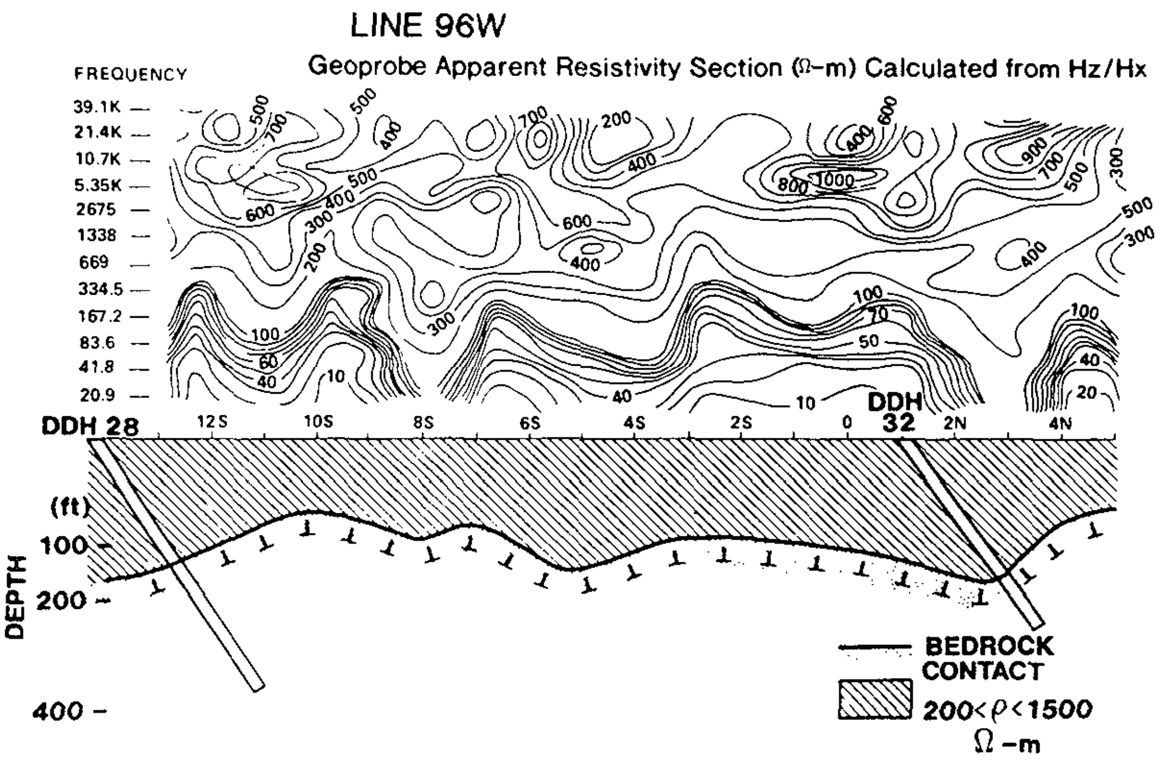

Figure 25-11. Geoprobe response along line 96W and a rough interpretation using a layered earth model.

used. This ensures that the transmitter can be approximated by a magnetic dipole (Best, 1992). The apparent resistivity was computed for each frequency and location (mid-point between the transmitter and receivers). A rough interpretation, based on a multi-layer earth model at each location, indicates the overburden is about 60 metres thick. This is consistent with the other data. The interpretation did not pick up the upper conductive layer but did pick up the deeper more conductive layer. The bedrock conductor at drill hole 29 can easily be observed at location 67S, although the bedrock resistivity could not be calculated because a layer model was used. The Geoprobe data along line 96W (Figure 25-11) indicates the overburden in this area is not as conductive. This is consistent with the interpretation from sounding ES-12 shown in Figure 25-12. Again, the strong bedrock conductors located at drill holes 28 and 32 are easily observed in these data.

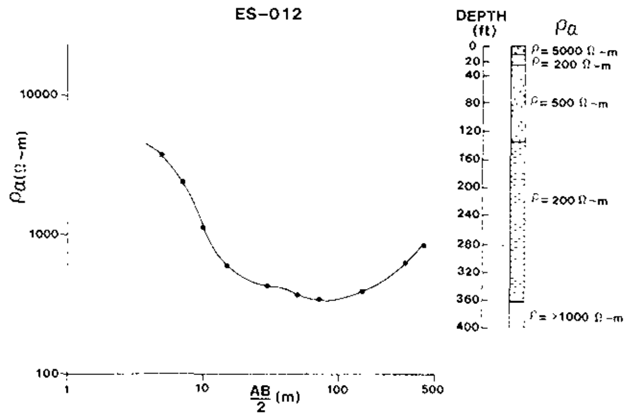

Figure 25-12. Schlumberger resistivity sounding (ES-012).

Shell Canada generated a bedrock geology map (Figure 25-13) under the Quaternary overburden (the area labelled Duff in Figure 25-5) as part of a regional study to delineate areas suitable for massive sulphide exploration. The bedrock geology was obtained from the drill holes shown on the figure and from interpretation of the airborne magnetic data available in the area.

This map, in conjunction with bedrock depths obtained from the drill holes, demonstrates a relationship that exists between bedrock lithology and bedrock depth (overburden thickness). As a general observation the depth to basement is shallow (0-30 m) for gabbros, peridotites, andesites and basalts and deeper (greater than 30 m) for rhyolites and metasediments. This observation is perhaps not surprising as rhyolites and metasediments weather easier than the other rocks. These results are consistent with the observations that depth to bedrock is variable and bedrock conductors are often associated with changes in overburden thickness due to lithology changes. Resistivity mapping can provide estimates of depth to bedrock while magnetic mapping can provide information on lithology. The combination of the two

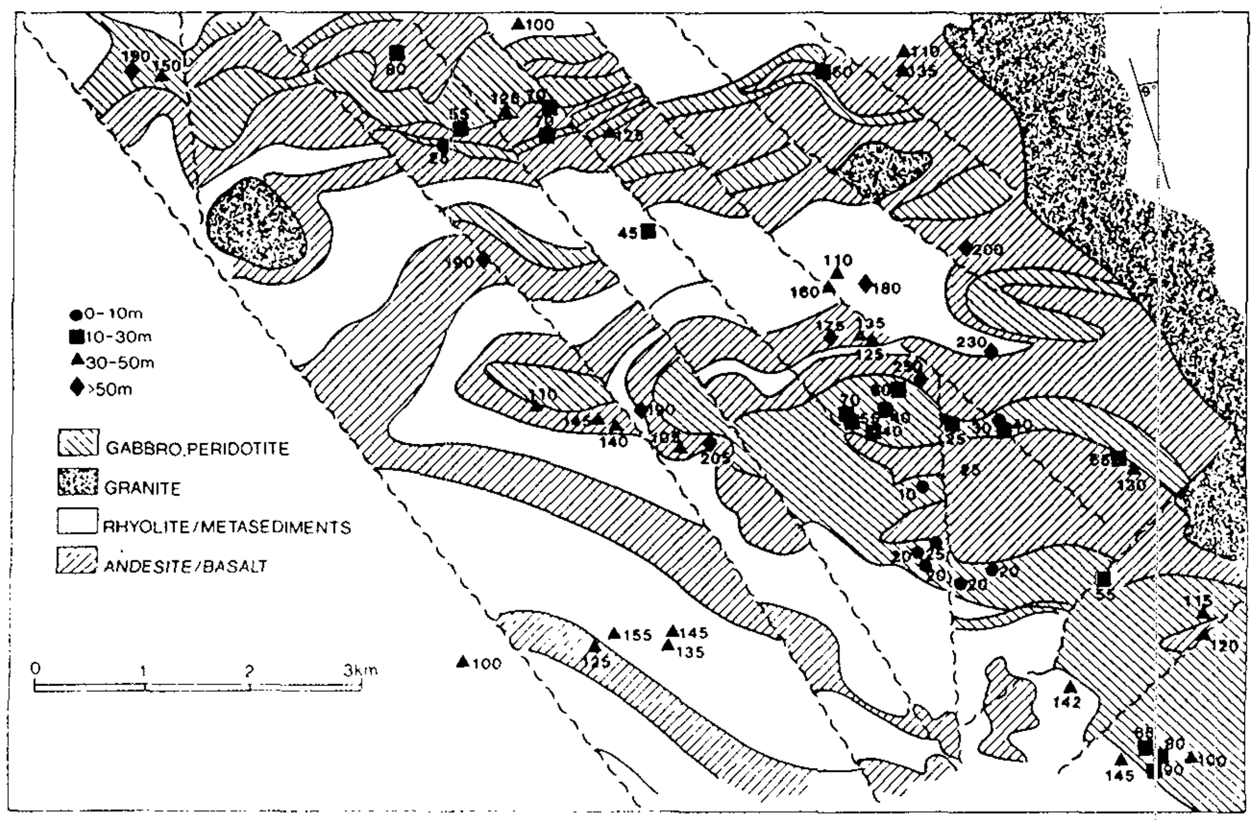

Figure 25-13. Geological map of Duff project area, together with depths of overburden at drill hole locations.

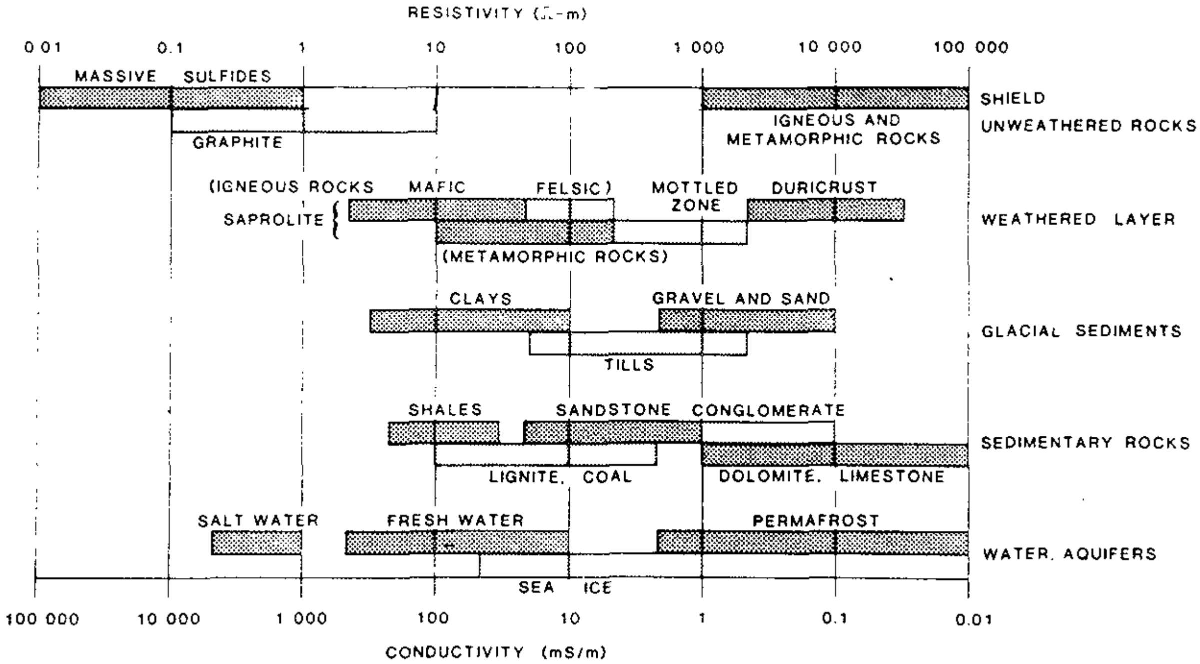

Figure 25-14. Typical resistivity ranges of rocks and unconsolidated sediments.

approaches can provide an effective method for mapping bedrock lithology in areas where there are limited outcrop and drilling data.

RESISTIVITY CHARACTERISTICS OF UNCONSOLIDATED SEDIMENTS

As noted earlier, many mineral provinces containing volcanic environments suitable for massive sulphide deposits are covered with unconsolidated sediments. These sediments vary in composition from glacial till in northern regions to lateritic deposits in equatorial regions. In this section we investigate the resistivity characteristics of the Quaternary sediments in the Timmins clay belt in more detail. The excellent work carried out by Palacky and his co-workers (Palacky, 1988, 1989, 1991; Palacky and Stevens, 1990, 1991) provide the basis for this investigation.

Typical conductivity ranges for glacial sediments (*viz.* clay, till, sand and gravel), are given in Figure 25-14. They were obtained by averaging samples from many different regions. On the other hand, a given region can be expected to have conductivity ranges characteristic of the local bedrock source and chemistry of the pore water. Consequently Quaternary sediments in the Timmins clay belt should have unique resistivity characteristics related to the region.

Palacky and his co-workers obtained conductivity data at the locations shown in Figure 25-15. The 70 locations were selected from helicopter AEM transects flown to locate areas of thick Quaternary overburden. The transects were along or near roads in order to reduce the costs for ground EM follow-up and drilling. One transect went from Smokey Falls to Timmins via Fraserdale and Smooth Rock Falls, the other extended north and south of Kapuskasing from Gurney Lake to hole 22. During their investigation they encountered a wide variety of Quaternary sediments and many bedrock features such as fractures and sulphide or graphite conductors. Note the area covered in Figure 25-15 overlaps the area covered in Figure 25-5.

Ground follow-up employed the Apex MaxMin EM system, a horizontal loop EM (HLEM) system, on all targets except numbers 44 to 46. It is a horizontal coplanar EM system operating at fixed frequencies of 110, 220, 440, 880, 1760, 3520, 7040, and 14080 hertz. The coil separation and station spacing were fixed at 100 metres and 25 metres respectively for the entire follow-up program. In-phase and quadrature values were measured at all eight frequencies, for quantitative interpretation. The instruments were carefully calibrated and topographic corrections were made in hilly regions in order to obtain data that could be used for absolute resistivity measurements.

The interpretation of multi-frequency EM data over a layered earth can be carried out either with Argand diagrams (Eadie, 1979) or with EM inversion techniques (Hohmann and Raiche, 1988; West and Bailey, 1989). Argand diagrams consist of in-phase and quadrature values plotted at a number of discrete frequencies at a given location (Figure 25-22). Palacky and Stevens (1990) made use of the Marquardt algorithm discussed earlier (Marquardt, 1963; Inman, 1975). The algorithm can be used either unconstrained, where all unknown parameters are allowed to vary, or constrained where one or more of the parameters have fixed values.

Figure 25-16 is an example of MaxMin in-phase and quadrature profiles from this study. The profiles, over target 17, which is along the helicopter transect from Gurney Lake to hole 22 south of Kapuskasing, will be used to illustrate the inversion method. The in-phase responses are positive on all frequencies except 14 080 hertz while the quadrature responses are negative at the highest three frequencies (3520, 7040 and 14 080 Hz); indicating the presence of conducting overburden (clay). The changes in quadrature and

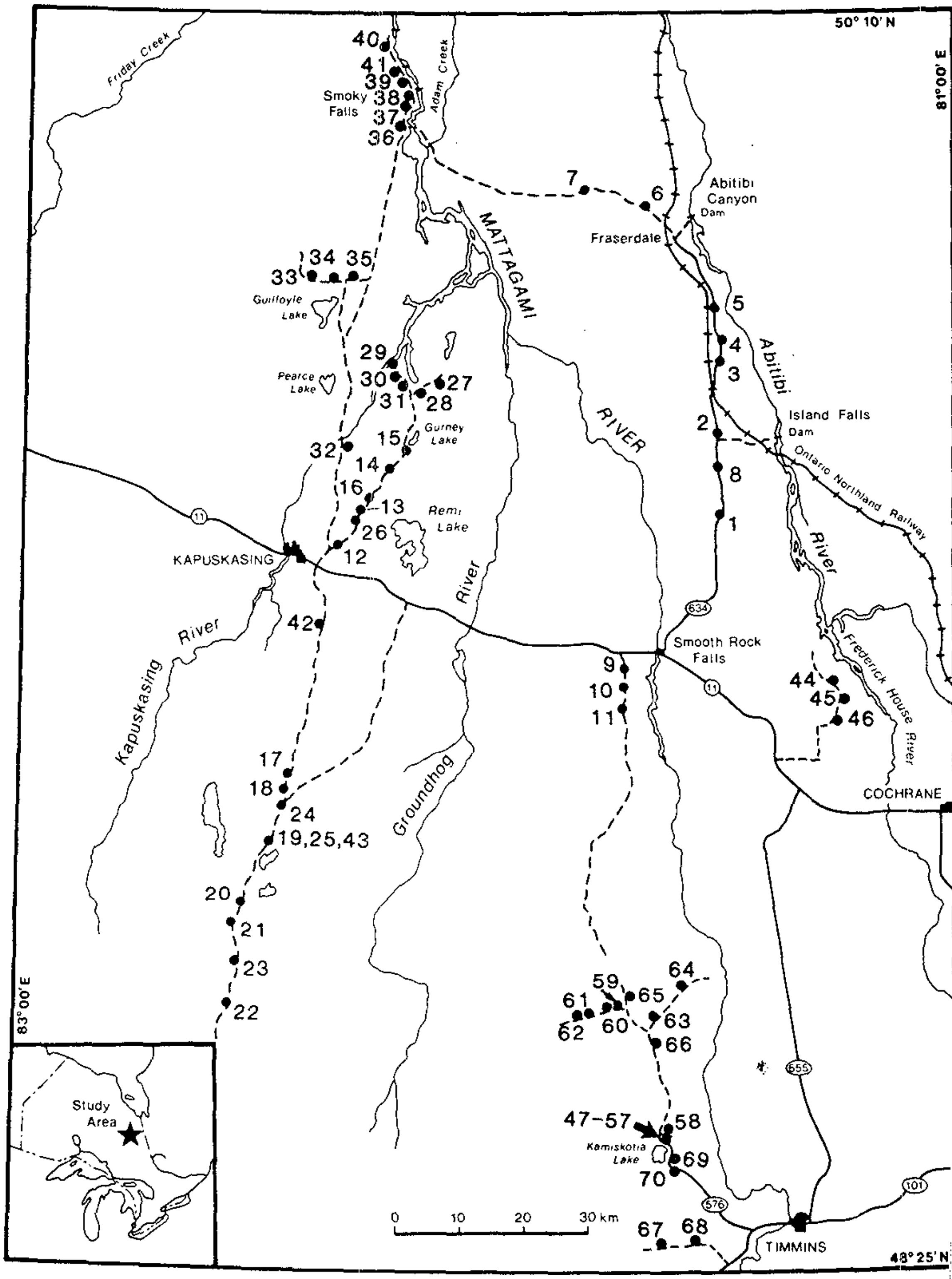

Figure 25-15. Location of Quaternary test sites (from Palacky and Stevens, 1990).

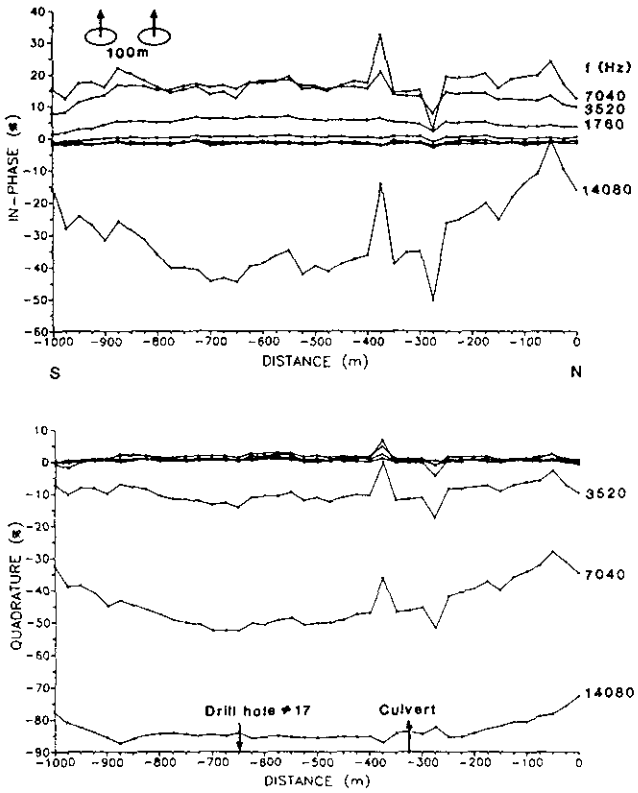

Figure 25-16. Results of MaxMin survey over a bedrock depression (location 17 in Figure 25-15).

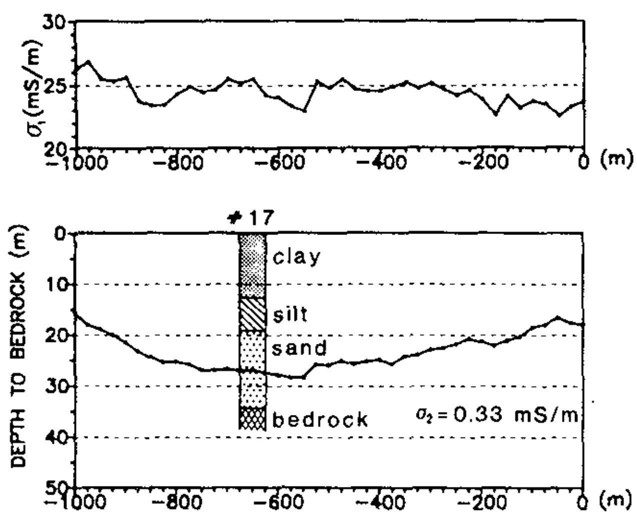

Figure 25-17. Overburden conductivity and depth to bedrock profiles obtained by ridge regression inversion of the MaxMin data in Figure 16. Drilling results are shown at position 650 m (from Palacky and Stevens, 1990).

in-phase values along the profiles indicate the overburden has a variable thickness. The result of inverting all the data in Figure 25-16 (16 data points at each station, 8 in-phase and 8 quadrature) is shown in Figure 25-17. In this case the overburden was represented by a single layer with unknown thickness and conductivity and the basement conductivity was fixed at 0.33 millisiemens per metre (3000 ohm-metres). The inversion is nearly insensitive to the value of basement resistivity so any realistic resistivity value is acceptable for volcanic basement. The Marquardt algorithm therefore estimated the overburden thickness and conductivity. The inversion was stable, with estimates of conductivity between 23 and 27 millisiemens per metre along the profile. The root mean square error averaged 2.8% after six iterations with no significant variation along the profile.

Drill hole 17 (location 650 m) intersected 12 metres of massive clays, 6 metres of silt and varved clays, and 17 metres of sand for a total depth to bedrock of 35 metres. This depth is 8 metres deeper than predicted from the constrained inversion. A three-layer overburden model mimicking layer thicknesses of 12, 6 and 17 metres for the clay, silt and sand thicknesses, respectively, was inverted using the sixteen observations at drill hole 17. The inversion generated layer resistivities of 56 ohm-metres (17.9 mS/m) for clay, 13 ohm-metres (76.9 mS/m) for silt, and in excess of 10 000 ohm-metres (0.1 mS/m) for sand and bedrock. The above example points out the difficulties with inversion if *a priori* geological knowledge is not available. The actual overburden layering would be difficult to determine from EM alone without some indication of overburden composition. More details can be found in Palacky and Stevens (1990), and the references therein.

In addition, resistivity profiles were generated utilizing the helicopter AEM data. An example of composite AEM profiles for the helicopter transect going from target 17 to 24 is illustrated in Figure 25-18. The composite profiles were generated by averaging the profiles of the two lines flown in opposite directions along the transect. They consist of in-phase and quadrature data for horizontal coaxial coils at 935 and 4600 hertz and in-phase and quadrature data for vertical coplanar coils at 4175 hertz and 32 kilohertz. The separation between the coils is approximately 10 metres and the coil height above ground is approximately 30 metres.Target 17 corresponds with the clay-filled depression indicated on the composite profile. The HLEM responses for the bedrock conductors (target 18) and the shear zones (target 24) indicated on the profile are shown in Figures 25-19 and 20, respectively. The four responses seen on the helicopter EM profiles in Figure 25-18 have characteristic horizontal loop EM responses for a shear zone with trough-like anomalies that are wider on quadrature than in-phase data.

Drill hole 18 (location 550 m) intersected 8.5 metres of sand and clay before intersecting bedrock. The two anomalies (locations 275 m and 515 m) seen on the HLEM profiles of Figure 25-20 have the characteristic shape and frequency response of bedrock conductors. Drill hole 24 (located at 500 m) intersected 6 metres of poorly sorted sediments, 14 metres of sand and 15 metres of till but missed the narrow basement conductor by approximately 15 metres.

The two apparent conductivity profiles in Figure 24-18 were computed using the horizontal coplanar data at 4175 hertz and 32 kilohertz in conjunction with a thick horizontal layer model. The clay-filled depression at the north end of the profile shows up as a conductivity high (5 to 10 mS/m). The two bedrock conductors appear as a broad conductivity high with values between 7 and 10 millisiemens per metre

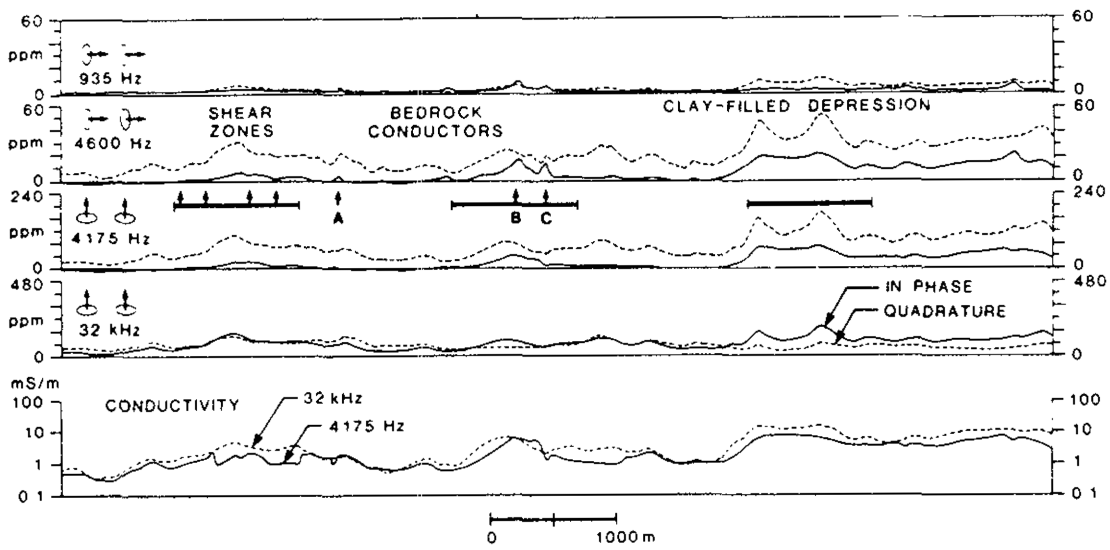

Figure 25-18. Composite profile of helicopter AEM data (in-phase and quadrature components at four frequencies, two coil configurations) and calculated conductivity based on horizontal coplanar data. This section goes from target 17 to target 24 in Figure 25-15.

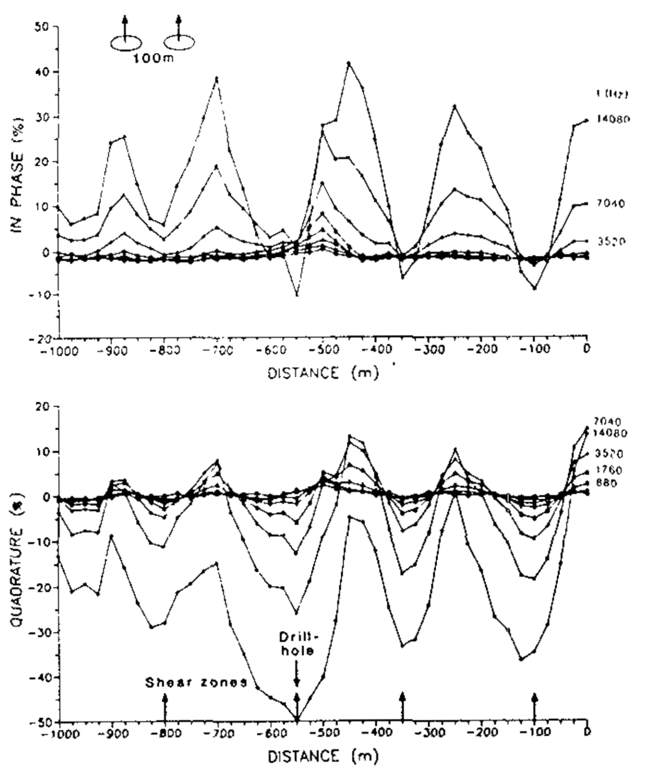

Figure 25-19. MaxMin data at all eight frequencies. The location of the follow-up survey for these shear zones is indicated in Figure 17 and corresponds to target 24 in Figure 25-15.

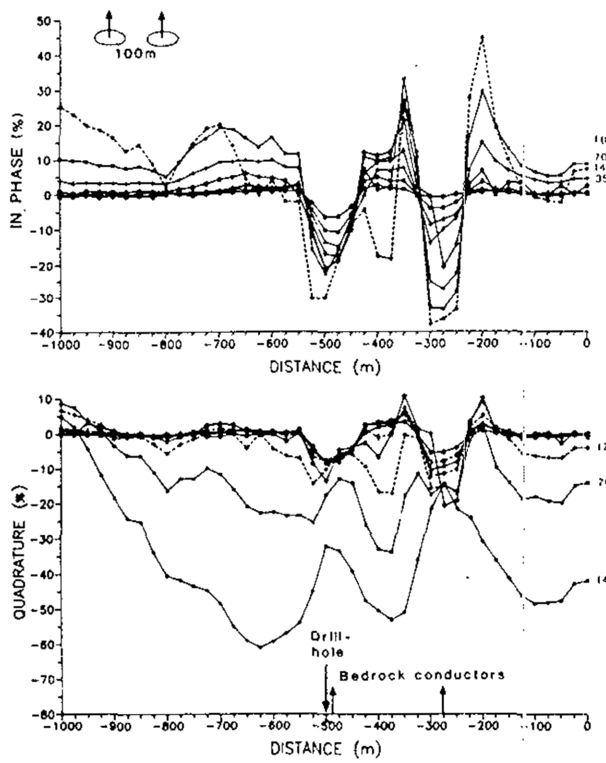

Figure 25-20. MaxMin data at all eight frequencies. The location of the follow-up survey for these two bedrock conductors is indicated in Figure 18 and corresponds to target 18 in Figure 15.

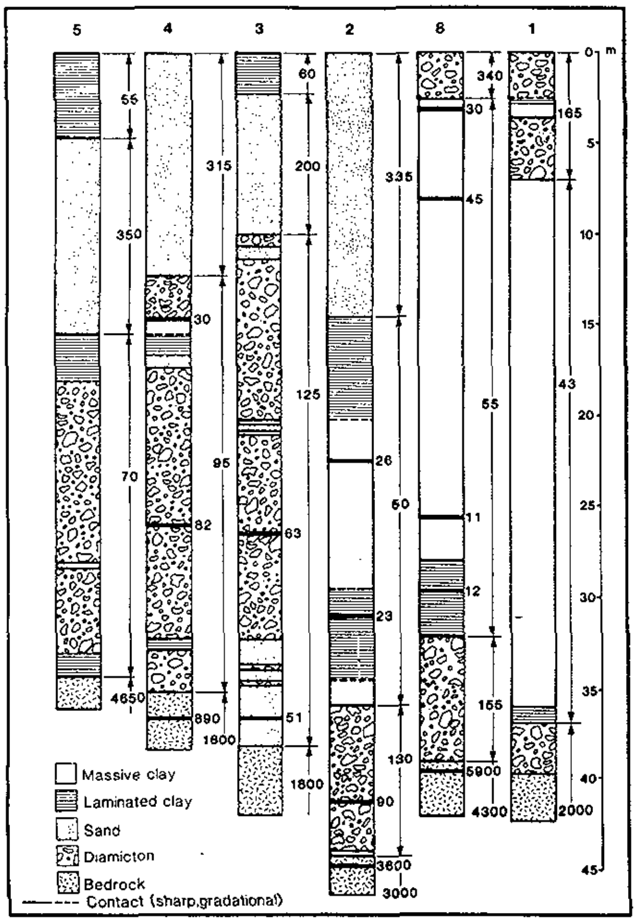

Figure 25-21. Stratigraphic logs of holes along the Fraserdale - Smooth Rock Falls transect. Numbers between arrows indicate resistivities (-m) which were determined as the best fit to the HLEM data. The actual thicknesses of the indicated layers on the logs were used as fixed parameters in the inversion. Numbers next to the horizontal lines are resistivities determined in the laboratory on core samples.

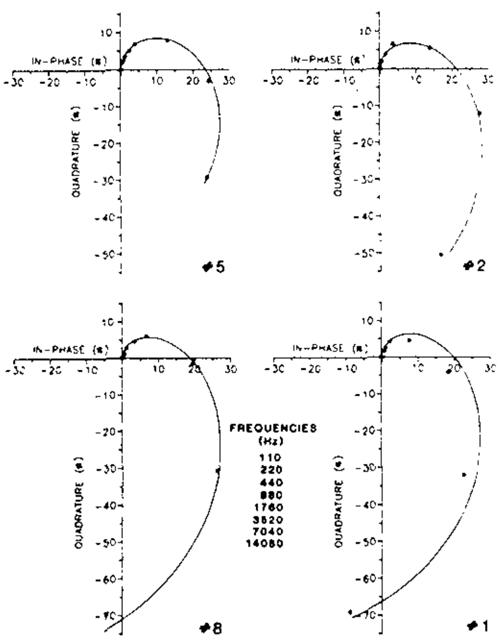

Figure 25-22. Argand diagrams displaying the HLEM observations (stars) and the responses from the best fit (solid curves) for locations 1, 2, 5 and 8. The layer parameters are given in Figure 25-20.

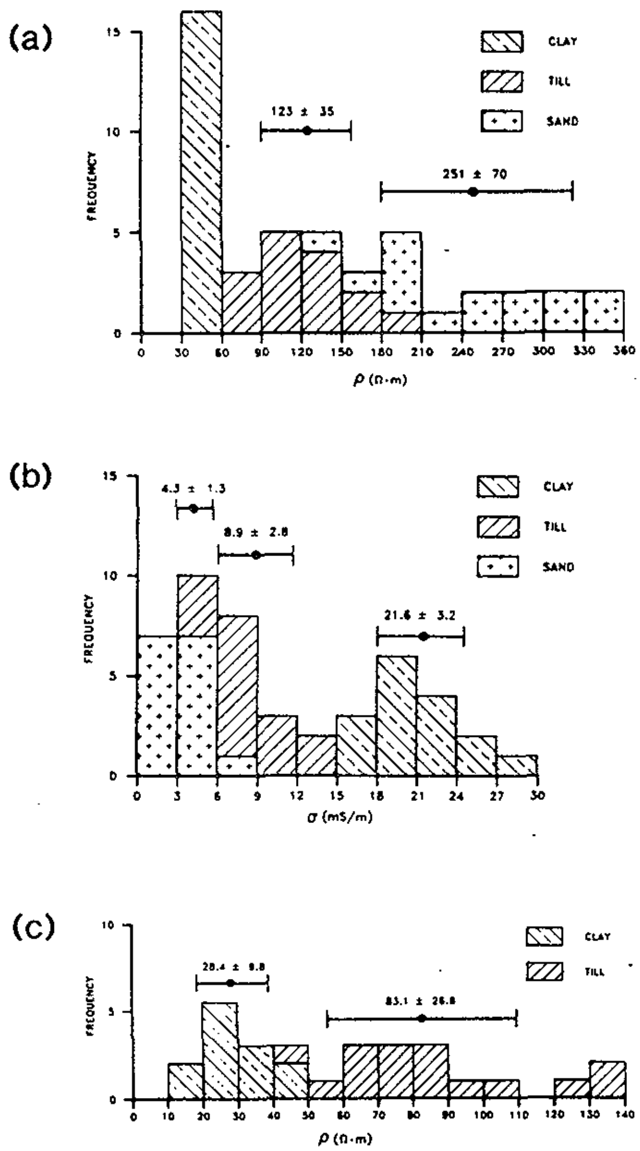

Figure 25-23. (a) Histogram of resistivities obtained from inversion of HLEM data over drill holes with clay, till and sand. Numbers indicate mean standard deviations. Forty six samples were used in this analysis, (b) Histogram of conductivities for the same data in part (a). (c) Histogram of resistivities determined in the laboratory on core samples. Measurements were carried out on 13 clay samples and 16 till samples.

on the low and high frequencies. As expected the conductivity profiles tend to echo the coplanar data from which they were derived.

A selected number of the 70 drill sites were used to estimate the conductivities of clay, till, and sand and gravel. The layer thicknesses of each unit (if they were greater than 2 m) were fixed and the HLEM data was used to obtain the best fit for each of the layer conductivities by using the inversion procedures outlined earlier. Figure 25-21 is an example showing six drill holes along the Fraserdale - Smooth Rock Falls transect. The resistivities obtained from the inversion are shown in the figure together with the resistivities of selected core samples obtained by laboratory measurements. The resistivity of sand determined from this study ranged from 200 to 350 ohm-metres, till from 70 to 165 ohm-metres, and clay from 43 to 60 ohm-metres. The resistivities from the core samples are generally lower than those obtained from the inversion. Figure 25-22 displays the data and the best fit in the form of Argand diagrams.

A statistical analysis of the resistivity obtained from these inversions, that is layer thicknesses fixed using the stratigraphic logs, was carried out by Palacky and Stevens (1990). Drill holes with more than four lithologically distinct layers were not used because the inversion process is less reliable in areas of complex layering. Histograms of the resistivities obtained from the inversion, as well as from core measurements, are shown in Figure 25-23. These results indicate clay, till and sand resistivities in the Timmins region investigated by this study have narrow, well defined ranges. Resistivity mapping may therefore be an effective tool for determining sediment lithology.

SUMMARY

This paper has demonstrated the potential use of electromagnetic methods for mapping bedrock conductors beneath drift and for mapping and delineating overburden thickness and lithology. Different regions have different conductivity characteristics that depend on the type of material deposited, the underlying bedrock and the pore water in drift and bedrock. There is a large range of EM systems available today, each with its own resolution and depth of exploration. The limited examples presented can do no more than provide the reader with a cursory look at EM techniques. You are encouraged to use the references listed at the end of this paper to provide more detailed information.

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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.

By Daniel E. Kerr
Geological Survey of Canada

(Geological Survey of Canada Contribution 28093)

INTRODUCTION

Drift exploration in British Columbia has been hindered in many areas of high mineral potential by thick overburden sequences and poorly understood Quaternary history. Nevertheless, early drift exploration surveys such as those by White and Allen (1954) in the southern Okanagan area and Warren *et al.* (1957) in the Ashcroft-Kamloops region, for example, demonstrated the utility of geochemical sampling for mineral exploration. Despite these early geochemical successes, relatively few results of systematic drift prospecting surveys in British Columbia have since been published in scientific journals. However, over 9000 references exist in the form of British Columbia Ministry of Energy, Mines and Petroleum Resources (B.C.M.E.M.P.R.) assessment reports relating to geochemical sampling of soils, stream sediments and plants. In addition, many contain useful information relating to overburden type and thickness, as well as to geophysical and drilling data pertinent to many drift exploration techniques.

Geological, geochemical and geophysical data relating to drift exploration techniques have been summarized from assessment reports covering the southern half of the Manson River (93N) map area (Figure 26-1). This compilation is a response to the need for a greater awareness of the role of surficial geology in drift prospecting as a guide to mineral exploration. It is one example of how previously collected and readily available data can be used for planning and assessing the usefulness of geochemical sampling, assisting in geological interpretation, determining which reports to read, gauging levels and types of exploration by NTS sheet, and encouraging more field observations and recordings of Quaternary geology information. It is recommended that, prior to any fieldwork, similar summaries of assessment reports be undertaken by exploration companies in target areas.

METHODS

The region covered in this survey consists of eight NTS 1:50 000 map sheets in the southern half of the Manson River map area: 93N/01 to 93N/08. Numerous mineral exploration activities have been focused in this region, and many mineral discoveries are reported. The area has also received considerable attention from the mining industry following the discovery of the Mount Milligan porphyry copper-gold deposit. A total of 244 assessment reports were filed for this region between 1966 and 1991. These were reviewed and the 238 that contain data relevant to drift exploration were summarized. Compilation of data from assessment reports pertains to four general categories:

- *Quaternary geology*: overburden thickness and determination method, existance of surficial geology map, ice-flow directions and overburden type.
- *Geochemistry*: number of geochemical soil samples and soil horizon from which sample was taken, number of geochemical stream sediment samples, number of geochemical rock samples, number of biogeochemical plant samples.
- *Geophysics*: magnetic and electromagnetic surveys (expressed in line kilometres), resistivity and induced polarization surveys (also in line kilometres), ground *versus* airborne.

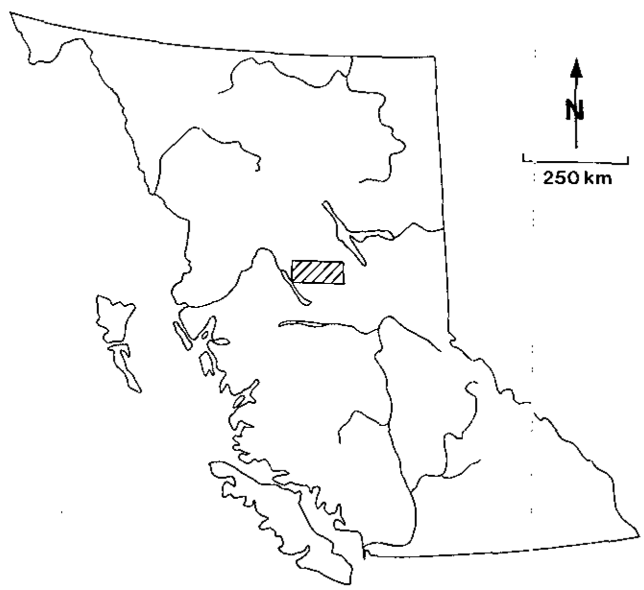

Figure 26-1. Study area, southern half of the Manson River (93N) map area.

TABLE 26-1
SUMMARY OF ASSESSMENT REPORT DATA

NTS 93N	NO. OF REPORTS	OVERBURDEN (m)	GEOCHEMICAL			GEOPHYSICAL		DRILLING (h, m)
			SOIL	SILT	R/BIO	MAG/EM (km)	R/IP (km)	
01E	33	<1 to 189	8373	209	798(R) 6(BIO)	8863.9	49.9	361 h 18188 m
01W	30	1 to 96	5375	10	485(R) 58(BIO)	4397.1	91.6	37 h 6616 m
02E	39	0 to 30	21175	216	237(R)	2298.0	148.8	3 h 345 m
02W	32	0 to 30	6330	178	225(R)	4327.4	280.1	52 h 4582 m
03E	16		3363	49	166(R)	155.2		
03W	1					106.0		
04E	1	3 to 83						157 h 6063 m
04W	4		598	39	32(R)			
05E	6	<1 to 9	949	58	68(R)			2 h 44 m
05W	4		306	9		37.0		
06E	25	>2 to 6	12946	696	103(R)	2566.6	37.4	9 h 82 m
06W	16	1 to 7	5075	331	455(R)	174.8	115.8	34 h 3225 m
07E	9	4 to 43	3867	192	554(R)	880.0	25.3	5 h 692 m
07W	24	<1 to 31	4511	44	226(R)	658.9	134.1	19 h 2674 m
08E	1			167	12(R)			
08W	2	4 to 17	140		454(R) 6(BIO)	1300.0	25.3	5 h 692 m

LEGEND FOR SUMMARY TABLE
NTS
NTS 1:50 000 map sheet designation for 93N
OVERBURDEN (m)
Reported range of overburden thickness in metres.
GEOCHEMICAL
Soil - Number of geochemical soil samples.
Silt - Number of geochemical stream sediment samples.
R/Bio - Rock/Biogeochemical samples.
(R) - Number of geochemical rock samples.
(BIO) - Number of biogeochemical plant samples.
GEOPHYSICAL (km)
MAG/EM (km) - Magnetic/electromagnetic surveys and extent in line kilometres.
R/IP (km) - Resistivity/induced polarization and extent in line kilometres.
DRILLING (hm)
h - Number of holes drilled.
m - Total length of core in metres.
ddh - Diamond-drill hole
pcdh - Percussion-drill hole

- *Drilling*: number of holes drilled and method, total length of core.

A brief review of regional physiography, bedrock geology and surficial geology is presented below. This is followed by an overview of data on Quaternary geology, geochemistry, geophysics and drilling for the eastern and western halves of each of the eight 1:50 000 map sheets in Table 26-1. The main drift exploration data are reported in Table 26-2.

Assessment reports and indexes in microfiche and diskette format are available from the British Columbia Ministry of Energy, Mines and Petroleum Resources in Victoria, as well as in the five District offices throughout the province: Vancouver, Kamloops, Cranbrook, Prince George and Smithers. Partial libraries are maintained in nineteen Gold Commissionerss offices, including Nanaimo, Merritt, Penticton, Revelstoke, Princeton, Kaslo, Trail and Vernon. Data products are also distributed through the British Columbia and Yukon Chamber of Mines in Vancouver. Other useful sources of data for mineral exploration include the Surficial Geology Map Index of British Columbia (Bobrowsky *et al.*, 1992) and Regional Geochemical Survey Database (Information Circular 1993-5) which lists provincial RGS database coverage by NTS map sheets. Additional regional till geochemistry survey data are also available for much of the Manson River (93N) and Fort Fraser (93K) region (Plouffe and Ballantyne, 1993).

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The Manson River map area falls within the Interior System of the Canadian Cordillera which can be further subdivided into the Interior Plateaus and the Omineca Mountains (Holland, 1976; Mathews, 1949). The Interior Plateaus consist of the Nechako Lowland and Plateau which vary from gently rolling to flat-lying terrain, ranging in elevation from 635 to 1515 metres. Bedrock geology is characterized by deformed sedimentary, metasedimentary, volcanic and igneous rocks of Permian to Cretaceous age (Nelson *et al.*, 1991a, b). Syenite, granodiorite and granitic intrusions of Jurassic age are also present. Extensive areas are capped by

TABLE 26-2
DRIFT PROSPECTING DATA (93N)
(KEY TO ABBREVIATIONS AT END OF TABLE 26-1)

NTS (93N)	REPORT	YEAR	PROPERTY	OWNER	OPERATOR	LATITUDE	LONGITUDE	MN NORTH MN EAST	COMMODITY	QUATERNARY GEOLOGY				GEOCHEMICAL			GEOPHYSICAL		DRILLING (m)
										OB (m)	MAP	ICE FLOW	OB TYPE	SOIL(h)	SILT	R/BIO	MAG/EM(km)	R&IP(km)	
01E	02412	69	"G" CLAIM GROUP	CYPRUS EX. CORP. LTD.		55° 6' 12"	124° 12' 36"	6106743 422796					D				MAGG 66.0	SURVEY DONE	
01E	04274	73	MOSQUITO CLAIMS	PECHINEY DEV. LTD.	PECHINEY DEV. LTD.	55° 9' 6"	124° 3' 42"	6111968 432342						115 (B)					
01E	04742	73	ZAP CLAIMS	PECHINEY DEV. LTD.		55° 9' 6"	124° 3' 42"	6111968 432342										SURVEY DONE	
01E	05175	74	MOSQUITO-ZAP CLAIMS	PECHINEY DEV. LTD.	PECHINEY DEV. LTD.	55° 9' 6"	124° 3' 42"	6111968 432342						433 (B)			MAGG 14.7	SURVEY DONE	
01E	05371	74	MOSQUITO-ZAP CLAIMS	PECHINEY DEV. LTD.	PECHINEY DEV. LTD.	55° 9' 6"	124° 3' 42"	6111968 432342		1 to 9(d)									4 ddh 529
01E	11951	83	PHIL 1 CLAIM GROUP		SELCO DIVISION-BP EX. LTD.	55° 8' 18"	124° 2' 42"	6110468 433381						295		22(R)			
01E	12912	84	PHIL A, B, & 1 CLAIM GROUPS	SELCO DIVISION-BP RESOURCES	SELCO DIVISION-BP RESOURCES	55° 7' 0"	124° 2' 0"	6108046 434089					D	1 175		123(R)			
01E	13508	85	PHIL 17 CLAIM	SELCO DIVISION-BP RESOURCES	SELCO DIVISION-BP RESOURCES	55° 11' 0"	124° 4' 0"	6115496 432077						64 (B)	27	5(R)			
01E	13891	85	MT. MILLIGAN CLAIM GROUP	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 10' 0"	124° 4' 0"	6113642 432048						192 (B)		8(R)			
01E	14377	86	PHIL 1-HASLINGER GRPS	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 7' 30"	124° 2' 0"	6108973 434103						638 (B)		503(R)	MAGG 47.7 EMGR 47.7	18.5	
01E	16966	88	MT. MILLIGAN PROPERTY	LINCOLN RESOURCES INC.	LINCOLN RESOURCES INC.	55° 7' 30"	124° 2' 0"	6108973 434103	Cu, Au	<1 to 24(d)									23 ddh 2 305
01E	17860	88	RAIN PROPERTY	BP MINERALS LTD.	BP MINERALS LTD.	55° 2' 0"	124° 3' 0"	6098789 432887	Cu				C, Mb, FG	108		7(R) 6(BIO)			
01E	17936	88	MT. MILLIGAN PROPERTY	UNITED LINCOLN RESOURCES INC.	UNITED LINCOLN RESOURCES INC.	55° 8' 0"	124° 4' 0"	6109933 431992	Cu, Au	6(d)									1 ddh 153
01E	18523	89	MT. MILLIGAN PROPERTY	UNITED LINCOLN RESOURCES INC.	UNITED LINCOLN RESOURCES INC.	55° 8' 0"	124° 4' 0"	6109933 431992	Au, Cu	2 to 39(d)									31 ddh 4 482
01E	19164	89	RAIN CLAIM GROUP	BP MINERALS LTD.	BP MINERALS LTD.	55° 2' 0"	124° 3' 0"	6098789 432887	Cu, Au								MAGA 120.0 EMAB 120.0		
01E	19268	89	MT. MILLIGAN PROPERTY	CONTINENTAL GOLD CORP.	CONTINENTAL GOLD CORP.	55° 8' 0"	124° 4' 0"	6109933 431992	Cu, Au				D				MAGA 694.0 EMAB 694.0		
01E	19296	89	NATION RIVER PROPERTY	PACIFIC SENTINEL GOLD CORP.	PACIFIC SENTINEL GOLD CORP.	55° 7' 0"	124° 12' 0"	6108216 423459	Cu, Au	131 to 189 (d)			Mb						3 ddh 701
01E	19585	89	BOW CLAIMS	COOKE-NATION SYNDICATE	HLX RESOURCES LTD.	55° 1' 0"	124° 7' 0"	5985736 426831					D				MAGG 17.2		
01E	19921	90	HEIDI LAKE PROPERTY	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 8' 0"	124° 7' 0"	6109982 428804	Cu, Au								MAGG 43.0 MAGA 425.0 EMAB 425.0		
01E	20007	90	GREG CREEK CLAIMS (GR)	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 13' 0"	124° 25' 0"	6119602 409866	Cu, Au					344 (B)					
01E	20205	90	WN-A CLAIM GROUP	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 10' 0"	124° 26' 0"	6114060 408692	Cu, Au					112 (B)					
01E	20227	90	NATION RIVER PROPERTY	CONTINENTAL GOLD CORP.	CONTINENTAL GOLD CORP.	55° 8' 0"	124° 4' 0"	6109933 431992	Cu, Au				D	745 (B)	15	23(R)	MAGG 80.8 EMGR 80.8		
01E	20280	90	LIP 1 CLAIM	D.L. COOKE/ R.U. BRUASET	BP RESOURCES CANADA LTD.	55° 5' 0"	124° 1' 0"	6104321 435099	Cu, Au					249 (B,A,C)		5(R)			
01E	20446	90	MT. MILLIGAN PROPERTY	CONTINENTAL GOLD CORP.	CONTINENTAL GOLD CORP.	55° 8' 0"	124° 2' 0"	6109901 434117		2 to 65(d)			F, FG, Mb						132 dh 2 528
01E	20853	90	SKIDOO PROPERTY	HIXON GOLD RESOURCES INC.	GOLDEN RULE RESOURCES INC.	55° 4' 0"	124° 7' 0"	6102564 428685			yes	SW	Mb	1 483 (B)		6(R)	MAGA 162.0 EMAB 162.0		
01E	20978	91	DOO CLAIMS	M.A. COOKE	D.L. COOKE & ASSOC. LTD.	55° 3' 0"	124° 5' 25"	6100683 430342					D				MAGA 95.0 EMAB 95.0		
01E	20979	91	[illegible]	M.A. COOKE	D.L. COOKE & ASSOC. LTD.	55° 6' 0"	124° 10' 0"	6106325 425554					D				MAGA 170.0 EMAB 170.0		
01E	21078	91	HEIDI LAKE PROPERTY	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 8' 0"	124° 7' 0"	6109982 428804	Cu, Au	3 to 46(d)									10 ddh 1 427
01E/02E	20899	91	WITCH PROPERTY	RIO ALGOM EX. INC.	RIO ALGOM EX. INC.	55° 9' 0"	124° 32' 30"	6112353 401750	Cu, Au			SW	D	92 (B)		84(R)		31.4	

NTS (93N)	REPORT	YEAR	PROPERTY	OWNER	OPERATOR	LATITUDE	LONGITUDE	MN NORTH MN EAST	COMMODITY	QUATERNARY GEOLOGY OB (m)	MAP	ICE FLOW	OB TYPE	GEOCHEMICAL SOIL(s)	SILT	R/BIO	GEOPHYSICAL MAG/EM(km)	R&IP(km)	DRILLING (m)
01E/08E	20859	90	MILL PROPERTY	HIXON GOLD RESOURCES INC.	GOLDEN RULE RESOURCES LTD.	55° 16' 0"	124° 8' 0"	6124836 427982			yes	W, SW	FG, Mb	2 328	167	12(R)	MAGA 1 324.0 EMAB 1 324.0		
01E/04E	19121	89	MT. MILLIGAN PROPERTY	CONTINENTAL GOLD CORP.	CONTINENTAL GOLD CORP.	55° 8' 0"	124° 2' 0"	6109901 434117		3 to 83(d)			Mb, FG						157 dh 6 063
01E/04W	20416	90	BEE CLAIM GROUP	CONTINENTAL GOLD CORP.	CONTINENTAL GOLD CORP.	55° 2' 0"	124° 5' 0"	6098821 430757									MAGA 523.0 EMAB 523.0		
01E/04W	21089	91	PHILIPS LAKE PROPERTY	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 3' 0"	124° 0' 0"	6100597 436109					D				MAGA 720.0 EMAB 720.0		
01W	01119	67	CHUCHI 1&2 GROUPS	ROYAL CANADIAN VENTURES LTD.	ROYAL CANADIAN VENTURES LTD.	55° 13' 36"	124° 28' 24"	6120789 406285			yes			267 (B)			MAGG 34.7		
01W	01215	68	JAY CLAIM GROUP	TRO-BUTTLE EX. LTD.		55° 12' 54"	124° 30' 0"	6119527 404561						392 (B)					
01W	01660	68	CHUCHI GROUP	ROYAL CANADIAN VENTURES LTD.		55° 13' 36"	124° 28' 24"	6120789 406285										20.7	
01W	03406	71	KING GROUP	KING-BELL RESOURCES LTD.	AMBASSADOR MINES LTD.	55° 7' 0"	124° 25' 0"	6108475 409640		2 to 9(s)			Mb	157 (B,A)			MAGG 2.4		
01W	03468	70	EVE GROUP	CANWEX EX. LTD.		55° 10' 6"	124° 28' 24"	6114299 406148						240 (C)					
01W	09705	81	WIT-MINERAL CLAIM	TITAN RESOURCES LTD.		55° 13' 36"	124° 28' 24"	6120789 406285	Pb, Zn, Ag					239 (B)		15 (R)			
O1W	17793	88	MITZI 1&2 CLAIMS	RICHARD HASLINGER	PLACER DOME INC.	55° 7' 2"	124° 25' 36"	6108550 409004						45 (B)		17(R)			
01W	19184	89	MITZI 1&2 CLAIMS	RICHARD HASLINGER	NORANDA EX. CO. LTD.	55° 7' 30"	124° 27' 30"	6109457 407002	Cu, Au					176 (B)					
01W	19365	89	GOLDFINGER CLAIM GROUP	S.C.M. SERVICES LTD.	C.E.C. ENGINEERING LTD.	55° 12' 0"	124° 23' 0"	6117705 411950	Cu, Au					97 (B)		19(R)			
01W	19926	90	MITZI1-4, TT1-2 &WS1-6 CLAIMS	R. HASLINGER/ NORANDA EX. CO.	NORANDA EX. CO. LTD.	55° 7' 30"	124° 27' 30"	6109457 407002	Cu, Au					950 (B)		43(R)		6.4	
01W	19950	89	AOK CLAIMS	WILLIAM C. BALE	NORANDA EX. CO. LTD.	55° 5' 0"	124° 12' 0"	6104507 423396	Au, Cu				FG	665 (B)			MAGG 12.2		
O1W	20008	90	WITCH NORTH CLAIM GROUP	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 9' 0"	124° 29' 0"	6114127 405507	Cu, Au					229 (B)					
01W	20228	90	NAT/WEBB PROPERTY	GRAND AMERICA MINERALS	MOONDUST VENTURES INC.	55° 7' 0"	124° 16' 0"	6108291 419207	Au, Cu				FG				MAGA 680.0 EMAB 680.0		
01W	20383	90	MITZI PROPERTY	RICHARD HASLINGER	NORANDA EX. CO. LTD.	55° 7' 30"	124° 27' 30"	6109457 407002	Cu, Au					239 (B)		28(R)	MAGG 51.3	12.0	
01W	20509	90	GOLDFINGER 1-4 CLAIMS	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 12' 0"	124° 25' 0"	6114038 409753	Cu, Au								MAGA 250.0 EMAB 250.0		
O1W	21068	90	WITCH NORTH PROPERTY	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 9' 0"	124° 29' 0"	6001011 403118	Cu, Au					239 (B)		8(R)	MAGA 121.0 EMAB 121.0		
01W	21069	91	GOLDFINGER 1 CLAIM GROUP	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 12' 0"	124° 23' 0"	6117705 411950	Cu, Au								MAGG 44.0	44.0	
01W	21213	91	WITT 1 CLAIM	COOKE NATION SYNDICATE	HLX RESOURCES LTD.	55° 8' 0"	124° 23' 0"	6110287 411803	Cu, Ag				D				MAGG 11.0		
01W	21288	91	MITZI PROPERTY	R. HASLINGER/ NORANDA EX. CO.	NORANDA EX. CO. LTD.	55° 7' 30"	124° 27' 30"	6109457 407002	Cu, Ag	6 to 9(d)							MAGA 305.0 EMAB 305.0	8.5	4 ddh 398
01W	21355	91	WIT GROUP	A. RAVEN	A. RAVEN	55° 3' 0"	124° 19' 0"	6100932 415879					D			4(R) 58(BIO)			
01W	21368	91	WIT PROPERTY	HARVARD CAPITAL CORP.	HARVARD CAPITAL CORP.	55° 3' 55	124° 20' 8"	6102655 414704		5 to 96(d)			D						4 ddh 902
01W/02E	03851	71	MT & D CLAIMS	ATTILA RESOURCES LTD.	AGILIS EX. SERVICES LTD.	55° 11' 0"	124° 42' 0"	6116296 391751					D				MAGG 39.5		
01W/02E	03852	72	MT & D CLAIM GROUPS	ATTILA RESOURCES LTD.	AGILIS EX. SERVICES LTD.	55° 11' 0"	124° 42' 0"	6116296 391751						862 (B)					
01W/02E	14381	86	PHIL 13 CLAIM GROUP	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 15' 30"	124° 33' 0"	6124419 401487	Cu, Au					238 (B)		244(R)			
01W/02E	18073	88	SKOOK PROPERTY	NATION RIVER RESOURCES LTD.	NATION RIVER RESOURCES LTD.	55° 12' 0"	124° 30' 0"	6117858 404525	Cu, Au, Ag					173 (B,C)		99(R)			
01W/02E	21108	91	SKOOK PROPERTY	NATION RIVER RESOURCES LTD.	NATION RIVER RESOURCES LTD.	55° 12' 0"	124° 30' 0"	6117858 404525	Cu, Au, Pb Zn, Ag								MAGA 210.0 EMAB 210.0		

NTS (93N)	REPORT	YEAR	PROPERTY	OWNER	OPERATOR	LATITUDE	LONGITUDE	MN NORTH MN EAST	COMMODITY	QUATERNARY GEOLOGY OB (m)	MAP	ICE FLOW	OB TYPE	GEOCHEMICAL SOIL(k)	SILT	R/BIO	GEOPHYSICAL MAG/EM(km)	R&IP(km)	DRILLING (m)
01W/02E 07E/08W	19399	89	GOLDBRICK CLAIMS	S.C.M. SERVICES LTD.	C.E.C. ENGINEERING LTD.	55° 15' 0"	124° 30' 0"	6123422 404645	Cu, Au				Mb	67 (B)	10	8(R)	MAGA 45.0 EMAB 45.0		
01W/07E 08W	20510	90	GOLDBRICK CLAIMS	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 15' 0"	124° 28' 0"	6123377 406763	Cu, Au								MAGA 210.0 EMAB 210.0		
01W/07E 08W	21113	91	CHUCHI A CLAIM GROUP	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 16' 0"	124° 33' 0"	6125346 401508	Cu, Au	1 to 54(d)									29 ddh 5316
01W/08W	21099	91	GR-GOLDBRICK CLAIMS	NORANDA EX. CO. LTD.	BP RESOURCES CANADA LTD.	55° 14' 0"	124° 25' 0"	6121457 409904	Cu, Au								MAGA 280.0 EMAB 280.0		
02E	02007	69	TAN & JUDY GROUPS	D.L. MOORE/ R.M. REININGER		55° 9' 18"	124° 43' 6"	6113172 390506					D	1 000 (A,B)			MAGG 53.2 EMGR 53.2		
02E	02932	70	CHUCHI GROUP	FALCONBRIDGE NICKEL MINES	FALCONBRIDGE NICKEL MINES	55° 13' 30"	124° 44' 6"	6120987 389638		0 to 30			D	462 (B)					
02E	03127	71	FT. ST. JAMES AREA	IMPERIAL OIL ENTERPRISES LTD.		55° 5' 24"	124° 34' 54"	6105734 399050										9.6	
02E	03339	71	BARB & JUDY CLAIM GROUPS	BORONDA EX. LTD./ G. JILSON		55° 9' 36"	124° 42' 42"	6113718 390945	Cu					300 (B)			MAGG 35.1 EMGR 35.1		
02E	03383	71	LAKE GROUP CLAIMS	FALCONBRIDGE NICKEL MINES	FALCONBRIDGE NICKEL MINES	55° 13' 30"	124° 44' 6"	6120987 389638					Mb				MAGG 5.7		
02E	03384	71	CHUCHI CLAIMS	FALCONBRIDGE NICKEL MINES	FALCONBRIDGE NICKEL MINES	55° 13' 30"	124° 44' 6"	6120987 389638										3.2	

NTS (93N)	REPORT	YEAR	PROPERTY	OWNER	OPERATOR	LATITUDE	LONGITUDE	MN NORTH MN EAST	COMMODITY	QUATERNARY GEOLOGY OB (m)	MAP	ICE FLOW	OB TYPE	GEOCHEMICAL SOIL(k)	SILT	R/BIO	GEOPHYSICAL MAG/EM(km)	R&IP(km)	DRILLING (m)
02E	03409	71	CHUCHI LAKE PROPERTY	PLATEAU METALS LTD.	PLATEAU METALS LTD.	55° 12' 12"	124° 40' 36"	6118485 393290						609 (B)					
02E	03410	71	TOP & POT CLAIMS GROUP	PLATEAU METALS LTD.	PLATEAU METALS LTD.	55° 12' 54"	124° 39' 48"	6119763 394170	Cu					1 086 (B)			MAGG 51.5		
02E	03462	71	CAMP-POE MINERAL CLAIMS	COLIN I. CAMPBELL	IMPERIAL OIL ENTERPRISES LTD.	55° 5' 24"	124° 34' 54"	6105734 399050	Cu				D	680 (B)			MAGG 40.2		
02E	03720	72	SRM CLAIM GROUP	SEREM LTEE		55° 13' 48"	124° 33' 0"	6121266 401417						1 139 (B)			MAGG 23.4		
02E	03853	72	PU CLAIMS	PECHINEY DEV. LTD.	PECHINEY DEV. LTD.	55° 8' 24"	124° 31' 30"	6111217 402788						243 (B)			MAGG 16.2		
02E	04589	73	PU CLAIM GROUP	PECHINEY DEV. LTD.	PECHINEY DEV. LTD.	55° 8' 24"	124° 31' 30"	6111217 402788										9.2	
02E	05145	74	PU CLAIM GROUP	PECHINEY DEV. LTD.	PECHINEY DEV. LTD.	55° 8' 24"	124° 31' 30"	6111217 402788		0 to 5(d)				540 (B)			MAGG 11.4	11.4	3 ddh 345
02E	07887	79	BAG 1-4 CLAIMS	SAHQUA MINERALS LTD.		55° 9' 0"	124° 32' 48"	6112360 401432					D					80.0	
02E	10971	82	NATION 1 CLAIMS CHU 1&2 CLAIMS	ALEX E. MARR	WESTMIN RESOURCES LTD.	55° 13' 30"	124° 44' 6"	6120987 389638						620 (B)	100				
02E	17973	88	CAMP 1 CLAIM	C.J. CAMPBELL	C.J. CAMPBELL	55° 5' 0"	124° 35' 0"	6104994 398927	Cu, Au				FG	60 (B)		3(R)			

NTS (93N)	REPORT	YEAR	PROPERTY	OWNER	OPERATOR	LATITUDE	LONGITUDE	MN NORTH MN EAST	COMMODITY	QUATERNARY GEOLOGY OB (m)	MAP	ICE FLOW	OB TYPE	GEOCHEMICAL SOIL(k)	SILT	R/BIO	GEOPHYSICAL MAG/EM(km)	R&IP(km)	DRILLING (m)
02E	18282	89	CHUCHI B GROUP	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 11' 0"	124° 35' 0"	6116121 399179						186 (B)					
02E	18392	89	CHUCHI PROPERTY	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 11' 0"	124° 35' 0"	6116121 399179					D	789 (B)					
02E	19582	90	CHUCHI B GROUP	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 11' 0"	124° 35' 0"	6116121 399179						155 (B)		10(R)	MAGG 10.0		
02E	19720	90	WITCH CLAIM GROUP	RIO ALGOM EX. INC.	RIO ALGOM EX. INC.	55° 9' 0"	124° 32' 30"	6112353 401750	Cu, Au		yes		D	3 642 (B)	70	83(R)	MAGA 520.0 EMAB 520.0		
02E	20009	90	WI 1 CLAIM	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 3' 0"	124° 31' 0"	6101191 403102	Cu, Au					86 (B)					
02E	20199	90	CAMP PROPERTY	C.J. CAMPBELL	MUTUAL RESOURCES LTD.	55° 5' 0"	124° 34' 0"	6104970 399991	Cu, Au			W, SW	D, LG	1 681 (B)					
02E	20865	90	CHUCHI B GROUP	NOREX	NORANDA EX. CO. LTD.	55° 11' 30"	124° 35' 0"	6117048 399200					D				MAGA 23.2 EMAB 23.2		
02E	21070	91	ANOM 1 GROUP		BP RESOURCES CANADA LTD.	55° 12' 0"	124° 39' 0"	6118074 394978	Cu, Au								MAGA 207.0 EMAB 207.0		
02E	21447	91	POE GROUP	NATION RIVER RESOURCES LTD.	NATION RIVER RESOURCES LTD.	55° 2' 21"	124° 38' 0"	6100154 395620	Ag, Cu, Au					131 (B,C)			MAGG 6.0 EMGR 6.0		
02E/01W	04244	72	MT. D, & DP CLAIMS	ATTILA RESOURCES LTD.	AGILIS EX. SERVICES LTD.	55° 9' 30"	124° 30' 24"	[illegible] 404001					D	996 (B)			MAGG 23.8		

NTS (93N)	REPORT	YEAR	PROPERTY	OWNER	OPERATOR	LATITUDE	LONGITUDE	MN NORTH MN EAST	COMMODITY	QUATERNARY GEOLOGY				GEOCHEMICAL			GEOPHYSICAL		DRILLING (m)
										OB (m)	MAP	ICE FLOW	OB TYPE	SOIL(a)	SILT	R/BIO	MAG/EM(km)	R&IP(km)	
02E/02W	03286	71	COL CLAIMS	C.J. CAMPBELL	FALCONBRIDGE NICKEL MINES	55° 13' 42"	124° 45' 24"	6121392 388269											
02E/02W	03337	71	NATION LAKE AREA	BORONDA EX. CORP. LTD.	BORONDA EX. CORP. LTD.	55° 10' 30"	124° 47' 18"	6115509 386103						SURVEY DONE			MAGG 213.4 EMGR 213.4	SURVEY DONE	
02E/02W	03338	70	NATION COPPER PROPERTY	BORONDA EX. CORP. LTD.	BORONDA EX. CORP. LTD.	55° 11' 0"	124° 50' 54"	6116536 382307					D					13.0	
02E/02W	19810	90	TCHENTLO LAKE PROPERTY	WESTMIN MINES LTD.	WESTMIN MINES LTD.	55° 10' 0"	124° 47' 0"	6114574 386398	Au, Cu				Mb	751 (B)		14(R)			
02E/02W	21124	91	TCHENTLO LAKE PROPERTY	WESTMIN MINES LTD.	WESTMIN MINES LTD.	55° 10' 0"	124° 47' 0"	6114574 386398	Au, Cu	<1 to >5			Mb	2 400 (A,B)	38	11(R)			
02E/07E	02714	70	COL CLAIMS	C.J. CAMPBELL	FALCONBRIDGE NICKEL MINES	55° 15' 36"	124° 44' 54"	6124902 388888											
02E/07E	03218	71	LSD CLAIMS	HUDSON BAY EX. & DEV. CO. LTD.	HUDSON BAY EX. & DEV. CO. LTD.	55° 15' 0"	124° 35' 0"	6123539 399348						749 (B)					
02E/07E	03862	72	LSD CLAIMS	HUDSON BAY EX. & DEV. CO. LTD.	HUDSON BAY EX. & DEV. CO. LTD.	55° 15' 0"	124° 35' 0"	6123539 399348										10.9	
02E/07E	03863	72	LSD CLAIMS	HUDSON BAY EX. & DEV. CO. LTD.	HUDSON BAY EX. & DEV. CO. LTD.	55° 15' 0"	124° 35' 0"	6123539 399348						383 (B)					
02E/07E	04099	72	KLAWDETELLE PROPERTY	NORANDA MINES LTD.	NORANDA EX. CO. LTD.	55° 15' 12"	124° 33' 48"	6123881 400627						574 (B,C)					
02E/07E	19748	90	COL CLAIM GROUP	C.J. CAMPBELL/ KOOKABURRA GOLD	KOOKABURRA GOLD CORP.	55° 15' 0"	124° 45' 0"	6123792 388754	Cu, Au	<1 to >2			D	287 (A,B)	8	116(R)		22.4	
02E/02W	02933	70	CHUCHI 1&2 GROUPS	C.J. CAMPBELL/ H. CAMPBELL	FALCONBRIDGE NICKEL MINES	55° 15' 36"	124° 44' 54"	6124902 388888					D	748 (B)					
02E/07W	18123	88	COL GROUP	C.J. CAMPBELL	KOOKABURRA GOLD CORP.	55° 15' 0"	124° 45' 0"	6123792 388754	Cu, Au				D	878 (B)					
02W	00851	66	NATION COPPER PROPERTY	DAVID L. MOORE	WEST COAST MINING & EX.	55° 11' 24"	124° 52' 12"	6117315 380947										3.9	
02W	01056	67	NATION COPPER& ALEXANDER LAKE	DAVID L. MOORE	WEST COAST MINING & EX.	55° 9' 18"	124° 43' 6"	6113172 390506										10.8	
02W	01599	68	NATION COPPER PROPERTY	DAVID L. MOORE		55° 11' 24"	124° 52' 12"	6117315 380947						(B)				71.2	
02W	01994	69	FAR CLAIM GROUP	W.R. BACON	N.B.C. SYNDICATE	55° 10' 18"	124° 46' 0"	6115103 387474					D				MAGG 14.5		
02W	02241	69	JEAN I, II, & III CLAIM GROUPS	W.R. BACON	N.B.C. SYNDICATE	55° 6' 18"	124° 54' 0"	6107909 378780	Cu				D	750 (B)	81				
02W	02242	69	JEAN I, II, & III CLAIM GROUPS	W.R. BACON	N.B.C. SYNDICATE	55° 6' 18"	124° 54' 0"	6107909 378780										14.5	
02W	02626	70	JEAN II CLAIM GROUP	W.R. BACON	N.B.C. SYNDICATE	55° 6' 18"	124° 54' 0"	6107909 378780											
02W	03899	72	JEAN PROPERTY	W.R. BACON	N.B.C. SYNDICATE	55° 6' 18"	124° 54' 0"	6107909 378780	Cu				Mb					19.3	
02W	04774	73	JEAN PROPERTY	N.B.C. SYNDICATE	COMINCO LTD.	55° 6' 18"	124° 54' 0"	6107909 378780									MAGG 49.9	24.8	
02W	05343	74	JEAN PROPERTY	N.B.C. SYNDICATE	COMINCO LTD.	55° 6' 18"	124° 54' 0"	6107909 378780		0 to 26(d)									40 pcdh 3 200
02W	05590	75	JEAN PROPERTY	N.B.C. SYNDICATE	COMINCO LTD.	55° 6' 18"	124° 54' 0"	6107909 378780									MAGG 17.7	17.7	
02W	05633	75	JEAN PROPERTY	N.B.C. SYNDICATE	COMINCO LTD.	55° 6' 18"	124° 54' 0"	6107909 378780		8 to 13(d)									2 ddh 316
02W	05737	75	JEAN PROPERTY	N.B.C. SYNDICATE	COMINCO LTD.	55° 6' 18"	124° 54' 0"	6107909 378780		5 to 30(d)									4 ddh 446
02W	06332	77	JEAN PROPERTY	N.B.C. SYNDICATE	COMINCO LTD.	55° 6' 18"	124° 54' 0"	6107909 378780									MAGG 51.0	44.7	
02W	06948	78	JEAN PROPERTY	N.B.C. SYNDICATE	COMINCO LTD.	55° 6' 12"	124° 51' 6"	6107641 381859									MAGG 11.2	11.2	
02W	07530	79	JEAN PROPERTY	N.B.C. SYNDICATE	COMINCO LTD.	55° 4' 30"	124° 50' 48"	6104480 382094						121 (B)					
02W	09320	81	JEAN PROPERTY	N.B.C. SYNDICATE	COMINCO LTD.	55° 6' 18"	124° 54' 0"	6107909 378780									MAGA 1 425.0 EMAB 1 425.0		

NTS (93N)	REPORT	YEAR	PROPERTY	OWNER	OPERATOR	LATITUDE	LONGITUDE	MN NORTH MN EAST	COMMODITY	QUATERNARY GEOLOGY				GEOCHEMICAL			GEOPHYSICAL		DRILLING (m)
										OB (m)	MAP	ICE FLOW	OB TYPE	SOIL(h)	SILT	R/BIO	MAG/EM(km)	R&IP(km)	
02W	11572	83	JEAN PROPERTY		COMINCO LTD.	55° 3' 24"	124° 49' 18"	6102398 383637	Cu, Mo					344(B)	12				
02W	13509	85	PHIL 20 CLAIM	SELCO DIVISION- BP RESOURCES	SELCO DIVISION- BP RESOURCES	55° 9' 0"	124° 52' 0"	6112858 381040		0 to 2				67 (B)	31	2(R)			
02W	13510	85	PHIL 19 CLAIM	SELCO DIVISION- BP RESOURCES	SELCO DIVISION- BP RESOURCES	55° 10' 0"	124° 47' 0"	6114574 386398		<1 to >5				42 (B)	25	2(R)			
02W	17859	88	PHIL 20 CLAIM	BP MINERALS LTD.	BP MINERALS LTD.	55° 9' 0"	124° 52' 30"	6112873 380509	Au				C, Mb	80		5(R)			
02W	18393	89	MARIE PROPERTY		NORANDA EX. CO. LTD.	55° 3' 0"	124° 53' 0"	6101761 379678						818 (B)					
02W	19163	89	PHIL 20 CLAIM	BP MINERALS LTD.	BP MINERALS LTD.	55° 9' 2"	124° 52' 31"	6112945 380500									MAGA 63.0 EMAB 63.0		
02W	19239	89	EAGLE PROPERTY	A.&W. HALLERAN/ U. SCHMIDT	NORANDA EX. CO. LTD.	55° 12' 0"	124° 51' 0"	6118393 382250	Cu, Au					308 (B)					
02W	20245	90	EAGLE PROPERTY	W.H. HALLERAN/ NORANDA EX. CO.	NORANDA EX. CO. LTD.	55° 12' 0"	124° 51' 0"	6120538 318617	Cu, Au					996 (B)		98(R)	MAGG 32.5	13.0	
02W	20314	90	KLAW ONE & TWO CLAIM GRPS	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 15' 5"	124° 29' 55"	6123575 404736	Cu, Au	3 to 11(d)									6 ddh 620
02W	20333	90	JEAN PROPERTY	IMPERIAL METALS CORP.	IMPERIAL METALS CORP.	55° 8' 0"	124° 52' 30"	6111018 380460	Cu, Mo				D				MAGA 545.0 EMAB 545.0		
02W	20406	90	EAGLE PROPERTY	W.H. HALLERAN/ NORANDA EX. CO.	NORANDA EX. CO. LTD.	55° 12' 0"	124° 52' 0"	6118422 381189	Cu, Au, Pb Zn, Ag	0 to 20			D	534 (B)	21	54(R)		49.0	
02W	20454	90	JEAN MARIE PROPERTY		NORANDA EX. CO. LTD.	55° 3' 0"	124° 55' 0"	6101819 377549					D	264 (B)	8	4(R)			
02W/02E 07W	15423	86	COL GROUP	COLIN CAMPBELL	COLIN CAMPBELL	55° 14' 48"	124° 45' 12"	6123427 388533	Au							60(R)			
02W/03E	21254	91	AIRLINE LAKE PROPERTY	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 10' 0"	125° 0' 0"	6116802 372651					D	225 (B)					
02W/07W	03460	71	CHUCHI PROPERTY	M. BRATLIEN/ T.H. CROSS	DENISON MINES LTD.	55° 14' 48"	124° 49' 42"	6123549 383765		<6 to >30			Mb, Fg	1 781 (B)			MAGG 84.6		
03E	01947	68	HI 1 CLAIM GROUP	W.R. BACON	N.B.C. SYNDICATE	55° 13' 36"	125° 7' 48"	6121869 364522						(B)			MAGG 7.5 EMGR 7.5		
03E	02010	69	BAL 1-6 CLAIMS	TCHENTLO LAKE MINES LTD.	TCHENTLO LAKE MINES LTD.	55° 12' 30"	125° 4' 36"	6119726 367853											
03E	02609	70	BAL GROUP	TCHENTLO LAKE MINES LTD.	TCHENTLO LAKE MINES LTD.	55° 12' 30"	125° 4' 36"	6119726 367853											
03E	02617	70	HI I, II, & III CLAIM GROUPS	W.R. BACON	N.B.C. SYNDICATE	55° 13' 36"	125° 7' 48"	6121869 364522						318 (B)			MAGG 35.3		
03E	02729	70	BAL GROUP	TCHENTLO LAKE MINES LTD.	TCHENTLO LAKE MINES LTD.	55° 12' 30"	125° 4' 36"	6119726 367853						743					
03E	09403	81	JP 1 MINERAL CLAIM	PLACER DEV. LTD.	PLACER DEV. LTD.	55° 13' 42"	125° 6' 24"	6122009 366011						148 (B)		22(R)	EMGR 8.3		
03E	10077	81	OVB CLAIM GROUP	PLACER DEV. LTD.	PLACER DEV. LTD.	55° 13' 0"	125° 2' 42"	6120594 369895						16	15		MAGG 13.7 EMGR 13.7		
03E	10904	82	OVB CLAIM GROUP	PLACER DEV. LTD.	PLACER DEV. LTD.	55° 13' 0"	125° 2' 42"	6120594 369895					D				MAGG 17.7 EMGR 17.7		
03E	11698	83	LEON 2-4 CLAIMS		DOME EX. CANADA LTD.	55° 7' 18"	125° 6' 12"	6110135 365865						1		80(R)			
03E	19223	89	TCHENTLO PROPERTY	PLACER DOME INC.	PLACER DOME INC.	55° 11' 24"	125° 13' 50"	6118000 358000	Au				D	318 (Ao,B,C)		28(R)	EMGR 5.8		
03E	20272	90	FALCON PROPERTY	HALLERAN/ SCHMIDT	A.D. HALLERAN	55° 13' 0"	125° 7' 0"	6120730 365336	Cu, Mo										
03E	20825	90	FALCON PROPERTY	HALLERAN/ SCHMIDT/FORSTER	INDEPENDENCE MINING CO. INC.	55° 13' 0"	125° 7' 0"	6120730 365336	Cu, Mo, Au				C	690 (B)					
03E/03W	15211	86	WETCH PROPERTY	EQUINOX RES./ DARREN RES. LTD.	EQUINOX RES./ DARREN RES. LTD.	[illegible]	[illegible]	[illegible] 356445	Au							5(R)			
03E/03W	20037	90	TCHENTLO PROPERTY	PLACER DOME INC.	PLACER DOME INC.	55° 11' 0"	125° 14' 0"	6117253 357796	Au, Hg			NW	D	1 080 (C,B)	5	17(R)			
03E/06E	02321	70	HI I, II, & III CLAIM GROUPS	W.R. BACON	N.B.C. SYNDICATE	55° 13' 36"	125° 7' 48"	6121869 364522									MAGG 12.4 EMGR 15.6		

NTS (93N)	REPORT	YEAR	PROPERTY	OWNER	OPERATOR	LATITUDE	LONGITUDE	MN NORTH MN EAST	COMMODITY	QUATERNARY GEOLOGY				GEOCHEMICAL			GEOPHYSICAL		DRILLING
										OB (m)	MAP	ICE FLOW	OB TYPE	SOIL(h)	SILT	R/BIO	MAG/EM(km)	R&IP(km)	(m)
03E/06W	11882	83	WETCH PROPERTY	AUME RESOURCES LTD.	AUME RESOURCES LTD.	55° 16' 0"	125° 14' 0"	6126524 358093					D	49	29	14(R)			
03W	19673	89	TCHENTLO PROPERTY	PLACER DOME INC.	PLACER DOME INC.	55° 11' 24"	125° 13' 50"	6118000 358000	Au				D				MAGG 53.0 EMGR 53.0		
04W	08113	79	NALCUS 1 CLAIM	NALCUS RESOURCES LTD.	NALCUS RESOURCES LTD.	55° 14' 6"	125° 50' 0"	6124388 319835						57 (B)					
04W	11215	82	NALCUS PROPERTY	NALCUS RESOURCES LTD.	NALCUS RESOURCES LTD.	55° 14' 6"	125° 50' 0"	6124388 319835						313 (B)					
04W/05W	09352	80	NALCUS PROPERTY	NALCUS RESOURCES LTD.	NALCUS RESOURCES LTD.	55° 14' 6"	125° 50' 0"	6124388 319835						228 (B)		32(R)			
04W/05W	10366	81	NALCUS PROPERTY	NALCUS RESOURCES LTD.	NALCUS RESOURCES LTD.	55° 14' 6"	125° 50' 0"	6124388 319835							39				
05E	06814	78	DON & JOHN CLAIMS	PLACER DEV. LTD.	PLACER DEV. LTD.	55° 17' 18"	125° 34' 0"	6129664 337006	Mo					346 (B,C)	36				
05E	07468	78	DAIRY CLAIM	PLACER DEV. LTD.	PLACER DEV. LTD.	55° 17' 18"	125° 34' 0"	6129664 337006	Mo					162 (B,C)					
05E	08357	80	DON 1 CLAIM	P. BUCKLEY	PLACER DEV. LTD.	55° 17' 18"	125° 34' 0"	6129664 337006		5(d)									1 ddh 16
05E	08358	80	DAIRY CLAIM GROUP	P. BUCKLEY/ PLACER DEV. LTD.	PLACER DEV. LTD.	55° 17' 18"	125° 34' 0"	6129664 337006		9(d)									1 ddh 28
05E	13506	85	LATE 1 CLAIMS	SELCO DIVISION- BP RESOURCES	SELCO DIVISION- BP RESOURCES	55° 26' 0"	125° 42' 0"	6146114 329167		<1 to 5				86 (B)	22	10(R)			
05E	16095	87	CYPRUS CLAIMS	IMPERIAL METALS CORP.	IMPERIAL METALS CORP.	55° 23' 30"	125° 36' 0"	6141238 335319						355 (B)		58(R)			
05W	15376	86	TLITI CLAIM	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 22' 48"	125° 46' 12"	6140356 324503							9		MAGG 2.9 EMGR 2.7		
05W	16654	87	TLITI GROUP	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 23' 11"	125° 48' 2"	6141144 322596									MAGG 11.0 EMGR 15.0		
05W	18283	89	BASE PROPERTY	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 16' 0"	125° 53' 0"	6128041 316803						236 (B)					
05W/12W	14781	86	TL 4 CLAIM	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 29' 30"	125° 54' 0"	6153113 316787						70 (B)			MAGG 3.3 EMGR 2.1		
06E	01064	67	NOS 1-20 CLAIMS	W. RIGLER/ R. JACKSON	J. RICHARDSON	55° 20' 48"	125° 10' 54"	6135321 361654	Cu				D	326 (Ao,Ai,B)					
06E	01236	68	INDATA LAKE GROUP	AJAX MERCURY MINES LTD.	AJAX MERCURY MINES LTD.	55° 17' 36"	125° 13' 54"	6129488 358294						250 (B)					9 ddh 82
06E	01965	69	HEATH 1-11 CLAIMS	COLIN CAMPBELL	AMAX EX. INC.	55° 16' 30"	125° 10' 12"	6127324 362145						144 (B)	5				
06E	02799	70	NS CLAIM GROUP		SENATE MINING EX. LTD.	55° 16' 30"	125° 10' 12"	6127324 362145	Cu				Mb	273					
06E	02938	71	ROT CLAIMS	PAT MARTIN		55° 21' 0"	125° 9' 12"	6135636 363462											
06E	03200	71	HEATH COPPER PROPERTY	SENATE MINING EX. LTD.	SENATE MINING EX. LTD.	55° 16' 30"	125° 10' 12"	6127324 362145											
06E	03201	71	HEATH COPPER PROPERTY	SENATE MINING EX. LTD.	SENATE MINING EX. LTD.	55° 16' 30"	125° 10' 12"	6127324 362145									MAGG 34.1		
06E	03407	71	ROTTACKER CK. PROPERTY	NATION LAKES MINES LTD.	NATION LAKES MINES LTD.	55° 21' 0"	125° 9' 12"	6135636 363462					D	495		1(R)			
06E	03611	71	NOBLE CLAIMS	UNION MINIERE EX.&MINING LTD.		55° 25' 12"	125° 10' 30"	6143467 362332					D	369 (B)					
06E	03774	72	HALOBIA PROPERTY	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 27' 0"	125° 9' 0"	6146755 364017						589 (C,B)					
06E	03854	72	FUM CLAIMS	C.J. CAMPBELL	C.J. CAMPBELL	55° 17' 48"	125° 5' 30"	6129583 367193											
06E	04672	73	HEATH & CAT CLAIMS	C.J. CAMPBELL	NATION LAKE MINES LTD.	55° 16' 30"	125° 10' 12"	6127324 362145										19.8	
06E	05619	75	BURN PROPERTY	LUC SYNDICATE	DOME EX. CANADA LTD.	55° 29' 0"	125° 14' 42"	6150654 358129		3 to 6			Mb	383			MAGG 12.9		
06E	08988	80	HALO 1 CLAIM	J.C. STEPHEN	DOME EX. CANADA LTD.	55° 25' 54"	125° 10' 0"	6144748 362900						34	25	16(R)	MAGG 52.5		

NTS (93N)	REPORT	YEAR	PROPERTY	OWNER	OPERATOR	LATITUDE	LONGITUDE	MN NORTH MN EAST	COMMODITY	QUATERNARY GEOLOGY OB (m)	MAP	ICE FLOW	OB TYPE	GEOCHEMICAL SOIL(n)	SILT	R/BIO	GEOPHYSICAL MAG/EM(km)	R&IP(km)	DRILLING (m)
06E	17988	88	HEATH 1 CLAIM	C.J. CAMPBELL	C.J. CAMPBELL	55° 17' 0"	125° 9' 0"	6128212 363444	Au, Ag, Cu Pb, Zn					75 (B,C)		2(R)			
06E	20338	90	ERICKSON PROPERTY	RICHARD HASLINGER	PLACER DOME INC.	55° 29' 0"	125° 10' 0"	6150497 363079	Cu, Ag, Mo					169 (B)	10	5(R)			
06E	20552	90	HEATH PROPERTY	INDATA RESOURCES LTD.	TECK EX. LTD.	55° 16' 0"	125° 10' 0"	6126391 362328	Cu, Au, Ag, Pb, Zn			NNW, NW		4 152 (B)			MAGG 86.0 EMGR 86.0		
06E/06W	12433	83	INDA 1-6 CLAIMS		COMINCO LTD.	55° 22' 0"	125° 31' 0"	6138263 340496					FG	270 (B)		24(R)			
06E/06W	14940	86	INDIO-JASPEROID CLAIM GROUP	EASTFIELD RES./ IMPERIAL METALS	IMPERIAL METALS CORP.	55° 16' 30"	125° 15' 0"	6127486 357064		>2(t)			F	10					
06E/07E 10W	21228	91	WUDLEAU PROPERTY	WESTMIN RESOURCES LTD.	WESTMIN RESOURCES LTD.	55° 23' 30"	124° 49' 30"	6139677 384400	Au				Mb		200		MAGA 1 100.0 EMAB 1 100.0		
06E/07W 11E	19868	90	KWANIKA/VAL-LEAU PROPERTY	WESTMIN MINES LTD.	WESTMIN MINES LTD.	55° 30' 0"	125° 5' 0"	6152190 368400	Au, Cu				Mb	806 (B)	143				
06E/07W 11E	20897	91	KWANIKA/VAL-LEAU PROPERTY	WESTMIN RESOURCES LTD.	WESTMIN RESOURCES LTD.	55° 30' 0"	125° 0' 0"	6152036 373663	Au, Cu				Mb	1 750 (B)	250				
06E/11E	03856	71	KWANIKA PROPERTY	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 30' 24"	125° 10' 0"	6153093 363160					D	2 481 (C,B)					
06E/11E	03857	72	KWANIKA PROPERTY	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 30' 24"	125° 10' 0"	6153093 363160										17.6	
06E/11E	07432	79	BURN CLAIM GROUP	LUC SYNDICATE	PLACER DEV. LTD.	55° 29' 0"	125° 14' 42"	6150654 358129		7			D	370 (B)	63	55(R)	MAGG 9.1		
06W	04577	73	MAYA, KQ & POST CLAIMS	BOW RIVER RESOURCES	PECHINEY DEV. LTD.	55° 28' 42"	125° 18' 18"	6150222 354320											
06W	10492	81	K4, T4 CLAIMS	T. MILLARD/ T. GRAHAM	PLACER DEV. LTD.	55° 28' 12"	125° 18' 54"	6149316 353657					D	35 (B,C)		16(R)			
06W	13180	84	INDIO-SCHNAPPS GRP.	IMPERIAL METALS CORP.	IMPERIAL METALS CORP.	55° 22' 0"	125° 20' 0"	6137858 352113						330 (Bmf)					
06W	13227	84	INDIO-JASPEROID GRP.	IMPERIAL METALS CORP.	IMPERIAL METALS CORP.	55° 17' 0"	125° 16' 0"	6128447 356036						330 (Bmf)					
06W	14074	85	INDIO-SCHNAPPS PROPERTY	IMPERIAL METALS CORP.	IMPERIAL METALS CORP.	55° 22' 0"	125° 20' 0"	6137858 352113		1 to 5(d)						23(R)	EMGR 4.2	6.0	4 ddh 231
06W	16129	87	INDATA GROUP	EASTFIELD RESOURCES LTD.	EASTFIELD RESOURCES LTD.	55° 23' 36"	125° 20' 0"	6140825 352212		3 to 5				65 (B)			MAGG 4.2		
06W	17185	88	INDATA GROUP	EASTFIELD RESOURCES LTD.	EASTFIELD RESOURCES LTD.	55° 23' 30"	125° 20' 19"	6140650 351872	Au, Ag, Cu	3 to 5			Mb	849 (B)					
06W	18613	89	INDATA PROPERTY	EASTFIELD RESOURCES LTD.	EASTFIELD RESOURCES LTD.	55° 23' 0"	125° 19' 0"	6139677 353231	Au, Ag, Cu	3 to 5			Mb	1 230			MAGG 30.0 EMGR 30.0	11.7	
06W	19382	89	INDATA PROPERTY	EASTFIELD RES./ IMPERIAL METALS	EASTFIELD RES./ IMPERIAL METALS	55° 23' 0"	125° 19' 0"	6139677 353231	Au, Ag, Cu					1 273		147(R)		10.4	
06W	19955	90	TOOTH 1 PROPERTY	PLACER DOME INC.	PLACER DOME INC.	55° 19' 0"	125° 29' 0"	6132624 342410	Au					151 (B,AC,XC)	68	12(R)			
06W/07E 10E/11W	19859	90	VALLEAU CREEK PROPERTY		PLACER DOME INC.	55° 35' 0"	125° 0' 0"	6161308 373930	Au					187 (B)	120	95(R)			
06W/11W	04773	73	KWANIKA CREEK PROPERTY	BOW RIVER RES./ PECHINEY DEV.	PECHINEY DEV. LTD.	55° 30' 12"	125° 20' 0"	6153063 352623									MAGG 64.4		
06W/11W	04826	73	KWANIKA CREEK PROPERTY	BOW RIVER RESOURCES LTD.	PECHINEY DEV. LTD.	55° 30' 12"	125° 20' 0"	6153063 352623										64.4	
06W/11W	05266	74	KWANIKA CREEK PROPERTY	BOW RIVER RES./ PECHINEY DEV.	PECHINEY DEV. LTD.	55° 28' 42"	125° 18' 18"	6150222 354320		3 to 49(d)									30 pddh 2 994
06W/11W	18781	89	NATION PROPERTY	EASTFIELD RESOURCES LTD.	EASTFIELD RESOURCES LTD.	55° 32' 0"	125° 25' 0"	5822886 336080	Au				D	570 (Bcf)			MAGG 21.0 EMGR 21.0		
06W/11W	19131	89	SWAN & KWAN CLAIMS	EASTFIELD RESOURCES LTD.	NORTHAIR MINES LTD.	55° 30' 0"	125° 20' 0"	6152692 352611	Cu, Au	4 to 32(d)			D	55 (B)	143	162(R)		23.3	
07E	03408	71	GIL CLAIMS	GREAT PLAINS DEV. CO.	GREAT PLAINS DEV. CO.	55° 20' 24"	124° 38' 54"	6133649 395453						1 429 (B)	71				
07E	13325	84	PHIL 13 CLAIM GROUP	SELCO DIVISION-BP RESOURCES	SELCO DIVISION-BP RESOURCES	55° 16' 0"	124° 33' 0"	6125346 401508	Au, Cu				Mb	46 (C)		28(R)			
07E	19505	89	AWL PROPERTY	CATHEDRAL GOLD CORP.	CATHEDRAL GOLD CORP.	55° 20' 0"	124° 40' 0"	6132935 394272	Cu, Au					146		12(R)			

NTS (93N)	REPORT	YEAR	PROPERTY	OWNER	OPERATOR	LATITUDE	LONGITUDE	MN NORTH MN EAST	COMMODITY	QUATERNARY GEOLOGY OB (m)	MAP	ICE FLOW	OB TYPE	GEOCHEMICAL SOIL(h)	SILT	R/BIO	GEOPHYSICAL MAG/EM(km)	R&IP(km)	DRILLING (m)
07E	19615	90	PHIL 2 CLAIM GROUP	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 18' 0"	124° 53' 0"	6129576 380429	Cu, Au								MAGA 250.0 EMAB 250.0		
07E	19844	90	GILLIS CREEK PROPERTY	PLACER DOME INC.	PLACER DOME INC.	55° 25' 0"	124° 35' 0"	6142084 399769	Au				D	50 (B)	56	18(R)			
07E	20524	90	ANDY 1&2 CLAIMS	B.H. KAHLERT	INDEPENDENCE MINING CO.	55° 22' 0"	124° 44' 55"	6142335 389308	Cu, Au				D	22 (A,B)					
07E/08E	19719	90	KLA CLAIMS	RIO ALGOM EX. INC.	RIO ALGOM EX. INC.	55° 17' 0"	124° 31' 0"	6127154 403666	Cu, Au	43(d)	yes	SE	D	2 034 (B)	65	42(R)	MAGA 190.0 EMAB 190.0		
07E/08W	20612	90	KLA CLAIMS	RIO ALGOM EX. INC.	RIO ALGOM EX. INC.	55° 17' 0"	124° 31' 0"	6127154 403666	Cu, Au	4 to 17(d)		SE	D	140 (B)		454(R)	MAGA 500.0 EMAB 500.0	25.3	5 ddh 692
07E/08W 02W	19024	89	PHIL 13 CLAIM GROUP		BP RESOURCES CANADA LTD.	55° 16' 0"	124° 33' 0"	6125346 401508	Cu, Au, Ag								MAGA 150.0 EMAB 150.0		
07W	02450	70	LUC CLAIM GROUP	JOHN KING		55° 19' 36"	124° 52' 0"	6132515 381567	Cu					192 (B)			MAGG 9.6		
07W	02916	71	VAL CLAIMS	DRIFTWOOD MINES LTD.	DRIFTWOOD MINES LTD.	55° 21' 24"	124° 49' 6"	6135772 384720											
07W	03865	72	CUL CLAIM GROUP	CALICO SILVER MINES LTD.	ATLED EX. MGMT. LTD.	55° 19' 36"	124° 52' 0"	6132515 381567	Cu					88 (B)					
07W	03962	71	AHDATAY PROPERTY	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 19' 0"	124° 54' 24"	6131471 378999					D	702 (C,B)					
07W	04430	73	IAN CLAIM GROUP	PECHINEY DEV. LTD.	PECHINEY DEV. LTD.	55° 20' 42"	124° 54' 0"	6134612 379508					D	73 (B)			MAGG 7 .8		
07W	04431	72	AHDATAY PROPERTY	NORANDA EX. CO. LTD.	NORANDA EX. CO. LTD.	55° 19' 0"	124° 54' 24"	6131471 378999					D					10.1	
07W	04653	73	IAN-B GROUP	PECHINEY DEV. LTD.	PECHINEY DEV. LTD.	55° 20' 42"	124° 54' 0"	6134612 379508						350 (B)				10.5	
07W	05148	74	IAN GROUP	PECHINEY DEV. LTD.	PECHINEY DEV. LTD.	55° 20' 42"	124° 54' 0"	6134612 379508		<1 to 6(d)									3 ddh 78
07W	05212	74	IAN-B GROUP	PECHINEY DEV. LTD.	PECHINEY DEV. LTD.	55° 20' 42"	124° 54' 0"	6134612 379508		6(d)									1 ddh 152
07W	12149	83	PHIL 2 CLAIM GROUP		BP EXPLORATION CANADA	55° 20' 0"	124° 53' 0"	6133285 380530	Cu, Au					1 100 (B)		41(R)			
07W	12908	83	GOLD 1-4 CLAIMS	ERIC A. SHAEDE	ERIC A. SHAEDE	55° 17' 0"	124° 46' 0"	6127528 387788	Au, Ag							12(R)			
07W	13342	84	PHIL 2 CLAIM GROUP	SELCO DIVISION- BP RESOURCES	SELCO DIVISION- BP RESOURCES	55° 21' 0"	124° 53' 0"	6135140 380580	Au, Cu				D			52(R)			
07W	14579	85	GOLD SUPPLE- MENTAL GROUP	J.D. POLIQUIN/ E.A. SHAEDE	HAWK MOUNTAIN RES.	55° 17' 0"	124° 46' 0"	6127528 387788					D	72(B)	21		MAGG 14.5 EMGR 14.5		
07W	15634	86	VALLEY GIRL PROPERTY	IMPERIAL METALS CORP.	IMPERIAL METALS CORP.	55° 29' 0"	124° 54' 0"	6150004 379928	Au					1 518 (B-2)		47(R)			
07W	16865	87	GOLD SUPPLE- MENTAL GROUP	E.A. SHAEDE/ J.D. POLIQUIN	E.A. SHAEDE	55° 17' 35"	124° 46' 55"	6128634 386846	Au, Ag, Cu				D			12(R)			
07W	19406	89	GOLD CLAIM GROUP	E.A. SHAEDE	E.A. SHAEDE	55° 17' 42"	124° 46' 54"	6128850 386869	Au, Ag, Cu				D	6 (B)	2				
07W	19450	89	VALLEY GIRL PROPERTY	IMPERIAL METALS CORP.	IMPERIAL METALS CORP.	55° 29' 0"	124° 54' 0"	6150004 379928	Au				Mb	410	21	28(R)			
07W	20177	90	LYS CLAIMS	CATHEDRAL GOLD CORP.	CATHEDRAL GOLD CORP.	55° 26' 0"	124° 57' 0"	6144528 376613									MAGA 55.0 EMAB 55.0		
07W	20178	90	VALLEY GIRL PROPERTY	IMPERIAL METALS CORP.	IMPERIAL METALS CORP.	55° 29' 0"	124° 55' 0"	6150033 378875									MAGA 200.0 EMAB 200.0		
07W	20876	91	PHIL 2 CLAIM GROUP	BP RESOURCES CANADA LTD.	BP RESOURCES CAN LTD.	55° 20' 0"	124° 53' 0"	6133285 380530	Cu, Au								MAGG 72.5	72.5	
07W	20943	91	PHIL A CLAIM GROUP	BP RESOURCES CANADA LTD.	BP RESOURCES CANADA LTD.	55° 20' 0"	124° 53' 0"	6133285 380530	Cu, Au	1 to 7(d)						34(R)			6 ddh 1 068
07W/02W	20018	90	PHIL 13 CLAIM GROUP	BP RESOURCES/ DIGGER RESOURCES	BP RESOURCES CANADA LTD.	55° 15' 23"	124° 32' 31"	6124200 402000	Cu, Au	6 to 31(d)							MAGG 30.0	41.0	9 ddh 1 376
08E	20286	90	SKUNK LAKE PROPERTY	CONTINENTAL GOLD CORP.	CONTINENTAL GOLD CORP.	55° 23' 30"	124° 7' 0"	6138729 429265	Ls							12(R)			

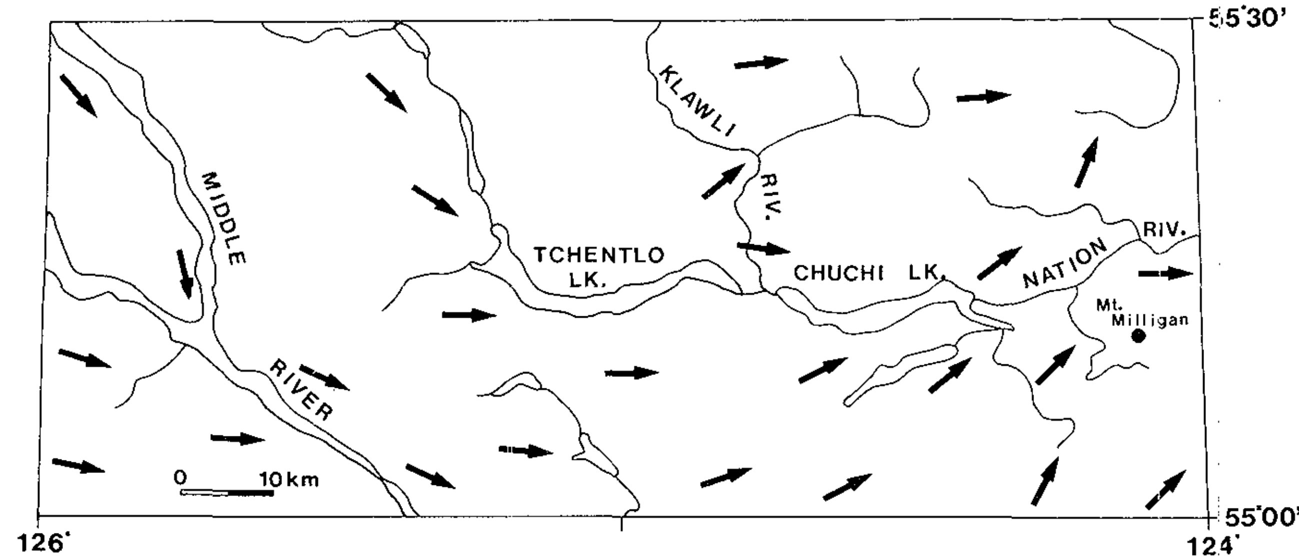

Figure 26-2. Regional ice movement during Fraser glaciation.

gently dipping Tertiary lava flows. The Omineca Mountains to the northeast consist of numerous peaks with well developed aretes and cirques surrounding U-shaped valleys. Elevations range from 1520 metres to greater than 1820 metres. The core of the mountains is composed of granitic rocks associated with the Omineca Plutonic Suite (Armstrong, 1949).

REGIONAL SURFICIAL GEOLOGY

The last glacial episode in the southern half of the Manson River map area occurred during the Late Wisconsinan (Fraser glaciation) between 26 940±380 years B.P. (GSC-573) and 10 100±90 years B.P. (GSC-2036). Regional ice movement (Figure 26-2) during this event was towards the east-southeast in the western half of the map area and towards the northeast in the eastern region, as interpreted from ice-flow indicators such as well developed striae scoured into bedrock and drumlinoid features developed in unconsolidated sediments. This observation of regional flow is in accordance with earlier studies by Armstrong and Tipper (1948) and Armstrong (1949) to the north, west and south, and more recently by Kerr (1991) and Kerr and Bobrowsky (1991) in the Mount Milligan area and by Plouffe (1991, 1992) in the Chuchi, Stuart and Fraser lakes region and Nation River valley. South of the Nation River and northeast of the Mount Milligan porphyry copper-gold deposit, a gradual change in flow direction towards the east is suggested by drumlinized features (Kerr, 1991).

Surficial sediments in the southern half of the Manson River map area include till, glaciofluvial and fluvial sand and gravel, glaciolacustrine sand, silt and clay, colluvium and organic materials. Two surficial geology units predominate: an extensive morainal (till) blanket and large glaciofluvial outwash complexes. Till was deposited during the last glacial episode and is commonly hummocky and drumlinized. It consists of a dense matrix-supported diamicton composed of very poorly sorted, angular to well rounded pebbles to boulders in a sand-silt-clay matrix.

Large concentrations of glaciofluvial sand and gravel dominate many regions. Outwash-sediment complexes consist of sinuous esker ridges up to tens of kilometres long, kame deposits and a series of broad overlapping outwash fans. These stratified sands and gravels were deposited by glacial meltwater during phases of ice retreat. They generally represent the end product of a long period of glacial and fluvial erosion, transportation and reworking of many types of surficial sediments from a region which may be hundreds of square kilometres in area. Within the narrow valley now occupied by the Klawli River, Chuchi Lake and the Nation River, glaciofluvial sediments are locally overlain by up to 20 metres of glaciolacustrine silt and clay. These sediments were deposited during ice retreat in a glacial lake with an elevation of approximately 850 metres (Kerr, 1991; Plouffe, 1992). In the McLeod Lake area to the southeast, Struik and Fuller (1988) mapped the extent of glacial lake deposits and noted the presence of mineralized clasts in morainal deposits. Colluvial sediments derived from till and weathered bedrock form a veneer over steep hillsides and valley walls in areas of high relief.

Overburden thickness on rocky highlands and plateaus is highly variable. Unconsolidated sediments in excess of 10 to 30 metres are common, and a thickness of greater than 185 metres has been reported in the western Nation River area (Ronning, 1989), possibly relating to a buried valley. The complexity of the stratigraphic record, the presence of pre-Fraser glaciation till and the large variations in drift thicknesses over lateral distances of tens of metres are important elements to note because they can directly influence the application and interpretation of drift exploration data.

ACKNOWLEDGMENTS

Thanks are extended to C. Bauer, University of Victoria Co-op Program, for her diligence in reviewing several of the assessment reports referred to in this report. The author would also like to acknowledge the many exploration companies who responded favorably to a questionnaire which provided them with an opportunity to indicate what type of information they would like to see summarized from assessment reports. A. Plouffe (G.S.C.) provided helpful comments on an earlier version of this report.

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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 2693.

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APPENDIX I: ANNOTATED BIBLIOGRAPHY OF DRIFT PROSPECTING ACTIVITIES IN BRITISH COLUMBIA

Compiled by Daniel E. Kerr and Victor M. Levson

INTRODUCTION

This annotated bibliography covers several different types of drift prospecting methods, focusing mainly on lithogeochemical and biogeochemical exploration programs. Emphasis is placed on methods that are generally used at a property or local level rather than a regional scale. Thus, papers dealing solely with regional lake sediment and stream sediment geochemical surveys are not included. Eighty-five citations of papers, published between 1947 and 1993, dealing with soil geochemistry, sampling methods, mechanical and hydromorphic dispersion processes, overburden profiles, boulder tracing and other applications of surficial geology to drift prospecting are presented (Table 27-1). Emphasis is placed on published papers because of the ease of public access and because these papers have been subjected to peer scrutiny. For this reason, unpublished data such as assessment reports are not included. The authors acknowledge, however, that a wealth of valuable information is contained in these reports and, as an example of the kind of data provided, a compilation of assessment reports available for NTS map sheet 93N (south half), an area representing many drift-covered regions in British Columbia, is included in this volume. There is also much relevant information available in research theses across Canada dealing with topics ranging from detailed mineral deposit studies to regional mapping and mineral potential evaluations. Although not intended to be comprehensive, the papers listed here give a broad cross-section of drift exploration programs that have been conducted in British Columbia. The location of properties cited is given in Table 27-2 by NTS number. Key words and corresponding citations are listed in Table 27-3.

Each citation in the bibliography is followed by the name of the property, mine or geographic location where the study took place, National Topographic System (NTS) map sheet designation, principal commodity and key words related to the main topic of discussion. Original or edited abstracts, outlining the relevance of the work to drift exploration, are also included with each entry. Where abstracts were not provided in the original paper, the introduction, summary or conclusions have been edited as explanatory notes.

ANNOTATED BIBLIOGRAPHY

1. Barr, D.A. (1978): **Chappelle Gold-Silver Deposit, British Columbia**; *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 71, pages 66-79.

   Chappelle gold-silver deposit   Au, Ag   NTS 94E/6

   Keywords: Chappelle, soil geochemistry, threshold values, stream sediment surveys, felsenmeer, magnetic surveys.

High-grade gold-silver mineralization, with electrum and argentite, was discovered in a quartz vein at the Chappelle property, 273 kilometres north of Smithers, B.C. in 1969 following a regional geochemical program in the Cassiar and Omineca mountains. Subsequent exploration resulted in the discovery of numerous quartz veins with associated precious metal values in a belt 17 kilometres long by 3 kilometres wide in an area centrally located within Toodoggone Group volcanic and sedimentary rocks of Early to Middle Jurassic age and a window of Takla Group volcanic rocks of Late Triassic age. More detailed investigations, consisting principally of 5677 metres of surface drilling in 57 holes and crosscutting, drifting and raising on the Chappelle Vein A, outlined a high-grade gold-silver-bearing shoot with a strike length of 200 metres, an average width of about 3 metres and extending to an average depth of about 40 metres below surface.

Over 2000 soil, silt and rock samples from the Chappelle property have been collected and analyzed. Reconnaissance stream sediment surveys indicated anomalous copper and molybdenum values. More detailed stream sediment coverage was obtained to produce a silt sample site-density of about 9 per square kilometre in the property area. Limited soil sampling over the known mineralized part of Veins A and B showed contents of up to 3 grams gold per tonne (0.08 oz/ton) and up to 70 grams silver per tonne (2.0 oz/ton). Stream sediment from drainages in the vicinity of these veins is anomalous in gold and silver.

2. Bobrowsky, P.T., Kerr, D.E., Sibbick, S.J. and Newman, K. (1993): **Drift Exploration Studies, Valley Copper Pit, Highland Valley Copper Mine, British Columbia: Stratigraphy and Sedimentology**; *in* Geological Fieldwork 1992, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, pages 427-437.

   Highland Valley Copper mine   Cu   NTS 92I/6, 7, 10 and 11

   Keywords: Valley Copper, Highland Valley, stratigraphy, till, glaciolacustrine, lake sediment surveys.

This paper mainly details the stratigraphy and sedimentology in the Valley pit area of Highland Valley Copper mine, but some relevant comments on drift prospecting are also provided. The mine is located some 370 kilometres northeast of Vancouver. The exceptional thickness of valley-fill sediments documented in Highland Valley is similar to other over-deepened valleys of the southern Interior Plateau. Large lakes such as Kamloops, Okanagan and Shuswap and others in the region, occupy structurally controlled valleys which were glacially eroded to depths exceeding 400 metres below the present surface. Highland Valley provides another example of this pattern, differing only in that it does not support an active lake environment but is instead filled with a complex sequence of glacial and nonglacial sediments. It is reasonable to suggest that most of the glaciated valleys in the region are similar insofar as they are probably overdeepened and now filled with complex Quaternary deposits. In the immediate vicinity of Highland Valley, this could include Pimainus Lakes valley, Guichon Creek valley and Nicola valley. The near-surface sediments in these valleys probably bear little resemblance (genetically or geochemically) to the underlying surficial deposits and bedrock. Drilling costs are expected to be high considering the potentially thick accumulation of sediment. Most of the valley-fill sediments in the Highland Valley are glaciolacustrine deposits, a characteristic shared by the large lakes listed above and a feature probably typifying other valleys. Since ancient lake sediments may provide a reliable sampling medium for exploration, the authors suggest that exploration strategies in the valleys sample lake sediments which are present at depth beneath the uppermost glacial sediment cover.

3. Bolviken, B. and Gleeson, C.F. (1977): **Focus on the Use of Soils for Geochemical Exploration in Glaciated Terrain**; *in* Geophysics and Geochemistry in the Search for Metallic Ores, Hood, P.J., Editor, *Geological Survey of Canada*, Economic Geology Report 31, pages 295-326.

   Lornex porphyry copper orebody Cu NTS 92I/11

   Keywords: Lornex, gaseous dispersion, H_2S, SO_2, mechanical dispersion, till, glacial transport.

Large portions of the earth's surface have been glaciated several times during the last 2 million years. The overburden in these areas is made up of glacial drift, which has been laid down by the action of glaciers and their meltwaters and thereafter subjected to postglacial processes. In glacial terrain, therefore, geochemical dispersion can be divided into two main classes: (1) syngenetic dispersion, that is principally mechanical or particulate dispersal which took place during glaciation; and (2) epigenetic dispersion, that chemical and mechanical dispersion which has taken place after glaciation. In combination, these processes may result in intricate geochemical dispersion patterns and anomalies that are difficult to interpret. The sampling and analytical methods used should therefore be those which will disclose anomalies that are genetically not too complex. Interpretation of syngenetic patterns presupposes a thorough knowledge of the glacial history. To obtain meaningful results, it is frequently necessary to sample tills in section to the bedrock surface. This often requires heavy equipment and sampling costs may be relatively high. The analytical methods used should employ rigorous chemical digestion as well as mineralogical determination of resistant minerals.

Epigenetic dispersion patterns in glacial overburden can be produced downslope due to metal dispersion in groundwater, or immediately over the bedrock source due to capillary forces, biological activity or gaseous movement of volatile compounds. Mineral deposits in contact with groundwater may act as natural galvanic cells which may result in electrochemical dispersion of metals into the overlying glacial drift. Epigenetic dispersion patterns may be detected in near-surface soils at relatively low sampling costs and by weak chemical extraction. Empirical evidence supporting these principles is provided by published and unpublished data. This paper reviews those data that have appeared in the western literature during the last decade, the intention being to outline the present state of the art in utilizing analysis of soil samples as an exploration tool in a glacial terrain.

4. 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.

   Capoose batholith area Cu, Mo NTS 93F/6

   Keywords: Capoose batholith, stream sediment geochemistry, pedogeochemical profiling, glacial overburden, biogeochemistry, factor analysis.

A geochemical exploration survey was carried out in the Capoose Lake area of central British Columbia. Drainage sediments, stream waters, soil profiles, bogs and trees were sampled at a density of not less than one sample per square mile. In addition, the pH of the stream and bog waters was recorded. All samples were analyzed for copper, molybdenum, lead and nickel. The area features a large granodiorite batholith surrounded by an arcuate range of volcanics. A number of known and inferred areas of copper-molybdenum mineralization are present in the batholith. In the volcanics one area of lead and possibly zinc, mineralization is known. Glaciation in the area is characterized by the formation of ground moraine, of variable thickness, which covers the entire batholith. Reproducible anomalies and associations exist among the various sampling media. A compilation of the factors obtained from a factor analysis of the soil data indicates the presence of mineral zoning within the batholith. Application of factor analysis to stream sediment and soil data indicates that this type of statistical treatment is useful in classifying batholiths with respect to porphyry copper-molybdenum potential.

5. Bradshaw, P.M.D., Clews, D.R. and Walker, J.L. (1979): **Canadian Problems - Valley Glaciated and Non-glaciated Areas**; *in* Exploration Geochemistry, *Barringer Research Ltd.*, Toronto, pages 41-49.

   Newman copper property (Bell mine)
   Boss Mountain, Cariboo-Bell deposits
   Cu, Mo NTS 93L, 93A/2, 93A/12

   Keywords: Valley glaciations, soil geochemistry, boulder clay, hydromorphic dispersion, analytical extractions, stream sediment geochemistry.

Valley and non-glaciated areas account for approximately 25% of Canada's land surface, principally in British Columbia, the Yukon Territory and the Maritime Provinces. Historically the use of exploration geochemistry in these areas has been more advanced than in the continentally glaciated Canadian Shield. This is due to the fact that the soils are generally in part residual and standard geochemical exploration methods are applicable in most of the areas. The factors discussed here are by no means exhaustive, but are chosen in an effort to cover the commonly encountered difficulties. Various aspects of geochemical exploration are discussed, including soil sampling, differences between soil horizons, masking effects, the influence of volcanic ash, hydromorphic dispersion and laboratory procedures.

6. 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.

Cariboo-Bell copper deposit	Cu, Au	NTS 93A/12

Keywords: Soil profiles, till, alpine glaciation, Cariboo-Bell, hydromorphic dispersion, chemical extractions.

This paper deals briefly with the principles of geochemical migration in the secondary (soil, sediment) environment, a knowledge of which is essential to a correct interpretation of exploration geochemical data. Examples are given which illustrate that the principles which apply in the more easily interpreted tropical areas, also apply in the more complicated glaciated regions. Any person using exploration geochemistry in geomorphically complicated areas is well advised to study data from strictly residual soil areas where the fundamentals of geochemical migration are more easily observed. From this base it is easier to understand the additional complications of geochemistry in mountainous and glaciated terrain. Of the variety of exploration geochemical techniques which can be used, this paper deals specifically with two: soil-profile sampling and different strengths of acid extraction of metal from samples. Examples from the different environments are compared and contrasted.

7. Brummer, J.J., Gleeson, C.F. and Hansuld, J.A. (1987): **A Historical Perspective of Exploration Geochemistry in Canada - The First 30 Years**; *Journal of Geochemical Exploration*, Volume 28, pages 1-39.

Canadian Cordillera	Cu, Zn, Pb, Mo, Au, Ag	Various NTS regions

Keywords: Stream sediments, biogeochemistry, pathfinder element, overburden, soils.

The history of geochemical exploration in Canada during the period from its initiation in 1938 by Dr. Hans Lundberg to 1968 is outlined in this paper. During this 30-year period, methods based on rock, soil, drainage sediment and vegetation analyses in areas as varied as those in the Appalachian orogen, the Canadian Shield and Cordilleran orogen have been applied with considerable success. Geochemical methods have led directly to or assisted in the discovery of some 18 significant metal deposits of a varied nature in Canada during this period and since then of another 23 deposits. The discoveries include: porphyry copper and molybdenum deposits, lead-zinc-silver deposits, zinc deposits, a rare earth deposit, uranium deposits and precious metal deposits.

8. Cargill, D.G., Lamb, J., Young, M.J. and Rugg, E.S. (1986): **Island Copper**; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 206-218.

Island Copper orebody	Cu, Mo	NTS 92L/11

Keywords:Island Copper, soil geochemistry, Cu-porphyry, biogeochemistry, magnetic surveys, induced polarization.

The Island Copper mine consists of 357 mineral claims and commenced production in 1971. Soil geochemical and geophysical surveys were undertaken, followed by drilling to define the orebody. The soil geochemical survey consisted of 4200 samples taken from the soil horizon immediately below the organic cover. Analyses ranged from background values of less than 70 ppm copper to strongly anomalous values of more than 200 ppm copper. The anomaly defined by the 200 ppm contour is approximately in the centre of the orebody. This anomaly corresponds to that part of the orebody overlain by less than 9 metres of overburden. Subsequent biogeochemical surveys indicated that the A soil horizon, hemlock bark and hemlock needles were also anomalous over the centre of the orebody. Ground and aeromagnetic surveys show an irregular shaped magnetic anomaly of more than 3000 gammas over the orebody. Induced polarization surveys, conducted over the geochemical anomaly, provided resistivity results which are inconclusive due to overburden thickness in the vicinity of the ore zone.

9. Carr, J.M., Bradshaw, P.M.D. and Smee, B.W. (1975a): **Cariboo Bell Cu Deposit, British Columbia**; *in* Conceptual Models in Exploration Geochemistry, *Journal of Geochemical Exploration*, Volume 4, Number 1, pages 60-62.

Cariboo-Bell copper deposit	Cu, Au	NTS 93A/12

Keywords: Cariboo-Bell, brunisol, podzol, chernozem, soil geochemistry, drainage.

The soil on the Cariboo-Bell property consists of three main types developed on till. The most prevalent is a brunisol which, when freely drained, becomes a podzol.The second type is found in bogs and is a chernozem. The third type is a gleysolic soil which is found near the edges of bogs and in the valley bottom. Erratic anomalous highs are controlled by topography and the development of seepage anomalies and show only a weak coincidence with subcropping mineralization. The profile collected from well-drained soil over mineralization shows a uniform level of copper content with depth in the mineral soil. The profile taken at the break in slope shows an order of magnitude decrease in total copper concentration with depth down to background values. The profile collected from a bog, although strongly anomalous throughout its depth, also shows significant drop in metal content with depth.

10. Carr, J.M., Bradshaw, P.M.D. and Smee, B.W. (1975b): **Afton Cu Deposit, British Columbia**; *in* Conceptual Models in Exploration Geochemistry, *Journal of Geochemical Exploration*, Volume 4, Number 1, pages 47-49.

Afton copper deposit	Cu	NTS 92I/10

Keywords: Afton deposit, Cu porphyry, luvisol, till, soil profiles, caliche.

The Afton porphyry copper deposit comprises native copper, chalcocite, bornite, chalcopyrite and pyrite, both disseminated and as fracture fillings. The paper describes copper distribution in several soil profiles along three transects developed in thin till (1 to 3 metres) over weathered and altered bedrock with oxidation to depths of 60 metres. Near-surface and subsurface soils reflect the presence of mineralization although the anomalies are generally very weak. The occurrence of a poorly developed caliche layer does not appear to have a direct effect on the anomaly.

11. Carr, J.M. and Reed, A.J. (1976): **Afton: A Supergene Copper Deposit**; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 376-387.

Afton copper deposit | Cu | NTS 92I/10E

Keywords: Afton, copper, soil geochemistry, soil profiles, glacial dispersion, till.

This paper reports mainly on the geology of the Afton copper deposit, but some relevant comments on soil geochemistry are also provided, with an accompanying map. The deposit is located at the 640-metre elevation in sagebrush country, 13 kilometres west of Kamloops. Except in an old prospect pit near its east end, the orebody was hidden by Tertiary and Pleistocene cover up to 27 metres thick and by a salt pond. Soil samples were collected from the B soil horizon at depths of about 20 centimetres, and analyzed for total copper. A population of background values in samples distant from known mineralization and chiefly representing Nicola volcanic and sedimentary terrain south of the pluton, has a normal distribution with a mode of 85 ppm copper, a mean of 88 ppm and a standard deviation of 21 ppm. A very large anomalous area defined by values greater than 200 ppm copper reflects mainly the southwestern pyrite zone, but is broadened southeastward because of glacial dispersion. This anomaly encloses the eastern part of the deposit and extends southeastward for more than 1500 metres. Within this broad area, several more intense anomalies are defined by the 500-ppm copper contour. The largest is 600 metres south of the orebody and coincides with abundant outcrops containing minor, widely distributed, sulphides. The orebody lacks a directly overlying soil anomaly because of a thick glacial cover at the western end, Eocene strata elsewhere and the presence of a salt pond. Immediately to the east, however, two parallel anomalies, each 300 metres long and trending at 115°, reflect glacial dispersion of ore around a central hump of bedrock situated at the eastern limit of the orebody. A bedrock knob 150 metres down-ice from the orebody has produced a narrow anomalous layer that fans upward through the thin till mantle to produce local, very high, copper values in the overlying soil.

12. Carson, D.J. and Jambor, J.L. (1976): **Morrison: Geology and Evolution of a Bisected Annular Porphyry Copper Deposit**; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 264-273.

Morrison deposit | Cu | NTS 93M/1W

Keywords: Morrison, porphyry deposit, weathering, stream sediments, overburden, glaciation, soils.

This paper reports mainly on the geology of the Morrison deposit, but some relevant comments on erosion and weathering are also provided. The deposit is a strongly zoned, annular porphyry copper deposit located north of Babine Lake with geological reserves of about 86 million tonnes averaging 42% copper. It was discovered in 1963 by the Norpex Syndicate during follow-up of anomalous copper concentrations in stream sediment samples. Trenching of the thin overburden uncovered relatively unweathered chalcopyrite-bearing bedrock in large areas on both sides of the stream, where soil samples were anomalous.

The authors concluded that if post-Eocene supergene enrichment occurred at Morrison (as at the nearby Bell Copper deposit), its effects were removed by later erosion and glaciation. Tertiary erosion and Pleistocene glacial scouring exposed the copper zone and surrounding hydrothermally altered rocks and carved a gully along the Morrison fault. Postglacial weathering is very minor.

13. Champigny, N. and Sinclair, A.J. (1982): **Cinola Gold Deposit, Queen Charlotte Islands, B.C. - A Geochemical Case History**; *in* Precious Metals in the Northern Cordillera, Levinson, A., Editor, *The Association of Exploration Geochemists*, pages 121-137.

Cinola gold deposit | Au | NTS 103F/9

Keywords: Cinola deposit, primary dispersion, secondary dispersion, soil geochemistry, stream sediments, threshold selections, probability graphs.

The Cinola deposit, a large-tonnage, low-grade gold deposit on Graham Island (Queen Charlotte Islands), was subject to extensive geochemical exploration shortly after its discovery in 1970. The authors reviewed the available rock, soil and silt multi-element geochemical data from this early exploration stage in a rigorous, statistically oriented manner and in the light of substantial geological information about the deposit. Some specific conclusions from this study are: (1) silver lithogeochemical data define the centre of the mineralized zone better than gold data. This is due to a more confined primary dispersion of silver relative to gold; (2) copper, nickel, cobalt, lead, zinc and molybdenum in rocks, soils or silts do not provide clear cut patterns or high enough abundance levels for use in exploration; (3) mercury in soils and in peat shows a pronounced secondary dispersion pattern, apparently due to fluid transport eastward from the main centre of mineralization; (4) threshold selection using probability graphs is a useful practical approach to evaluate spatial distribution patterns of subpopulations in geochemical data sets.

14. Coker, W.B. and DiLabio, R.N. (1989): **Geochemical Exploration in Glaciated Terrain: Geochemical Responses**; *in* Proceedings of Exploration '87, Garland, G.D., Editor, *Ontario Geological Survey*, Special Volume 3, pages 336-383.

Buttle Valley; St. Elias Mountains

Cu, Zn, Pb, Co, Au, Ag | NTS 92F/12, 114P/12E

Keywords: Glacial drift, soil geochemistry, grain size, drilling, dispersal trains, glacial comminution.

Mineral exploration in regions that were glaciated during the Quaternary period is hampered by the scarcity of outcrops and by the variable thickness of allochthonous glacial drift that mantles the bedrock. Geochemical strategies that have been successful in exploration usually involve an understanding of the history of the glaciated landscape.

Stratigraphic drilling programs and major reconnaissance surveys of till geochemistry have provided baseline data for other geochemical sets, mineral exploration, bedrock mapping and environmental studies. Data on surficial geology, glacial stratigraphy and ice-flow directions have been collected to aid interpretation of till geochemistry. Research on the residence sites of metals in till has indicated that specific grain-size ranges and mineralogical forms hold the bulk of the metals, depending on the species of primary metal-bearing minerals and the history of glacial comminution and weathering.

15. Cook, S.J. (1991): **The Distribution and Behaviour of Platinum in Soils of the Tulameen Ultramafic Complex, Southern British Columbia: Applications to Geochemical Exploration for Chromitite-associated Platinum Deposits**; unpublished M.Sc. thesis, *The University of British Columbia.*

Tulameen Ultramafic Complex,

Grasshopper Mountain Pt NTS 92H/10

Keywords: Grasshopper Mountain, Tulameen Complex, platinum, soil geochemistry, heavy minerals, soil profiles, till, colluvium, stream sediment geochemistry.

Exploration for chromitite-associated platinum (Pt) deposits is hampered by a poor understanding of the distribution and behaviour of platinum in the surficial environment. This study investigates platinum content, residence sites and PGE mineralogy of soils developed on till and colluvium above the Tulameen Ultramafic Complex in southern British Columbia.

Seventy-six soil profiles, as well as sediments, bogs and waters were sampled above the dunite core of the Tulameen Complex, within which platinum occurrences consist of massive to discontinuous segregations of platinic chromitite. Platinum content of the -212-micron fraction of soils and sediments was determined by fire assay - inductively coupled plasma spectroscopy. Samples from 14 selected profiles were then examined in detail to determine platinum mineralogy and its distribution between different size, density and magnetic fractions.

Platinum concentrations in the -212-micron fraction of the C-horizon soils range from 2 to 885 ppb and are closely related to soil dunite content, as estimated from MgO content and verified by X-ray defraction mineralogy. Dunite colluvium (mean: 24.2% MgO), locally derived dunitic till (mean: 16.5% MgO) and exotic non-dunitic till (mean: 5.7% MgO) have median platinum concentrations of 88 ppb, 36 ppb and 8 ppb respectively. This trend is evident in all grain-size and density fractions. Platinum content of heavy mineral (SG 3.3) fractions is ten to twenty times greater than in light mineral fractions. Platinum is most abundant in the heavy magnetic fraction from non-dunitic tills and dunitic tills remote from known mineralization, but the proportion of platinum in the heavy nonmagnetic fraction increases with increasing proximity to mineralization.

Scanning electron microscope and microprobe studies of heavy fractions from C-horizons identified platinum-iron-copper alloys as free grains and as inclusions in magnesium silicates and chromites. Chromite occurs as magnesium-chromite-rich anhedral fragments and as iron-rich euhedral to subhedral crystals. The latter, relatively more important in the magnetic fraction, are interpreted as platinum-poor grains disseminated throughout the dunite whereas fragments are relatively more important in the non-magnetic fraction and are interpreted as remnants of platinum-bearing massive chromitite segregations. The abundance of chromite fragments in soils near chromitite segregations accounts for the high platinum content of the nonmagnetic heavy fractions of these soils.

The -270-mesh fraction or the heavy magnetic fraction of C-horizon soils would be the most suitable sample media for reconnaissance geochemical sampling. However, the greater contrast, more limited dispersion and magnesium-chromite-rich chromite association of the non-magnetic heavy fraction make it a more suitable medium for detailed geochemical sampling.

16. Cook, S.J. and Fletcher, W.K. (1993): **Distribution and Behaviour of Platinum in Soils, Sediments and Waters of the Tulameen Ultramafic Complex, Southern British Columbia, Canada**; *Journal of Geochemical Exploration,* Volume 46, pages 279-308.

See also: Cook, S.J. and Fletcher, W.K. (1989): **Preliminary Report on the Distribution and Dispersion of Platinum in the Soils of the Tulameen Ultramafic Complex, Southern British Columbia**; *in* Geological Fieldwork 1989, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1990-1, pages 511-518.

Tulameen Ultramafic Complex,

Grasshopper Mountain Pt NTS 92H/10

Keywords: Grasshopper Mountain, Tulameen Complex, platinum, soil geochemistry, stream sediment geochemistry, populations, till, colluvium.

This paper reports platinum content of surficial media associated with platinum-rich chromitites in the dunite core of the Tulameen Ultramafic Complex. Platinum content of the -212-micron fraction of soils and sediments was determined by fire assay - inductively coupled plasma spectroscopy. C-horizon soils on dunite colluvium (mean: 24.2% MgO), locally derived dunitic till (mean: 16.5% MgO) and exotic non-dunitic till (mean: 5.7% MgO) have median platinum concentrations of 88 ppb, 36 ppb and 8 ppb, respectively. Corresponding medians in ashed LFH horizons are 65 ppb, 13 ppb and 7 ppb platinum. Platinum values of 8-91 ppb are found in sediments from the small stream that drains the area. Stream and bog waters contain less than 1 ppt to a maximum of 2.45 ppt platinum.

Geochemical patterns for platinum indicate that glacial transport and mass wasting are the dominant processes that control distribution in soils on Grasshopper Mountain. There is also slight evidence for very limited hydromorphic mobility of platinum and for its accumulation in bogs. During routine exploration geochemical programs, the considerable local variability in soil parent materials and related variations in background concentrations need to be taken into account in evaluating the significance of platinum values. This requires careful identification of soil parent materials. Soil MgO content provides a useful index of the dunite content of till for this purpose.

17. Cooke, B.J. and Barakso, J.J. (1987): **Soil and Plant Geochemical Orientation Surveys on the Congress Property, Bridge River District, B.C**; *in* GeoExpo /86, Elliott, I.L. and Smee, B.W., Editors, *Association of Exploration Geochemists,* pages 77-82.

Congress property Au, Ag NTS 92J/15

Keywords: Congress property, brunisolic soils, biogeochemistry, Douglas fir, ponderosa pine, pedogeochemistry.

The purpose of this paper is to report on geochemical orientation surveys carried out on the Congress property in 1984 and 1985. In particular, soil and plant samples were collected over two known gold zones in an attempt to identify the optimum sample medium for detecting gold-silver-arsenic-antimony vein mineralization in the Bridge River district. Soil profile studies over the Howard and Extension zones show that well developed brunisolic soils occur in the Bridge River district, but they contain a volcanic ash layer between the A and B horizons. The B-horizon gives pronounced gold, arsenic, antimony, cadmium and thallium anomalies over mineralized zones where glacial overburden is thin (<5 metres). Soil orientation survey lines over the two veins indicate that although the LFH horizon does contain moderate gold and arsenic anomalies and weak antimony anomalies, they are not as strong as the anomalies in the B-horizon for gold, silver, arsenic and antimony.

Plant sample studies over the Howard and Extension zones show that the vegetation is typical, subalpine coniferous forest, dominated by Douglas fir on the north slopes and ponderosa pine on the south slopes. Douglas fir first-year growth gave pronounced arsenic and gold anomalies above the mineralized zones. Ponderosa pine produced moderate gold, antimony, silver and arsenic anomalies, indicating that it too can be sampled in prospecting for gold. Plant orientation survey lines over the two veins suggest that biogeochemical samples do produce significant anomalies that can be ranked as follows: 1) arsenic in Douglas fir > ponderosa pine; 2) gold in Douglas fir > ponderosa pine; 3) antimony in ponderosa pine > Douglas fir; and 4) silver in Douglas fir > ponderosa pine. Although first year stems were the preferred sample medium, it was found that not enough material was available at each sample site due to lack of trees or sparsity of branches. Whole-branch sample results were generally lower but more consistent than first-year growths, so they were used in subsequent biogeochemical surveys. It was found that low-order gold, antimony, silver and arsenic biogeochemical anomalies were detectable over 10 metres of overburden, up to 100 metres from subcropping gold mineralization, whereas pedogeochemical anomalies were restricted to about 50 metres from the source and 5 metres of overburden. Sampling different trees over the same lines at the same spacings but different times of year (July vs. December), indicated that the same anomalies were identified but the numbers were quite variable from season to season. As the July survey gave lower numbers than the December survey, there must be more uptake of metals in the relatively wet winters compared to the usually dry summers, contrary to the normal spring-dominant growth cycle of most plants. Therefore, follow-up biogeochemical surveys should be carried out at the same time of the year as previous surveys in order for the data to be comparable.

18. Coope, J.A. (1975a): **Sheslay Cu-Mo Prospect, British Columbia**; *in* Conceptual Models in Exploration Geochemistry, *Journal of Geochemical Exploration*, Volume 4, Number 1, pages 97-99.

Sheslay Cu-Mo prospect Cu, Mo NTS 104K

Keywords: Sheslay prospect, Cu porphyry, cold-extractable heavy metals, seepage, soil geochemistry, soil creep.

The Sheslay prospect lies on a rolling plateau area and consists of widespread disseminated sulphides consisting of pyrite with lesser amounts of chalcopyrite and molybdenite. This study is based on two soil traverses down a hillside in well-drained residual soils to soils with extensive seepage. The distribution of copper, molybdenum and cold-extractable heavy metals in soils along the two traverses is presented. From this case history, it is apparent that cold-extractable methods on drainage material would be the most satisfactory reconnaissance technique in the Sheslay area to prospect for disseminated copper mineralization. However, these methods of soil analysis are likely to give misleading results if the mobility of the copper in the environment and its concentration in seepage areas are not studied.

19. Coope, J.A. (1975b): **Ingerbelle Cu Deposit, British Columbia**; *in* Conceptual Models in Exploration Geochemistry, *Journal of Geochemical Exploration*, Volume 4, Number 1, pages 75-76.

Ingerbelle copper deposit Cu NTS 92H/7

Keywords:Ingerbelle deposit, glaciofluvial sediments, boulder clay, weathered bedrock, soil geochemistry, soil profile.

The Ingerbelle mine is located south of Princeton on the eastern side of the Cascade Mountains. The mineral deposit is overlain by glaciofluvial gravels of variable thickness, from 0 to approximately 15 metres. Soil development is shallow (to 50 centimetres) and podzolic. A single soil profile illustrates the distribution of copper through transported glaciofluvial deposits and boulder clay into weathered bedrock to a total depth of 265 centimetres. The bedrock at this point is weakly mineralized andesite with approximately 0.15% copper. The transported glacial material (waterlain glacial sands and boulder clay) completely masks all geochemical response in the overlying soil.

20. Davidson, A.J. and Pirie, I.D. (1987): **The Rea Gold Massive Sulphide Deposits, Adams Lake, B.C.: A Geochemical Exploration Study**; Abstract, *in Journal of Geochemical Exploration*, Volume 29, page 390.

Rea Gold massive sulphide deposit
Au, Ag, Cu, Zn, Pb NTS 82M/4

Keywords: Rea Gold, soil geochemistry, heavy minerals, stream sediment geochemistry, soil profiles, downslope dispersion.

The original showing was discovered by Mr. A. Hilton as a result of persistent prospecting using a colorimetric geochemical field kit. Anomalous soil and silt samples localized the prospecting to an area of active logging where a red hematitic gossan overlying massive sulphides was exposed. Later, heavy mineral stream-sediment sampling by Corporation Falconbridge Copper also highlighted the deposit area. A detailed B-horizon soil survey both up and downslope from the original showing accurately located both massive sulphide lenses, although the downslope dispersion of some elements is significantly greater than others. Additional soil sampling defined a mineralized chert horizon at a lower stratigraphic level. Drill testing of this horizon has also confirmed the soil results.

21. Day, S. (1985): **A Petrographic and Geochemical Comparison of Massive Sulphide Boulders in East Arm Glacier, St. Elias Mountains, British Columbia with the Windy Craggy Deposit**; unpublished B.Sc. thesis, *The University of British Columbia*, Vancouver.

East Arm Glacier, Windy Craggy deposit
Cu, Co, Zn, Ag, Au NTS 114P/12E

Keywords: East Arm Glacier, Windy Craggy, massive sulphide boulders, outwash, probability graphs, multiple regression models.

Boulders of banded massive sulphides in outwash from the East Arm Glacier in the St. Elias Mountains are compared petrographically and geochemically with massive sulphide samples from the Windy Craggy copper-cobalt-zinc-silver-gold deposit to determine whether the deposit could be a possible source for the boulders. The petrographic study involved examination of hand samples, polished sections and thin sections to determine the mineralogical and textural characteristics of the suites. This was followed by a statistical study in which probability graphs, scatter plots, correlation diagrams and simple univariate comparison tests were used to determine trends within the datasets and to compare the results between datasets. Geochemically the East Arm boulders and the Windy Craggy deposit are very similar although there are subtle differences in ratios and intercorrelations of elements. Multiple regression models generated for the boulders do not appear to be good models for Windy Craggy.

22. Day, S. (1988): **Sampling Stream Sediments for Gold in Mineral Exploration, Southern British Columbia**; unpublished M.Sc. thesis, *The University of British Columbia*.

Tsowwin River, Salmonberry Creek,
Franklin River, Harris Creek,
Watson Bar Creek Au NTS 92E/15, 92F/03, 04, 92F/02, 82L/02, 92O/01

Keywords: Stream sediments, placer gold, Tsowwin River, 'Salmonberry Creek', Franklin River, Harris Creek, Watson Bar Creek.

The problems encountered by exploration geochemists when sampling stream sediments for gold were investigated by considering the sparsity of free gold particles and their tendency to form small placers at certain locations in the stream bed.

Fourteen 20-kilogram samples of -5-millimetre sediment were collected from contrasting energy and geochemical environments in five streams draining gold occurrences in southern British Columbia. The samples were sieved to six size fractions (420 μm to 52 μm) and gold content was determined by neutron activation analysis following preparation of two density fractions using methylene iodide. Gold concentrations were converted to estimated number of free gold particles and the Poisson probability distribution was used to show that much larger field samples (>100 kilograms of -1-millimetre screened sediment) would be required to reduce random variability due to nugget effects to acceptable levels. However, in a comparison of conventional sampling methods, the lowest probability of failing to detect a stream sediment gold anomaly is obtained using the sampling method described in this study.

Small-scale placer formation was investigated by collecting twenty 60-kilogram samples of -2-millimetre sediment from ten locations along 5 kilometres of Harris Creek in the Okanagan region, east of Vernon. Samples were prepared and analyzed as described above, though heavy-mineral concentrates were only prepared for two size fractions. Gold was found to be considerably enriched in sandy gravel deposits, with the effect decreasing as sediment size decreased. The level of enrichment varies on the stream in response to changing channel slope and local hydrologic conditions. Gold anomaly dilution is apparent in sand deposits but not apparent in sandy gravel deposits as gold is preferentially deposited in gravels as channel slope decreases. These results are presented in the framework of H.A. Einstein's sediment transport model.

Sediment collected from gravels may represent the best geochemical sample as placer-forming processes produce high gold concentrations, however, in very high energy streams, the small quantities of fine sediment in gravels may lead to unacceptable nugget effects. In the latter case, a sample collected from a sand deposit is a satisfactory alternative.

23. Day, S., Broster, B.E. and Sinclair, A.J. (1987): **Sulphide Erratics Applied to Subglacial Exploration: St. Elias Mountains, British Columbia**; *Canadian Journal of Earth Sciences*, Volume 24, pages 723-730.

East Arm Glacier area Cu, Co, Zn, Ag, Au NTS 114P/12E

Keywords: Sulphide erratics, subglacial exploration, glacial drift, ice flow, scatter plots, regression models.

Petrographic and geochemical data from glacial erratics provide evidence for a hidden subglacial source when compared with data from the only known sulphide deposit outcropping locally. These results are in agreement with geological and glaciological studies conducted as part of a reconnaissance exploration program. It is suggested that the integrated approach described here is an inexpensive and rapid exploration method that can determine the likelihood of additional subglacial occurrences in areas of known deposits.

24. Downing, B.W. and Hoffman, S.J. (1987): **A Multidisciplinary Exploration Case History of the Shasta Epithermal Gold-Silver Deposit, British Columbia, Canada**; *in* GeoExpo /86, Elliott, I.L. and Smee, B.W., Editors, *Association of Exploration Geochemists*, pages 72-76.

Shasta epithermal gold-silver deposit Au, Ag NTS 94E/6

Keywords: Shasta deposit, soil geochemistry, stream sediment geochemistry, till, dispersal trains, resistivity surveys.

The Shasta epithermal vein-stockwork gold-silver deposit is in the Toodoggone gold camp of north-central British Columbia. The property has been explored using geochemical and geophysical surveys, geological mapping and diamond drilling. Two mineralized zones subcrop within a 1000 by 300 metre area over an elevation range of 375 metres.

The Shasta deposit is hosted by orange-weathering, quartz-eye feldspar crystal tuff in a horst block on the flanks of a northwest-trending graben. Pyrite, electrum, acanthite and native silver with minor native gold, chalcopyrite, galena and sphalerite, in chalcedony, calcite and quartz fracture fillings, form stockwork vein systems. Best grades are hosted by silicified breccia at the intersection of two or more vein-filled fractures or faults. The Shasta deposit exhibits features common to othergold prospects in the Toodoggone camp and to epithermal deposits in the southwestern United States and Mexico. Known mineralized zones are reflected by gold, silver, lead and zinc soil anomalies, with gold being dispersed 25 to 100 metres eastwards. A potential 3-kilometre strike length of gold-bearing source rocks is indicated by the geochemical soil survey. Multi-element studies place the southern limit of the favorable quartz-eye feldspar crystal tuff unit 400 metres farther north than was appreciated previously. Known mineralized zones have high resistivities reflecting quartz veining and pervasive silicification. Radem VLF anomalies map major fault zones but do not generally correlate with zones of high resistivity. Areas of silicification and gold-silver occurrence are reflected by low values on a ground magnetometer survey. The Shasta deposit was found by prospecting. Orientation soil and geophysical surveys have detected anomalies near the discovery prospect which have been followed up successfully.

25. Dunn, C.E. and Scagel, R.K. (1989): **Tree-top Sampling From a Helicopter - A New Approach to Gold Exploration**; *Journal of Geochemical Exploration*, Volume 34, pages 255-270.

QR deposit | Au | NTS 93A/12

Keywords: Quesnel River deposit, lodgement till, biogeochemistry, Engelmann spruce, Douglas fir, dispersion train.

Foliage from Douglas fir (*Pseudotsuga menziesii*) tops was collected from 94 sites around the poorly exposed QR gold deposit in central British Columbia. Locally high concentrations of gold in ashed stems suggest a northwestward (down-ice) dispersion train of gold extending uphill for at least 500 metres from the deposit. In addition, a down-slope, hydromorphic dispersion train is evident. All trees sampled are extremely rich in arsenic, but the distribution patterns are less clearly related to the mineralization than those of gold enrichment. Summary statistics of analytical data for 35 elements are provided to serve as baseline information for future studies.

The sampling method, which is described in detail, is simple and cost effective. In one hour the foliage of tree tops from about 50 sites, spaced at intervals of 200 metres or more, can be collected by a three-person helicopter crew. The technique is particularly appropriate for rapidly screening rugged or heavily forested terrain, regardless of snow cover, in order to establish priorities for ground follow-up exploration targets.

26. Fletcher, W.K. (1989): **Preliminary Investigations of Platinum Content of Soils and Sediments, Southern British Columbia**; *in* Geological Fieldwork 1988, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1989-1, pages 607-610.

Franklin Camp, Tulameen Ultramafic Complex,
Scottie Creek | Pt | 82E/9, 92H/7, 10, 92I/14

Keywords: Tulameen Complex, Scottie Creek, Franklin Camp, soil geochemistry, stream sediment geochemistry, heavy minerals.

The lack of information on the distribution of platinum in soils and sediments is limiting application of exploration geochemical methods to the search for platinum deposits in British Columbia. This paper reports results of preliminary investigations of the platinum and palladium content of soils and sediments from the Franklin mining district near Grand Forks, from the Tulameen Ultramafic Complex and from Scottie Creek, north of Cache Creek. Platinum concentrations in soils tend to reflect the amount of ultramafic float in the profile. However, as a result of dilution by till, concentrations close to known bedrock occurrences are often less than 50 ppb. In poorly developed soil profiles there is no obvious redistribution between soil horizons or size fractions. In drainage sediments platinum is very cleanly partitioned into the heavy mineral fraction.

27. Fox, P.E., Cameron, R.S. and Hoffman, S.J. (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 61-71.

Quesnel River (QR) gold deposit | Au | NTS 93A/12

Keywords: Quesnel River deposit, lodgement till, colluvium, boulder trains, soil geochemistry, ice flow.

The Quesnel River (QR) gold deposit is situated near the eastern edge of the Intermontane Belt of British Columbia, in a northwesterly trending volcanic-plutonic assemblage of Upper Triassic to Lower Jurassic rocks. The deposit comprises two separate zones within a series of Triassic-Jurassic basaltic lavas, breccias and tuffs close to a small diorite stock. Hostrocks are pyritic and intensely propylitized. Routine sampling of glacial tills led directly to the discovery of both zones. Two clearly defined dispersion trains were obtained in which down-ice dispersion of gold and pathfinder elements (arsenic, cobalt, iron, antimony, copper, cadmium, lead) are well defined for about 1 kilometre from bedrock sources.

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

Mount Milligan | Cu, Au | NTS 93N/1E, 93O/4W

Keywords: Mount Milligan, geochemical dispersion, soil profiles, till, glaciofluvial sediments, colluvium, hydromorphic dispersion.

This paper examines some of the geochemical aspects of copper and gold dispersion in various surficial deposits at the Mount Milligan porphyry copper-gold deposit. The Mount Milligan deposits are concealed by complex surficial deposits comprising colluvial, morainal and glaciofluvial sediments of variable thickness. Anomalous dispersion patterns of gold and copper in the surficial materials are influenced by the type of surficial deposit and postglacial remobilization due to weathering. Significant differences in mean copper and gold concentrations exist in soils derived from till *versus* soils derived from outwash. The source of this difference is related to the origin of the surficial deposits, specifically the relative proportions of local mineralized material to nonlocal barren material incorporated in the two types of drift. Hydromorphic remobilization of copper resulting from oxidation and acid leaching in the near-surface environment produces steep vertical concentration gradients within soil. B-horizon samples over mineralization may be so depleted in copper as to be indistinguishable from background. Highest copper concentrations are noted in the fine (-80 mesh/-177 μm) fraction, probably due to remobilized copper precipitating as a surface coating on grains. In the Esker Zone trench, a mineralized dispersion train within the glaciofluvial outwash can be traced for a minimum of 50 metres down palaeocurrent from a bedrock source and probably extends beyond this distance. Grid soil sampling on 50-metre spacings would detect the anomalous drift.

Successful application of geochemical techniques in drift prospecting requires a solid understanding of glacial and postglacial processes. Failure to correctly classify surficial deposit types will complicate interpretation of soil geochemistry and may mask true anomalies and indiscriminate sampling of the B and C soil horizons could generate false anomalies.

29. Gunton, J.E. and Nichol, I. (1974): **Delineation and Interpretation of Metal Dispersion Patterns Related to Mineralization in the Whipsaw Creek Area**; *in* Exploration Geochemistry, *Canadian Institute of Mining and Metallurgy*, Volume 67, pages 66-74.

Whipsaw Creek area — Cu, Mo — NTS 92H/7

Keywords: Whipsaw Creek, basal till, soil geochemistry, hydromorphic dispersion, induced polarization, drilling.

The straightforward application of geochemical exploration techniques in certain areas of British Columbia is severely restricted due to marked variations in the surface environment. These variations create a situation in which anomalous metal distributions in the surface material do not necessarily reflect mineralization. A method is described involving deep overburden sampling whereby it has been possible to discriminate localized anomalous zones at depth associated with mineralization within extensive areas of surficial anomalies. Detailed sampling of the surficial material did not reveal any precise reflection of underlying mineralization. Low-grade copper-molybdenum mineralization occurs along the contact between a porphyry intrusive and chloritized extrusives adjacent to a granodiorite stock. The area is one of strong relief, bedrock being overlain by glacial material consisting of glacial till and possibly some stratified drift. A thin veneer of colluvial rubble with poor soil development covers the hill slopes; at the base of the slopes, organic debris has accumulated in narrow swampy areas. Previous geochemical drainage sampling had revealed strong and extensive copper anomalies in certain swamps and soil sampling had shown the presence of only relatively weak anomalies outside the swamp areas. An induced polarization survey over the swamp had indicated local responses, providing evidence of a metal source within the extensive anomalous swamp area and some of the earlier drilling had intersected minor mineralization.These features suggested that the anomalous metal values in the swamp might not be entirely due to accumulation of metal by organic material from background concentrations or remote mineralization.

Soil and organic samples were collected on a grid, together with till samples taken from depths of up to 10 metres, using a Cobra drill and soil sampler. Overburden sampling extended over selected portions of the anomalous swamp, including the area of the geophysical anomaly, and onto adjacent freely drained soils. Analyses of the glacial material underlying the swamp revealed localized areas of strongly anomalous copper relative to the broad anomaly in the surface organic material. The most strongly anomalous samples contained sulphide grains distinguishable under a binocular microscope, indicating a mechanical rather than hydromorphic origin for the anomaly. The zone of mechanically dispersed metal in the till was defined on the basis of the sulphide-held copper (ascorbic acid/hydrogen peroxide extractable) and sulphur distribution. Results of drilling carried out simultaneously with the basal-till sampling indicated that the more localized anomalies were closely related to mineralization.

30. Hicock, S.R. (1986): **Pleistocene Glacial Dispersal and History in the Buttle Valley, Vancouver Island, British Columbia: A Feasibility Study for Alpine Drift Prospecting**; *Canadian Journal of Earth Sciences*, Volume 23, pages 1867-1879.

Buttle Valley — Cu, Zn, Pb — NTS 92F/12

Keywords: Buttle Valley, lodgment till, outwash, dispersal trains, ice flow, soil geochemistry.

Lodgment till exposures in the Myra and Buttle valleys of central Vancouver Island reveal a short (approximately 20 kilometres) glacial dispersal train of Westmin massive sulphide ore in the clay fraction only (copper, zinc, lead). Ore dispersal was eastward down the tributary Myra Creek valley, then northward along the west side of the trunk valley. This study suggests that in alpine drift-prospecting projects, anomalies should be traced up valley into tributary valleys along the same valley side, using the geochemistry of the -0.002-millimetre fraction of the basal till matrix. Fraser glaciation in the valleys eroded and deformed underlying sediments and bedrock while removing evidence of previous glacial events. Glaciolacustrine silt and sand, lodgment till, deltaic recessional outwash and colluvial fans were deposited during the last 25 000 radiocarbon years. Ice movement followed the classical alpine glaciation model. Tributary lobes advanced down-valley and merged (without mixing) to form a main trunk Buttle lobe, which advanced northward, truncating some of the tributary valleys. At the Fraser maximum, glacier ice had built up to cover all but the highest peaks; drumlinoids imply southwestward flow over the highest glaciated ridges. During deglaciation, the Buttle lobe probably retreated rapidly, depositing recessional outwash and glaciolacustrine diamictons.

31. Hodgson, C.J., Bailes, R.J. and Verzosa, R.S. (1976): **Cariboo-Bell**; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 388-396.

Cariboo-Bell deposit — Cu, Au — NTS 93A/12E

Keywords: Cariboo-Bell, soil geochemistry, till, glaciofluvial sediments, soil anomalies, hydromorphic dispersion, geophysics.

This paper reports mainly on the geology of the Cariboo-Bell deposit, but some relevant comments on soil geochemistry and an accompanying map are also provided. This copper deposit is located 56 kilometres northeast of Williams Lake at an elevation of 1160 metres on the west slope of Polley Mountain in the Cariboo district. Although the copper showings on Polley Mountain probably were known locally for decades in this historic gold placer mining area, no record exists of their exploration before 1964. The deposit is mantled by till and glaciofluvial sand and gravel. Geochemically, the principal mineralized zones lie midway along a soil anomaly, 5000 metres long (with 200 ppm copper in the B-horizon), which trends northwestward parallel to the direction of the last glacial advance. The anomaly has three parts of equal length: a central part which is related to mineralized breccias, with overlying soils that contain consistently above 500 ppm copper; a southern part coinciding with pyritic monzonite that contains between 0.05 and 0.1% copper; and a northern part representing glacially transported copper in till. Hydromorphic dispersion of copper from the ore zones is apparently limited, contrary to the significance attributed to it by Bradshaw *et al.* (1974). Gold in soils generally shows a similar distribution to copper but less consistently than copper. Values greater than 30 ppb are considered anomalous and occur above the mineralized zones and throughout the length of the transported anomaly.

32. Hoffman, S.J. (1972): **Geochemical Dispersion in Bedrock and Glacial Overburden Around a Copper Property in South-central British Columbia**; unpublished M.Sc. thesis, *The University of British Columbia.*

Rayfield River copper property Cu NTS 92P/6

Keywords: Rayfield River, glacial deposits, soil geochemistry, stream sediments, boulder tracing, biogeochemistry.

Copper enrichment within glacial overburden is usually detectable over twice the area underlain by bedrock mineralization. Most secondary anomalies overlie batholithic rocks, except in the south where rounded syenite float blocks, mineralogically and structurally similar to the most striking bedrock anomaly, were transported by a glacier down the Bonaparte River valley to where they now overlie Nicola volcanics. On a regional survey, boulder tracing and lake sediment or lake water sampling are most likely to indicate the presence of a mineralized intrusive. Detailed sampling reveals anomalous stream sediments of the Rayfield River and copper-rich talus along the valley sides of the northern half of the property. Detailed soil sampling is not suitable for outlining copper mineralization, as alkaline soil and thick overburden restrict movement of copper ions. Erratic high copper values are usually related to mineralized float or bedrock. Analysis of second year growth of Douglas fir or lodgepole pine apparently does not detect mineralization in bedrock.

33. Hoffman, S.J. (1986): **Case History and Problem 5: A Copper Property**; *in* Exploration Geochemistry: Design and Interpretation of Soil Surveys, Fletcher, W.K., Hoffman, S.J., Mehrtens, M.B., Sinclair, A.J. and Thomson, I., Editors, *Reviews in Economic Geology*, Volume 3, pages 155-180.

McConnell Creek map area Cu, Au 94D

Keywords: McConnell Creek, soil geochemistry, till, stream sediment geochemistry, boulder tracing, alpine glaciation.

This case history illustrates the many interrelated variables that must be considered during interpretation in soil surveys. Recommendations must ensure that follow-up funds are well spent examining *bona fide* anomalies. The probable bedrock source for an anomaly must be predicted and it is a serious error to assume that contoured high values are a "bull's eye" for the bedrock source of metals. Failure to correctly identify anomaly sources at an early stage can seriously distract the exploration effort, resulting in lost time and money.

34. Hoffman, S.J. and Fletcher, W.K. (1972): **Distribution of Copper at the Dansey - Rayfield River Property, South-central British Columbia, Canada**; *Journal of Geochemical Exploration*, Volume 1, pages 163-180.

Dansey - Rayfield River property Cu NTS 92P/6

Keywords: Dansey, Rayfield River, till, glaciofluvial sediments, stream sediment geochemistry, soil geochemistry, dispersal trains.

The Dansey - Rayfield River property is located on the Interior Plateau of south-central British Columbia. Glacial deposits and the alkaline geochemical environment found on the property are typical of the semi-arid interior of southern British Columbia. Variations in copper content of bedrock, glacial float, overburden and stream and lake sediments and waters are described. Mineralized syenite is exposed in crags along the Rayfield River on the northern part of the property. From this source an indicator train of copper-rich syenite float can be traced up to 4 kilometres across the plateau in the direction of ice movement. Lake sediments associated with the mineralized zone also contain above average copper values.

Along the deeply incised valley of the Rayfield River, strong copper anomalies are developed in soils and sediments derived from mineralized syenite. In contrast, on the plateau, where soils and sediments are largely derived from glacial deposits, copper anomalies are either very weak or absent. In soil profiles developed over a variety of parent materials, copper content is shown to increase with depth. This trend, which follows pH, is attributed to leaching of copper from the surface horizons and its accumulation under increasingly alkaline conditions. Because of the limited solubility of copper in alkaline waters, the Rayfield River (pH 7.8) does not contain anomalous concentrations of dissolved copper. On the basis of these results, glacial float or lake sediment sampling are suggested as potentially useful techniques for reconnaissance geochemical exploration in southern British Columbia.

35. Horsnail, R.F. (1975): **Highmont Cu-Mo Deposits, British Columbia**; *in* Conceptual Models in Exploration Geochemistry, *Journal of Geochemical Exploration*, Volume 4, Number 1, pages 67-72.

Highmont Cu-Mo deposits Cu, Mo NTS 92I/7

Keywords: Highmont, geochemical anomalies, soil profiles, podzol, ice flow, hydromorphic dispersion.

The Highmont copper-molybdenum deposits are in the southern part of the Highland Valley porphyry copper district. Soil geochemistry survey data show the effect of mechanical down-ice movement of mineralized rock fragments by glacial action. The occurrence of mineralized rock fragments in the glacial till suggests that the original mode of secondary dispersion was mechanical by means of glacial scouring. Much of the fine-grained fraction of the till is, however, probably relatively near to its point of origin.

Based on comparisons between nine freely and imperfectly drained soil profiles, hydromorphic dispersion followed by organic chelation and accumulation is operative at the present time and this produces considerable distortion of the original till anomaly.

36. Horsnail, R.F. and Elliott, I.L. (1971): **Some Environmental Influences on the Secondary Dispersion of Molybdenum and Copper in Western Canada**; *in* Geochemical Exploration, *Canadian Institute of Mining and Metallurgy*, Special Volume 11, pages 166-175.

Various properties on the West Coast and Central and Southern Interior — Cu, Mo — NTS 92F, 92H, 92P, 93E, 93K

Keywords: Till, fluvial gravels, soil geochemistry, soil profiles, hydromorphic dispersion, analytical techniques.

Certain broad variations in the geochemical environment of British Columbia and their influences on the secondary dispersion of molybdenum and copper, are described. Some complicating factors in the use of geochemistry as an exploration tool for molybdenum and copper mineralization are outlined. Three environments, controlled by topography and climate, are considered: strong relief, high rainfall, podzolic soils; subdued relief, moderate rainfall, interrupted drainage, waterlogged organic-rich overburden; and moderate relief, low rainfall, caliche accumulations in overburden. Some areas of waterlogged overburden show accumulations of copper in organic topsoils where groundwater, made acid by the oxidation of pyrite, enters the swamp. To a lesser degree, enhancement of molybdenum is also apparent. Accumulation of molybdenum, with some tungsten but not accompanied by copper, is observed in areas where swamps are underlain by weakly alkaline clay. In neither case is any accumulation of iron, manganese, cobalt, nickel, lead or zinc apparent. These studies illustrate some effects of the ionic potentials and Eh-pH conditions of aqueous dispersion media on trace element migration. Acid groundwater, particularly in the vicinity of oxidizing pyrite, promotes the mobility of copper, whereas molybdenum is mobile under weakly alkaline conditions.

37. Hornbrook, E.H.W. (1970): **Biogeochemical Prospecting for Molybdenum in West-central British Columbia**; *Geological Survey of Canada*, Paper 68-56.

Lucky Ship molybdenum deposit — Mo — NTS 93L/3, 93L/4

Keywords: Lucky Ship, biogeochemistry, soil geochemistry, podzols, overburden, seismic surveys.

A biogeochemical prospecting program was conducted during the summer of 1967 at a molybdenum prospect to determine the distribution of molybdenum and associated elements in plant organs and soils, and to evaluate the effectiveness of plant prospecting techniques for detecting this and similar deposits. New and modified methods for the collection and preparation of soil and vegetation samples and the spectographic analysis of organic material in mobile trailer laboratories (separately developed during earlier work) were simultaneously used under field operating conditions. A sample grid of 144 stations was established over the deposit and the following materials were collected where possible at each station: B-horizon, Ah-horizon, bark (collected at breast height, 140 centimetres from the ground), second year twigs and needles. Alpine fir, *Abies lasiocarpa*, was sampled at all stations and lodgepole pine, *Pinus contorta*, at 60 stations. Shallow seismic determinations of the depth and nature of surficial material were carried out simultaneously with the geochemical surveys. Organic samples were analyzed spectographically for barium, strontium, manganese, titanium, silver, chromium and cobalt, and soil and vegetation samples were analyzed colorimetrically at the Geological Survey of Canada, Ottawa for molybdenum, copper, zinc, lead and nickel. An examination of the results of the plant prospecting program shows the plant analysis provides a substantially increased contrast of anomalous to background molybdenum concentrations, an increased ground-surface areal extent of the molybdenum anomaly and a more definite demarcation of its boundaries as compared to soil analysis.

38. Hornbrook, E.H.W. (1970): **Biogeochemical Prospecting for Copper in West-central British Columbia**; *Geological Survey of Canada*, Paper 69-49.

Huckleberry Mountain property — Cu, Mo — NTS 93E/11

Keywords: Huckleberry Mountain, biogeochemistry, podzols, soil geochemistry, overburden, seismic surveys.

A biogeochemical prospecting program was conducted during the late summer of 1967 at a copper-molybdenum deposit, to determine the distribution of copper, molybdenum and associated elements in plant organs and soils and to evaluate the effectiveness of plant prospecting techniques for detecting this and other similar deposits. New modified methods for the collection and preparation for soil and vegetation samples and the spectographic analysis of organic material in mobile laboratories (separately developed during earlier work), were simultaneously used during field operations. A sample grid of 96 stations was established over the deposit and the following materials were collected where possible at each station: B-horizon, Ah-horizon, bark (collected at breast height, 140 centimetres from the ground), second year twigs and needles. Shallow seismic determinations of the depth and nature of surficial material were carried out simultaneously with the geochemical surveys. A significant conclusion is that biogeochemical twig and needle results are equally as effective as soil geochemical results in detecting mineralized zones.

39. Kampala, G.J. (1972): **Trace Elements in Soils and Stream Sediments from the Nechako Range, Central British Columbia**; unpublished B.Sc. thesis, *The University of British Columbia.*

Nechako Range — Ba, Sr, Pb, Ni, Mn

Keywords: Nechako Range, soil geochemistry, stream sediment geochemistry, threshold values, statistical analysis.

A geochemical exploration program designed to detect the absence or presence of useful geochemical trends was carried out on the Nechako Range. About 120 samples of soils and stream sediments were collected and analyzed for copper and zinc by atomic absorption, and for barium, lead, nickel and manganese by emission spectroscopy. The results were analyzed statistically to determine the background and threshold values. The program failed to produce definite geochemical patterns which could be related to metallic mineralization, but it helped establish the background and threshold values for the area.

40. Kerr, D.E. and Bobrowsky, P.T. (1991): **Quaternary Geology and Drift Exploration at Mount Milligan and Johnny Mountain , British Columbia**; *in* Exploration in British Columbia 1990, Part B, *B.C. Ministry of Energy, Mines and Petroleum Resources*, pages 135-152.

Mount Milligan, Johnny Mountain
Cu, Au, Ag NTS 93N/1E, 93O/4W and 104B/6E, 7W, 10W, 11E

Keywords: Mount Milligan, Johnny Mountain glacier, drift exploration, till, glaciofluvial sediments, boulder trains, dispersal trains.

The surficial deposits of the Mount Milligan property consist predominantly of diamictons in the form of a till blanket which varies in thickness from 0.5 to over 30 metres. A belt of glaciofluvial sand and gravel is confined to the Heidi Lake valley, but fans out to the east over the MBX stock. Colluvium derived from till and bedrock dominates the hills north and south of Heidi Lake. Drill-hole logs indicate a complex stratigraphic record which changes laterally over short distances. Regional ice-flow was to the northeast as indicated by striae and drumlins. Pebble counts in till reflect local lithologies. Soil geochemical anomalies are classified into three patterns: amorphous-shaped in colluvium, discontinuous or fan-shaped in glaciofluvial outwash and linear in till.

The retreat of Johnny Mountain Glacier over the last 100 years or so has led to the exposure of a well-defined mineralized boulder train over 350 metres long. A strongly developed linear soil geochemical anomaly 0.9 kilometre long associated with the boulder train, together with smaller soil anomalies related to the Camp Glacier, are evident in till deposited by these glaciers. The orientation of the geochemical anomalies within the glaciated basins is parallel to the direction of local ice-flow (NW) as determined by striae. The linear distribution of mineralized clasts on the glacier surface and beyond the ice front, as well as their distribution as defined by ice trenching, suggest a local origin for the float. Glacier mechanics and the presence of debris bands and shear planes in areas where float was observed also point to local erosion of mineralized bedrock as a probable source. On the flats, away from the glacier terminus, regional ice-flow is to the southwest. Here, geochemical anomalies are discontinuous as a result of a complex glacial history of multiple ice-flow directions.

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

Galaxy property Cu, Au NTS 92I/9

Keywords: Galaxy, porphyry deposit, drift exploration, surficial geology, till, soil geochemistry, geochemical dispersion, biogeochemistry.

This paper describes the preliminary results of a drift exploration survey on the Galaxy porphyry copper-gold deposit, located 5 kilometres southwest of Kamloops. Drift sampling in the Galaxy area documents regional patterns of geochemical and lithological dispersion in till within arid regions of the Interior; it also aids in the determination of regional sampling densities and rates of anomaly decay in areas of high mineral potential. The relatively simple Quaternary glacial history and overburden stratigraphy make the Galaxy site amenable to this type of study.

Soil copper contents are generally highest in the C-horizon (till) and lowest in the A-horizon, possibly due to dilution of metal contents in the upper soil horizons by the addition of loess. Preliminary results indicate the existence of a strongly anomalous, ribbon-shaped dispersion train extending for up to 1 kilometre down-ice from the deposit. Copper concentrations about 1500 metres from the deposit average 136 ppm copper, suggesting that a significant (100 ppm) anomaly may extend for a greater distance. Ash from the stems, leaves and flowers of rabbitbush (*Chrysothamnus nauseous*), collected and analyzed by ICP, yielded higher copper contents than corresponding soils at eight of eleven sites, but show no consistent trend with distance from the deposit. Rabbitbush was also found to contain higher mean concentrations of boron, calcium, lead, magnesium, molybdenum, strontium and zinc.

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

Quatsino Multi-elements 92L/12

Keywords: Till , soil geochemistry, Quatsino, Island Copper, ice flow.

This open file package presents the analytical results of a drift exploration project in the Quatsino area, centred over the North Island copper belt on northern Vancouver Island. The -63-micron fraction of till samples were analyzed by instrumental neutron activation (INA) and inductively coupled plasma (ICP) methods. Data for 42 elements are included on 56 separate maps. The report includes a brief description of the surficial and bedrock geology and the Quaternary history of the area as well as the results of a geochemical orientation survey conducted around the Island Copper mine to provide analytical guidelines. Page-size maps of surficial and bedrock geology, ice-flow directions, sample reliability and a sample number mylar overlay are provided. A 1:50 000-scale sample location map and digital data file are also included.

43. Kimura, E.T., Bysouth, G.D. and Drummond, A.D. (1976): **Endako**; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 444-454.

Endako deposit Mo NTS 93K/3E

Keywords: Endako, soil geochemistry, mineralized float, overburden, drift, mechanical dispersion.

This paper reports mainly on the geology of the Endako molybdenum deposit but some relevant comments on soil geochemistry and a map are also provided. The deposit is 160 kilometres west of Prince George. It was discovered in 1927 by follow-up prospecting of mineralized float. An extensive and well defined molybdenum geochemical anomaly, outlined from a soil-sampling grid, is overprinted on the Endako ore deposit. Regional background is 2 ppm molybdenum. Comparatively high values were present directly over the orebody and a long train of anomalous values extends eastward for 5 kilometres. The trend of the anomaly has been directly influenced by eastward glacial movement. The topographic trace of the South Boundary fault sharply delimits the anomaly in a southerly direction. Highest geochemical values across the orebody are located over areas where overburden depth is relatively shallow (0.5 to 3 m). The glacial boulder-clay drift over other parts of the orebody averages about 10 metres and is locally in excess of 25 metres thick. Anomalous values over these deeper areas are assumed to have resulted from mechanical transport and dispersion. Essentially no molybdenum mineralization underlies the easterly trend of the anomaly. Isolated spotty anomalies occur in areas 1.5 to 5 kilometres north and northeast of the Endako orebody. Sources for these anomalies are attributed to local widely scattered molybdenite occurrences.

44. Knauer, J.D. (1975): **Bell Copper (Newman), British Columbia**; *in* Conceptual Models in Exploration Geochemistry, Journal of Geochemical Exploration, Volume 4, Number 1, pages 53-56.

Bell Copper (Newman) deposit — Cu — NTS 93L/16

Keywords: Bell Copper, till, glaciolacustrine, soil geochemistry, hydromorphic dispersion, stream sediment geochemistry.

The Bell Copper orebody, on Newman Peninsula on the east side of Babine Lake, is associated with a small Tertiary biotite feldspar porphyry plug. The overburden over the orebody is approximately 1.5 metres deep on the northwest to 12 metres deep towards the southeast. Initial soil sampling indicated several anomalous values with up to 500 ppm cold HCl extractable copper, immediately west and south of the ore deposit. Sixteen soil profiles also gave a few high values (maximum 1600 ppm copper) slightly downslope from the orebody. Profile results from the orientation survey indicate an absence of any anomaly at surface directly over the orebody, due to the masking effect of the transported glacial overburden. Samples collected from till within a few centimetres of the weathered bedrock are, however, strongly anomalous.

45. Lett, R.E.W. and Fletcher, W.K. (1978): **The Secondary Dispersion of Transition Metals Through a Copper-rich Hillslope Bog in the Cascade Mountains, British Columbia, Canada**; *in* Geochemical Exploration, Proceedings of the Seventh International Geochemical Exploration Symposium, pages 103-115.

Whipsaw Creek — Cu, Co, Ni, Zn — NTS 92H/10

Keywords: Whipsaw Creek, organic soils, lodgement till, soil geochemistry, hydromorphic dispersion.

Copper, cobalt, iron, zinc, nickel, manganese and organic carbon have been studied in a small hillside bog close to a known copper occurrence in the foothills of the Cascade Mountains, British Columbia. The bog is underlain by glacial till that almost completely covers the contact zone between copper-mineralized volcanic rocks and porphyry dikes. Soils with more than 16% organic carbon are enriched in copper, cobalt, nickel and zinc. Metal abundances generally increase with depth, especially where organic soil accumulations exceed 3 metres thickness. Contents of these metals fall sharply in the underlying till except in the northwest corner of the bog where the till contains more than 1000 ppm copper. Iron and manganese contents, however, are generally greater in the till than in organic soil. Subsurface bog waters have higher iron, manganese and organic carbon, but lower copper contents than surface waters. Metal distribution patterns in organic soils suggest that the metals are mostly present as humate complexes. The presence of pyrite concretions and copper sulphide grains, however, is evidence that some of the metal occurs as sulphides. Grains of chalcopyrite, covellite and native copper are present in the western part of the bog where copper-rich ground water discharges from concealed bedrock.

46. Levinson, A.A., Bland, C.J. and Dean, J.R. (1984): **Uranium Series Disequilibrium in Young Surficial Uranium Deposits in Southern British Columbia**; *Canadian Journal of Earth Sciences*, Volume 21, pages 559-566.

North Wow Flats,
Covert Basin, Prairie Flats — U, Th, Ra, Pb — NTS 82E/4, 82E/5, 82E/12

Keywords: North Wow Flats, Covert Basin, Prairie Flats, surficial uranium deposits, hydromorphic dispersion, activity ratio.

The deposits formed from groundwaters that leached labile uranium from intermediate to felsic igneous rocks. Two accumulation mechanisms concentrate the uranium: evaporation and adsorption onto organic matter. The uranium content and activities of the various daughter nuclides are highly variable within and between the various deposits studied. Some of the variations can be explained in terms of the accumulation processes. In the evaporative process the highest value of uranium and daughter nuclides will be found at the surface, whereas in those deposits in which adsorption is the dominant mechanism these nuclides are found in association with buried organic matter. Under these circumstances, accumulations will be influenced by the flow of groundwater from different sources and also depend on whether daughter nuclides remain immobile or are leached after formation.

47. Levinson, A.A. and Carter, N.C. (1979): **Glacial Overburden Profile Sampling for Porphyry Copper Exploration: Babine Lake Area, British Columbia**; *Western Miner*, Volume 52, Number 5, pages 19-32.

Old Fort prospect,
Bell Copper and
Granisle Copper deposits — Cu, Zn, Mo — NTS 93L/16 and 93M/1

Keywords: Old Fort, Bell Copper, Granisle Copper, till, glaciolacustrine, dispersal trains, hydromorphic dispersion.

Profile samples of glacial overburden, obtained from 14 locations in the Babine Lake area, British Columbia, were analyzed for base metals and other geochemical and mineralogical parameters in order to determine the value of glacial till for exploration purposes. The results show great variability in the trace element content and other features within the profiles. Most of the dispersion is considered to be mechanical and a 'total extraction' procedure should be used. Because of the complexity of the glacial deposits and dispersion in this area, the interpretation of the geochemical data is difficult. Accordingly, possible areas of mineral potential in central British Columbia should not be eliminated from consideration solely on the basis of geochemical data obtained from glacial overburden.

48. McDougall, J.J. (1976): **Catface**; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 299-310.

Catface Cu, Mo NTS 92/5W

Keywords: Catface, porphyry deposit, soil geochemistry, silt geochemistry, copper-moss, dispersal trains.

This paper reports mainly on the geology of the Catface deposit, but some relevant comments on geochemistry are also provided. This porphyry copper-molybdenum deposit is located 13 kilometres northwest of Tofino on the west coast of Vancouver Island on a heavily treed peninsula, 4 to 8 kilometres wide. Oxidation of the deposit, under a wet temperate climate and high relief, has been erratic, controlled chiefly by fault zones with resulting irregular and limited secondary enrichment. The deposit is detectable by geochemical and some geophysical methods, particularly self potential. The first soil and silt geochemical surveys on Catface Peninsula used rubeanic acid methods. Results from these surveys were later substantiated by atomic absorption techniques. Copper concentration in soils over and around mineralized outcrops ranges from 10 to 1000 ppm, with a modal range of 150 to 250 ppm. The average pH of the soils, which are subject to an average of 380 centimetres of rainfall per year, ranges from 4.0 to 4.5. "Copper-moss", a distinctive red algae identified as *trentopohlia-iolithus* and used as a prospecting guide because of its association with copper (content up to 200 ppb) or sulphur, is present on some rock surfaces in the area.

49. 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.

Chutanli Mo prospect Mo NTS 93F/7

Keywords:Chutanli, soil geochemistry, till, stream sediment geochemistry, hydromorphic dispersion, ice flow.

An extensive soil anomaly characterized by an up to sixfold anomaly to threshold contrast is developed immediately over the mineralized bedrock and spreads for 2000 metres in the direction of ice transport (which is opposed to that of the drainage). This anomaly is interpreted to have formed by mechanical (ice) dispersion processes. Immediately downslope of the bedrock metal source, intensely anomalous molybdenum values are detectable in the overburden having a maximum anomaly to threshold contrast of forty-eight fold. The mode of occurrence of these intensely anomalous molybdenum values is indicative of a hydromorphic origin.

50. Mehrtens, M.B., Tooms, J.S. and Troup, A.G. (1973): **Some Aspects of Geochemical Dispersion From Base-metal Mineralization within Glaciated Terrain in Norway, North Wales and British Columbia, Canada**; in Geochemical Exploration - 1972, Jones, M.J., Editor, *The Institution of Mining and Metallurgy*, pages 105-115.

Central Interior of B.C. Mo

Keywords: Soil geochemistry, till, dispersal trains, hydromorphic dispersion, lake sediment surveys, stream sediment geochemistry.

This paper presents some results of geochemical research and exploration in glaciated terrain over and in the vicinity of base metal mineralization in Norway, North Wales and the central Interior of British Columbia. These study areas are characterized by siliceous overburden and a topography of rolling hills and broad U-shaped valleys. The climates of the regions however, are somewhat dissimilar, varying from cold and dry to temperate and wet. The results of the investigations show that ore elements are dispersed from their bedrock source beneath glacial till, dominantly in shallow groundwaters and, to a lesser extent, by mechanical (ice) transport and biochemical processes.

It is concluded that secondary metal dispersion patterns related to sulphide mineralization in these and similar environments may be readily detected on a broad regional scale by sampling groundwater seepage sites. Where seepage occurs in lakes as, for example, the central Interior of British Columbia, the existence of bedrock mineralization in the general vicinity of the lakes can be detected by sampling the organic-rich bottom sediments in the deeper parts of these lakes. Interpretation of these seepage anomalies, as well as of anomalies which may occur as a result of seepage in streams or rivers, is dependent on an assessment of groundwater dispersion trains.

51. Meyer, W., Gale, R.E. and Randall, A.W. (1976): **O.K.**; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 311-316.

O.K. property Cu NTS 92K/2E

Keywords: O.K., till, glacial striae, roche moutonnée, geochemistry, geophysics.

This paper reports mainly on the geology of the O.K. deposit, but some relevant comments on geochemical surveys in the area are also provided. The O.K. property, situated near Powell River, was discovered in 1965 by a prospector using a rubianic acid field kit. Since that time, six companies have spent approximately $1 000 000 carrying out preliminary technical surveys and diamond drilling on the property. Approximately 85% of the area is covered by a thin layer of glacial till. Glacial striae and roche mountonnée are oriented southerly. Geochemical surveys for copper and molybdenum were carried out on grids ranging from 35 x 130 to 70 x 260 metres. The major anomalies lie generally within the 0.1% copper trend lines in the deposit. Copper in soil reached a peak value of 12 000 ppm. Two small anomalies of greater than 500 ppm copper in the area are not near known bedrock mineralization. At least one of these anomalies is related to drainage.

52. Miller, D.C. (1976): **Maggie**; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 329-335.

Maggie deposit Cu, Mo NTS 91I/14W

Keywords: Maggie, gossan, till, glaciation, alluvium, porphyry deposit, weathering.

This paper reports mainly on the geology of the Maggie porphyry copper-molybdenum deposit, but some relevant comments on weathering and glaciation are also provided. The deposit, located about 15 kilometres north of Cache

Creek, was discovered in 1970 by percussion and diamond drilling of a till and alluvium-covered area. The thickness of drift cover near the centre of the deposit varies from approximately 30 to 110 metres. Outcrops bordering the covered area contain anomalous copper values associated with strong pyrite mineralization and hydrothermal alteration. Surrounding the deposit, extensive gossans developed from the oxidation of the pyritic halo. In addition to pyrite, this gossan contains an average of 300 ppm copper. Weathering leached most of the sulphides from the gossan zones to a depth of about 2 metres and copper values in leached rock are about half of those obtained in rock below the zone of weathering.

In Quaternary time, the Maggie deposit was eroded and possibly unroofed by glaciation and subsequently covered by thick deposits of till and alluvium. Over the deposit, the oxidized zone was destroyed by the ice and the thick glacial mantle effectively prevented further oxidation. There is no zone of supergene enrichment above the deposit. The deposit is also partially obscured by a small landslide that occurred along the east side of the Bonaparte River valley in the latter part of the Quaternary period.

53. Montgomery, J.H., Cochrane, D.R. and Sinclair, A.J. (1975): **Discovery and Exploration of Ashnola Porphyry Copper Deposit near Keremeos, B.C.: A Geochemical Case History**; *in* Geochemical Exploration 1974, Fletcher, W.K. and Elliott, I., Editors, *Elsevier*, Amsterdam, pages 85-100.

Ashnola copper prospect   Cu, Mo   NTS 92H/1W

Keywords: Ashnola porphyry copper, stream sediment geochemistry, soil geochemistry, biogeochemistry, I.P. surveys, probability graphs.

The Ashnola property, a typical porphyry copper prospect, was discovered by regional stream sediment sampling. Subsequent geochemical studies included additional stream sediment sampling, soil sampling of A and B-horizons, biogeochemical sampling and rock sampling. The results of the geochemical studies are compared to geology and geophysical expression of the deposit. Important results of the study are: (1) B-horizon copper and molybdenum provide a sound basis for a soil geochemical survey in the general area of the Ashnola prospect because of close correlation of their subpopulations with geological features including those of economic importance; (2) A-horizon zinc is more useful than B-horizon zinc but neither appears necessary in this particular case; (3) biogeochemical analyses for copper and zinc correlate best with A-horizon soil analyses; (4) zinc is concentrated preferentially relative to copper in the vegetation analyzed. The zinc/copper ratio in A-horizon soils is about 2/1, whereas the ratio in ash of lodgepole pine needles is 10/1; and (5) the method of data analysis utilizing thresholds estimated from partitioned probability plots of all variables aided the interpretation immeasurably and appears a useful general procedure in the routine analysis of geochemical survey data.

54. Ney, C.S., Anderson, J.M. and Panteleyev, A. (1972): **Discovery, Geologic Setting and Style of Mineralization, Sam Goosly Deposit, B.C.**; *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 65, pages 53-64.

Sam Goosly deposit (Equity Silver mine)   Cu, Ag   NTS 93L/1

Keywords: Sam Goosly, soil geochemistry, stream sediments, ice transport, I.P. surveys, EM surveys.

The Sam Goosly prospect was discovered through geochemical reconnaissance. Mineralization is in a window of rocks thought to be Hazelton Group, surrounded by Tertiary volcanic rocks and intruded by two stocks separated by about 1600 metres. Soil sampling interpreted with respect to an east-to-west ice movement led to drilling targets; silver soil anomalies were not related to the underlying bedrock as they occurred in glacially transported material. The characteristics of some local outcrops and an air photo interpretation of the area confirmed the ice-transport direction from the east-northeast to west-southwest. It was concluded that the silver anomalies were for the most part ice-transported from a source area lying to the northeast of the quartz monzonite and subsequent drilling was successful in outlining the mineralized zone. A very close correspondence was obtained between the up-ice cut-off in soil sample values and the projected surface trace of mineralization.

55. Nichol, I. and Bjorklund, A. (1973): **Glacial Geology as a Key to Geochemical Exploration in Areas of Glacial Overburden with Particular Reference to Canada**; *Journal of Geochemical Exploration*, Volume 2, Number 2, pages 133-170.

Whipsaw Creek property   Cu, Mo   NTS 92H/7

Keywords: Whipsaw Creek, soil geochemistry, dispersal trains, till, geophysics, hydromorphic dispersion.

In the Princeton area of British Columbia, extensive anomalous copper trains are associated with drainage sediments in certain organic-rich headwater catchment areas. Conventional geochemical follow-up procedures defined a broad anomalous zone in the organic-rich overburden but failed to define a focus for further examination. Geophysical methods indicated the presence of conductors in the area, suggesting that the geochemical anomaly in the drainage was not due to accumulation of metal from background concentrations or mineralization remote from the drainage channel. Sampling of the till below the thick organic-rich surface material revealed the presence of discrete sulphide grains indicative of mechanical dispersion. Localized anomalous zones of sulphide-held copper and sulphur correspond with mineralization revealed by drilling. In this way it has been possible to identify focal points of interest related to glacial dispersion within broad anomalous zones attributed to post-Quaternary hydromorphic dispersion.

56. Okon, E.E. (1974): **Overburden Profile Studies in Glaciated Terrain as an Aid to Geochemical Exploration for Base Metals in the Babine Lake Area, B.C.**; unpublished M.Sc. thesis, *University of Calgary*, Alberta.

Babine Lake area   Cu, Zn, Mo, Fe, Mn

Keywords: Babine Lake, till, glaciolacustrine, soil geochemistry, mechanical dispersion, hydromorphic dispersion.

Deposits of glacial drift from the Babine Lake area of north-central British Columbia, consisting of both non-stratified till and stratified drift (specifically glaciolacustrine sediments), were analyzed and studied by various techniques in order to determine how these overburden materials may be used in geochemical exploration. Selected samples were analyzed for copper, zinc, molybdenum, iron and manganese. Cation exchange capacities, organic carbon, pH, particle size distributions and other studies were made on representative samples. The results of these studies show that the concentrations of copper, zinc and molybdenum vary not only with depth in the overburden profile, but also with the location of the profile relative to the zones of known copper mineralization. Mechanical dispersion of the base metals within sulphide grains in the overburden is of greater significance than hydromorphic dispersion at this location.

57. Peatfield, G.R. and Armstrong, A.T. (1980): **The Red-Chris Porphyry Copper-Gold Deposit, Northwestern British Columbia; A Geochemical Case History**; *in* Seventh International Geochemical Exploration Symposium, Geochemical Exploration Symposium, Watterson, J. and Theobald, P.K., Editors, Proceeding 7, pages 479-485.

Red-Chris porphyry copper-gold deposit
Cu, Au NTS 104H/12

Keywords: Red-Chris porphyry deposit, lodgment till, alpine glacier, stream sediment survey, soil geochemistry, hydromorphic dispersion.

Stream sediment sampling yielded strongly anomalous results where the mineralized pluton is dissected by deep stream gullies, but where little copper-gold mineralization has been exposed. Conventional surface soil sampling showed a similar pattern, with high copper values where altered bedrock is exposed and only very spotty anomalies over more strongly mineralized but till-covered areas. A limited program of hand-auger sampling, to a depth of approximately 1 metre, gave results which were no better than those gained from surface sampling. Sampling of till profiles exposed in the walls of bulldozer trenches suggests that the till has effectively blocked upward migration of metals from the bedrock surface. The till-bedrock interface is very sharp and there seems to be no more than 30 centimetres of upward migration of copper. The anomaly patterns correspond very well with the outlines of the two mineralized zones. That over the Main or lower-grade dispersed zone is a large subcircular anomaly with relatively gentle sloping sides and the second, over the narrow, high-grade East zone is a narrow, very sharply defined linear anomaly. Neither anomaly shows any significant evidence of lateral migration.

58. Proudfoot, D.N. (1993): **Drift Exploration and Surficial Geology of the Clusko River and Toil Mountain Map Sheets** ; *in* Geological Fieldwork 1992, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, pages 491-498.

Clusko River; Toil Mountain NTS 93C/9, 16

Keywords: Clusko River, Toil Mountain, surficial geology, basal till, glaciofluvial sediments, striation.

This paper mainly describes the surficial geology of the Clusko River and Toil Mountain map areas (NTS 93C/9 and 16), but as a consequence of the study, three major problems for drift exploration programs in the area are identified. First, there are large areas in the region that contain little or no basal till at the surface. Basal till is the most desirable sediment to sample as it is normally the shortest travelled of glacial sediment types and it can be most easily traced to its source. Although relatively far-travelled debris dominates the region, basal tills are exposed locally along incised meltwater channels. Detailed drift sampling programs should therefore be devised to sample carefully along these channels. The resulting sample distribution will be far less systematic but far more useful. In the absence of meltwater channels in hummocky topography, samples should be taken between hummocks to a depth of at least 1 metre. This will be more time consuming than typical sampling programs and will provide less samples for the same cost, but the results should be more effective. Secondly, roads in most of the study area follow valleys where glaciofluvial and fluvial sand and gravel deposits and glaciolacustrine sediments are most common. Anomalies in these second-derivative deposits potentially have had a more complex history of transport from bedrock source to final deposition than tills. To overcome this problem, sampling programs should be offset to adjacent till-covered terrain where possible. Finally, bedrock striation sites are rare and large-scale, glacial-flow features only occur in a few places. These data allowed for an interpretation of regional ice-flow but local variations can not be determined. Numerous detailed till-fabric measurements must be carried out to determine local ice-flow directions.

59. Reed, A.J. and Jambor, J.L. (1976): **Highmont: Linear Zoned Copper-Molybdenum Porphyry Deposits and their Significance in the Genesis of the Highland Valley Ores**; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 163-181.

Highmont deposits Cu, Mo NTS 92I/7W

Keywords: Highmont, Highland Valley, soil geochemistry, glacial transport, geochemical anomalies, glacial dispersion, geophysics.

This paper reports mainly on the geology of the Highland Valley property of Highmont Mining Corporation Ltd., but some relevant comments on soil geochemistry, with accompanying maps, are also provided. The area contains seven copper-molybdenum deposits, most of which are in Skeena quartz diorite of the Guichon Creek batholith. The largest of the deposits has reserves of 111 million tonnes of ore grading 0.287% copper and 0.042% molybdenite.

The results of soil geochemistry surveys in the area indicate that, although saline dispersion of the metals is important locally, glacial transport is probably largely responsible for the development of the principal geochemical anomalies southeast of the main sulphide deposits. Background levels of both copper and molybdenum prevail in the northern part of the property and values increase abruptly as the main sulphide deposits are approached. The complex geochemical patterns over most of the property and the high values at the southeastern part, apparently result from glacial dispersion as well as widespread copper-molybdenum mineralization.

60. Schreier, H. (1976): **Chemical Terrain Variability: A Geomorphological Approach Using Numerical and Remote Sensing Techniques**; unpublished Ph.D. thesis, *The University of British Columbia.*

Fraser Valley, Peace River
Ca, Mg, Na, K, Si NTS 92G, 94A

Keywords: Fraser Valley, Peace River, geomorphology, cluster analysis, factor analysis, multispectral remote sensing, direct digital reflection, regression trends.

The variability of chemical parameters over the landscape was examined in this research. A terrain hierarchy based on genetic geomorphological unit concepts was developed in two Quaternary landscapes in the Fraser Valley and in the Peace River area. The relative variablity within and between different hierarchical units ranging from 'site' to 'landform units' to 'landform unit types' was compared. Calcium, magnesium, sodium, potassium and silicon were found to be the most important differentiating parameters for all units. Site categories which reflected units of similar parent material, form and inferred genesis were determined by application of a cluster analysis procedure. The best grouping was obtained with the Peace River data where more natural conditions prevail. A data screening through factor analysis prior to the grouping improved the landform unit type classification in the Fraser Valley where chemical conditions are complicated by a more complex and intensive land-use pattern. Multispectral remote sensing techniques were used to assess the potential of predicting chemical ground conditions from spectral measurements. Areas of different soil moisture and carbon content could readily be identified and quantified by this means. The sliced colour-film image was slightly more useful for analyzing exposed soil surfaces, while the sliced color-infrared image proved to be more useful for the interpretation of vegetated surfaces. Direct digital reflection measurements were made with a multichannel spectrometer from the air and on soil samples on the ground and in the laboratory. Correlation and regression analysis revealed that percent carbon, percent iron, exchangeable magnesium and exchangeable potassium could be predicted from spectral reflection values. Despite differences in measuring techniques, similar regression trends were obtained for all three methods and the 500 to 1100-nanometre wavelength range was found to be the most useful in this analysis.

61. Seraphim, R.H. and Rainboth, W. (1976): **Poison Mountain**; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 264-273.

Poison Mountain deposit — Cu, Mo — NTS 920/2W

Keywords: Poison Mountain, porphyry deposit, talus, soil profiles, stream sediments, soil surveys, geophysics.

This paper reports mainly on the geology of the Poison Mountain porphyry copper-molybdenum deposit, but some relevant comments on soil geochemistry, with an accompanying map, are also provided. The deposit is located 37 kilometres west of Big Bar near Clinton and lies at 1700 metres elevation. Relief on the property is approximately 600 metres, from 1600 metres elevation at creek level to 2200 metres on adjacent mountain summits. Slopes are moderately steep and rock outcrop is restricted to shoulders along the creeks and ridge crests. Felsenmeer and talus are abundant above timberline, at approximately 2000 metres elevation. The B soil horizon, where present, was sampled at an average depth of 0.5 metre at 60-metre (200-foot) intervals along lines spaced 250 metres (800 feet) apart. The area of known mineralization was broadly outlined by the 200 ppm copper contour.

62. Sibbick, S.J. (1990): **The Distribution and Behaviour of Gold in Soils in the Vicinity of Gold Mineralization, Nickel Plate Mine, Hedley, Southern British Columbia**; unpublished M.Sc. thesis, *The University of British Columbia.*

Nickel Plate mine — Au, Ag — NTS 92H/8

Keywords: Nickel Plate mine, soil geochemistry, till, dispersal trains, soil profiles, heavy minerals.

A gold dispersion train extending from the Nickel Plate mine, Hedley, southwest British Columbia, was investigated in order to determine the distribution and behaviour of gold in soils developed from till. Results indicate that the gold content of soil profiles increases with depth while decreasing with distance from the mine site. Heavy mineral concentrates and the light mineral fraction gold abundances reveal that dilution by a factor of 3.5 occurs within the till over a distance of 800 metres. However, free gold in the heavy mineral fraction is both diluted and comminuted with distance. Chemical activity has not altered the composition of gold grains in the soil profiles. Compositional and morphological differences between gold grains are not indicative of glacial transport distance or location within the soil profile. Relative abundances of gold grains between sample locations can be used as an indicator of proximity to the mine site.

63. 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 1991*, Volume 47, pages 183-200.

Nickel Plate mine — Au, Ag — NTS 92H/8

Keywords: Nickel Plate mine, soil geochemistry, till, dispersal trains, soil profiles, humus.

The Nickel Plate deposit, in which gold occurs as <25-micron blebs associated with arsenopyrite in garnet-pyroxene skarns, is in the subalpine zone near the southern limit of the Thompson Plateau. During the last glaciation the Cordilleran ice sheet moved south-southwest across the deposit and deposited a stony basal till. A dispersion train with anomalous concentrations of gold in tills and soils now extends 2 kilometres down-ice from the deposit. Gold contents of samples of humus (LFH horizon) and the -212-micron fraction of mineral soils (A, B and C-horizons) were determined by instrumental neutron activation and fire assay - atomic absorption, respectively.

Despite erratic variability, gold contents of the - 212-micron fraction generally decrease from 200 to 400 ppb close to the mine site to less than 50 ppb at distal sites. At most sites there is also a twofold increase in gold values down the soil profile. Within samples, concentrations of gold in the -420 + 212 micron, -212 + 106 micron, -106 + 53 micron and -53 micron fractions are usually roughly constant. However, because of its abundance, the -53 micron fraction contains more than 70% of the gold. Amenability of gold in this fraction to cyanidation suggests that it is largely free. For size fractions less than 53 microns the contribution of the heavy mineral (SG3.3) fraction to total gold content increases with decreasing grain size.

Distribution of gold between size and density fractions is consistent with its release from the bedrock or preglacial regolith by glacial abrasion. Most of the gold was incorporated into the fine fractions of the till at or close to the source. However, differences between down-ice dilution ratios for gold in different heavy mineral size-fractions suggest that comminution of host minerals continued to transfer gold to the finer size fractions during glacial transport.

For exploration purposes, B and C-horizon samples provide the best anomaly contrast. Estimates of the abundance of gold particles in different size fractions indicate that the nugget effect, which causes erratic gold values in the -212 micron fraction, can be avoided by analysis of 30 grams of -53 micron material.

64. Sibbick, S.J. and Gravel, J.L. (1991): **Talus-fines Geochemistry of the Pellaire Mesothermal Au Vein Prospect**; *in* Geological Fieldwork 1990, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-1, pages 101-108.

Pellaire prospect Au NTS 92O/4E

Keywords: Pellaire, soil geochemistry, element dispersion, talus, cirque, mesothermal gold vein, moraine, lithogeochemistry, cluster analysis.

This paper reports on the results of study undertaken to demonstrate the geochemical dispersion of talus fines originating from a mineralization at the Pellaire prospect, located about 150 kilometres southwest of Williams Lake. Mineral exploration in alpine regions of extreme relief is often difficult and dangerous due to the inaccessibility of cliff faces or precipitous slopes. These areas are often characterized by thick aprons of postglacial talus mantling the lower slopes and concealing the underlying bedrock. Stream sediments may prove inadequate for reconnaissance follow-up as primary drainages in these areas are often short in length, fast flowing and lack fine-grained sediment. In this physiographic environment, exploration programs frequently rely upon exposures of gossans or alteration halos as exploration guides. However, mineralization does not always produce visual clues to its presence; detection may result only through the use of geochemical methods. As an aid to traditional geochemical techniques, sampling of talus fines (-177-µm fraction) is recommended as a method to detect mineralization in steep, mountainous areas.

Anomalies in talus fines have a restricted source area, either directly upslope or at a slight angle upslope from the sample site. Talus-fines sampling effectively detects mineralized and gossanous bedrock. Use of cluster analysis can differentiate between rock-forming elements and those associated with mineralization. Base of slope sample spacing should be approximately equivalent to the length of the talus slope. However, variations in local geology and physiography should be strongly considered when selecting sampling densities and sample locations. Use of talus-fines sampling as a geochemical exploration tool in mountainous terrain would be most effective as a follow-up technique for large-scale, stream sediment surveys. It would also serve as a quick method to assess gossans identified from the air. Identification of anomalous elements in talus fines would be followed by detailed sampling and prospecting upslope from the sample site.

65. Sibbick, S.J., Rebagliati, C.M., Copeland, D.J. and Lett, R.E. (1992): **Soil Geochemistry of the Kemess South Porphyry Gold-Copper Deposit**; *in:* Geological Fieldwork 1991, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1992-1, pages 349-361.

Kemess South deposit Au, Cu NTS 94E/2E

Keywords: Kemess, porphyry deposit, supergene enrichment, soil profiles, till, striae, geochemical dispersion.

This paper reports on the results of a geochemical orientation survey conducted at the Kemess South porphyry gold-copper deposit, located 550 kilometres northwest of Prince George. The relationship between the deposit and the overlying soils was studied to determine if the geochemical anomalies are a result of physical or hydromorphic (chemical) transport. Within the deposit, a blanket of enriched (supergene) copper mineralization is overlain in places by a copper-depleted oxidized cap.

Soil geochemical response to the deposit is strong; concentrations greater than 500 ppm copper and 150 ppb gold directly overlie the deposit in an area of 800 by 300 metres. The principal residence sites for copper in soils and bedrock in sample profiles outside the main supergene zone are secondary iron oxide minerals. Within the upper leached cap of the supergene zone, which has been exposed to Holocene (postglacial) weathering, oxidation of sulphides has resulted in the development of secondary minerals which retain upwards of 70% of the copper, probably present as native copper, chalcocite, malachite or adsorbed onto clays and iron oxides. Hydromorphic transport has increased the copper content of soils over mineralized bedrock. The degree of hydromorphic transport is significantly greater over the supergene enriched zone of the deposit than over the weathered hypogene bedrock.

66. Soregaroli, A.E. (1975a): **Brenda Cu-Mo Deposit, British Columbia**; *in* Conceptual Models in Exploration Geochemistry, *Journal of Geochemical Exploration*, Volume 4, Number 1, pages 58-60.

Brenda Cu-Mo deposit Cu, Mo NTS 82E/13

Keywords: Brenda Cu-Mo deposit, soil geochemistry, till, fluvial-glacial, stream sediments, ice flow.

A soil survey of the Brenda property conducted by Noranda Exploration Company, Limited defined a large area of interest centred on the Brenda deposit. Anomalous copper values (200 ppm) coincided with the area of known mineralization. Molybdenum values in the soil showed a remarkable coincidence with copper values. The soil results showed extensions to the east and northeast, but are cut off very sharply on the west. The cut-off agrees well with a rapid decrease in mineralization in the bedrock, but probably more significantly, there is a rapid increase in the depth of overburden in this area. Southeasterly trends in soil values probably are due to glacial smearing as well as downstream migration of metal ions along Peachland and MacDonald creeks. Changes in the nature and depth of overburden have also affected the distribution of metal values in the soil.

67. Soregaroli, A.E. (1975b): **Boss Mountain Mo Deposit, British Columbia**; *in* Conceptual Models in Exploration Geochemistry, *Journal of Geochemical Exploration*, Volume 4, Number 1, pages 56-58.

Boss Mountain Mo deposit   Mo   NTS 93A/2

Keywords: *Boss Mountain Mo deposit, till, stream sediments,* soil geochemistry, dispersal trains.

A molybdenum geochemical train in stream sediments extends down Molybdenite Creek for a distance of 10 kilometres. Molybdenite Creek cuts across the main breccia zone and stream sediments immediately below this point contain several hundred parts per million molybdenum. Anomalous molybdenum values in soils define a very large target area that generally coincides with the distribution of hydrothermal biotite. Highest soil values do not correlate with mineralization, but in general terms the 200-ppm contour essentially encloses all known molybdenum ore. Total copper values in soils clearly define a northwesterly trending anomalous zone that agrees in general with the 200-ppm molybdenum zone.

68. Sutherland Brown, A. (1967): **Investigation of Mercury Dispersion Haloes around Mineral Deposits in Central British Columbia**; *in* Proceedings, Symposium on Geochemical Prospecting, *Geological Survey of Canada*, Paper 66-54, pages 72-83.

Northwest Group, Serb Creek,	Hg, Mo	NTS 103I/9,
Glacier Gulch, Lucky Ship,		93L/12, 93L/14, 93L/4,
Huber Group, Owen Lake,		93L/10, 93L/2, 93K/3,
Endako, Centennial, Pinchi,		93K/8, 93K/9,
Takla Mercury		93N/11

Keywords: Northwest Group, Serb Creek, Glacier Gulch, Lucky Ship, Huber Group, Owen Lake, Endako, Centennial, Pinchi, Takla Mercury, soil geochemistry, secondary dispersion haloes.

During routine geological examination of mines and prospects in north-central British Columbia in 1965, the author collected soil samples and analyzed them in the field for mercury. Samples were taken along cut lines or access roads generally from the top of unmodified soil. An attempt was made to extend sample points well beyond the limits of known mineralization. Secondary dispersion halos of mercury were detected at all the properties which were examined, although the size of anomaly peaks varied greatly from mercury deposits to molybdenum deposits. Soil mercury and molybdenum profiles are believed to represent the extreme types at which mercury halos might be expected. In most localities background ranges from 0.01 to 0.1 ppm, but in some others is much higher. Background over whole regions may be so high that molybdenum peaks would not be noticed.

69. Sutherland Brown, A. (1974): **Aspects of Metal Abundances and Mineral Deposits in the Canadian Cordillera**; *in* Exploration Geochemistry, *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 67, pages 48-55.

Various NTS map sheets throughout British Columbia for which there are geochemical reports in EMPR assessment files

Cu, Zn, Mo, Pb

Keywords: regional metal abundances, silts, soils, background values

Mineral deposits in the Canadian Cordillera are distributed in a pronounced zonal pattern coincident with the five tectonic belts. Present information on regional metal abundances in rocks is inadequate, but similar information on silts and soils is more common, even though not necessarily in the public domain. The similarity between silt and soil background in pattern and in total value means that they both probably reflect regional geochemical abundances. The information available tends to substantiate the premise that the Insular Belt has high backgrounds for copper and iron and low backgrounds for lead. In contrast the Omineca and Foreland belts have erratic background values with selectively enriched domains commonly related to specific lithological units. This is particularly true for lead and zinc, but copper, molybdenum and iron are generally low. The lower values for copper and zinc in soils compared to silts in the Insular Belt may reflect ion mobility or extensive leaching in an organic-rich, rainy terrain.

70. Sutherland Brown, A. (1975a): **Sam Goosly Cu Deposit, British Columbia**; *in* Conceptual Models in Exploration Geochemistry, *Journal of Geochemical Exploration*, Volume 4, Number 1, pages 94-97.

Sam Goosly orebody   Ag, Cu, Zn   NTS 93L/1

Keywords: Sam Goosly, till, podzols, stream sediments, soil geochemistry, dispersal trains, hydromorphic dispersion

Stream sediment data for total copper, zinc, silver and molybdenum in stream sediments show anomalous dispersion close to the Sam Goosly deposit although silver shows by far the strongest contrast. Initially, metal anomalies upstream were attributed to glacial smear until it was established that the glacial direction most affecting the overburden transport was from the northeast and not the northwest as expected. The soil data presented show the marked effect of glacial smearing, although soil creep or hydromorphic movement may also have transported some metal in the same direction. The silver anomaly has been transported up to 2000 metres down-ice, while the up-ice limb of the anomaly coincides extremely closely with the surface projection of the deposit.

71. Sutherland Brown, A. (1975b): **Island Copper Deposit, British Columbia**; *in* Conceptual Models in Exploration Geochemistry, *Journal of Geochemical Exploration*, Volume 4, Number 1, pages 76-78.

Island Copper orebody   Cu, Mo   NTS 92L/11W

Keywords: Island Copper, till, glaciofluvial deposits, soil geochemistry, foreign provenance, soil profiles.

Island Copper ore consists of very fine grained chalcopyrite and abundant pyrite in an intense fracture stockwork with minor molybdenite in siliceous zones. The deposit is covered by a highly variable thickness of overburden. A regular soil grid was sampled over the entire area collecting samples from the B-horizon or its equivalent, as far as was possible. The distribution of copper in the soil is directly related to overburden type and thickness. Two soil profiles are also described. A thin till is overlain by up to 75 metres of glaciofluvial sands and gravels. The presence of glaciofluvial material of foreign provenance completely masks the copper anomaly in the upper soil. In areas where glaciofluvial material is absent and particularly where the till is thin, a moderate soil anomaly is detected.

72.Sutherland Brown, A. (1975c): **Huckleberry Cu-Mo Deposit, British Columbia**; *in* Conceptual Models in Exploration Geochemistry, *Journal of Geochemical Exploration*, Volume 4, Number 1, pages 72-75.

Huckleberry Cu-Mo deposit	Cu, Mo	NTS 93E/11

Keywords: Huckleberry, till, podzols, hydromorphic dispersion, soil geochemistry, stream sediments.

Detailed soil sampling has only been undertaken over the claims surrounding the best mineralization after successful drilling undertaken on the basis of the reconnaissance sediment survey and geology. The Ah and B-horizon soil samples were analyzed for total copper and molybdenum. The results for copper in the B-horizon only, are shown together with the position of the known mineralization. The soil anomaly clearly defines the location of the copper-molybdenum mineralized zone peripheral to the stock. However, this anomaly also coincides with the circumfluent drainage pattern about the stock and may be modified by metal-rich seepage zones. There is no indication of modification of the soil anomaly by glacial action.

73. Warren, H.V. (1982): **The Significance of a Discovery of Gold Crystals in Overburden**; *in* Precious Metals in the Northern Cordillera, *The Association of Exploration Geochemists*, pages 45-51.

Stirrup Creek	Au	NTS 92O/1

Keywords: Stirrup Creek, placer gold, biogeochemistry, soil geochemistry, gold grains.

In an attempt to discover the source of placer gold in Stirrup Creek, British Columbia, a soil sampling survey was undertaken and it revealed an area of about 120 hectares strongly anomalous in that metal. Careful panning of soil samples lying near gold-bearing outcrops resulted in finding several dozen fragments of gold crystals with many smooth and unscratched faces. A cyanogenic plant in the area, *Phacelia sericea*, was found to contain strongly anomalous concentrations of gold. On the basis of this it is concluded that not only is gold soluble under certain conditions, but also that it can be transported through vegetation and deposited in soil. Some of the particles of placer gold also clearly indicate a chemical rather than a mechanical origin.

74. Warren, H.V. and Delavault, R.E. (1949): **Further Studies in Biogeochemistry**; *Bulletin of the Geological Society of America*, Volume 60, pages 531-559.

Sullivan mine,	Pb, Zn,	NTS 82G/12,
Britannia mine	Ag	92G/11

Keywords: Sullivan mine, Britannia mine, biogeochemistry, groundwater, soils.

This paper outlines some of the methods used to re-examine previous conclusions (see Warren and Howatson, 1947) that there may be a striking relationship between the mineral content of plants and that of the underlying soils and rocks. The analytical methods used are described, including a dithizone method which seemed suitable for both copper and zinc analyses.

Evidence showed that twigs, rather than leaves or needles or even fruit, are probably more satisfactory as indicators of variations in the metal content of soils and rocks. Twigs are easier to collect, to sample and to ash and satisfactory results were obtained from 1 and 2-gram samples. This suggested that it may be possible to carry on biogeochemical prospecting in winter. Numerous analyses of samples from the Britannia and Sullivan mines were tabulated and their significance discussed. The results were compared with those obtained previously and suggested that in some areas the zinc-copper ratios may, for prospecting purposes, be more significant than the absolute amounts of zinc and copper present in the trees and lesser plants, particularly when the absolute amounts of copper and zinc are low.

75. Warren, H.V. and Delavault, R.E. (1954): **Variations in the Nickel Content of some Canadian Trees**; *Transactions of the Royal Society of Canada*, Volume 48, Series 3, Section 4, pages 71-74.

Unnamed nickel deposit - Coast Range Mountains	Ni	NTS 92H

Keywords: Biogeochemistry, mountain hemlock, mountain fir, western red cedar, pathfinder element, nickel.

On the evidence of more than 200 nickel determinations, the authors concluded that biogeochemical methods may prove useful in the search for buried nickel mineralization in some areas. These techniques were considered to be particularly useful for distinguishing geophysical anomalies caused by magnetite and/or pyrrhotite alone from those in which these minerals are accompanied by significant amounts nickel mineralization.

Except for very young tips and stems more than 4 years old, oven-dried leaves and needles of most trees carried from 0.2 to 2 ppm (10 to 100 ppm in ash) over the more common geological formations. Over nickel mineralization, nickel contents five to twenty times the above figures were found, with weak nickel occurrences providing intermediate results. The ease with which even slightly abnormal amounts of nickel were detected in some trees suggested that it may be considered a pathfinder element for base metal deposits such as zinc, much as molybdenum may, on occasion, be used for copper.

76. Warren, H.V. and Delavault, R.E. (1957): **Biogeochemical Prospecting for Cobalt**; *Transactions of the Royal Society of Canada*, Volume 51, Series 3, Section 4, pages 33-37.

Windpass	Co	NTS 92P/8E

Keywords: Windpass, biogeochemistry, cobalt, mountain balsam, lodgepole pine.

The cobalt content of trees and shrubs growing above cobalt ore was determined to be high enough to be estimated by a relatively simple laboratory method on samples 1 gram in weight. Variation between the cobalt contents of trees and lesser plants growing close to cobalt mineralization and those removed from such mineralization was considered sufficient to enable biogeochemistry to be used as a prospecting tool. Most positive samples contained from 1 to 3 ppm of cobalt in oven-dried plant material and from 50 to 300 ppm in ash. This appeared to be from ten to one hundred times the amount encountered in vegetation from unmineralized areas. There also was some evidence to suggest that more than normal amounts of cobalt may be associated with some favourable mineral-bearing formations and that it may be possible to use biogeochemistry to search for these favourable formations.

77. Warren, H.V., Delavault, R.E. and Cross, C.H. (1957): **Geochemical Anomalies Related to some British Columbia Copper Mineralization**; *in* Methods and Case Histories in Mining Geophysics, *Sixth Commonwealth Mining and Metallurgical Congress*, pages 277-282.

Bethlehem, Afton, Dutchman	Cu, Zn	NTS 92I/11, 92I/9, 92H/15

Keywords: Bethlehem, Afton, Dutchman, till, glaciofluvial sediments, biogeochemistry, soil geochemistry.

Geochemical techniques were applied to prospecting for copper in three areas in southern British Columbia. Soil and vegetation samples were collected along profiles over strong, medium and weak copper mineralization. The analyses were plotted on profiles and the location of the mineralization, as determined by various methods, is shown. Large geochemical anomalies were obtained over the areas of significant copper mineralization. The ratios of copper to zinc present in the samples were computed and plotted as aids in interpretation. The techniques were found to be effective for exploration in the section of British Columbia under study.

78. Warren, H.V. and Hajek, J.H. (1973): ***An Attempt to Discover* a "Carlin-Cortez" Type of Gold Deposit in British Columbia**; *Western Miner*, October, pages 124-134.

Stirrup Creek area	Au	NTS 92O/1

Keywords: Stirrup Creek, cemented glacial clay, soil geochemistry, biogeochemistry, stream sediment geochemistry, soil profiles.

In the area under consideration, a lack of outcrop, much glacial debris and a layer of cemented glacial clay tend to render the usual exploration techniques ineffective. Soil geochemistry data presented in this paper show that higher gold values are obtained neither on the surface nor necessarily close to bedrock, but rather in an intermediate or B-horizon which extends variously from 15 to 90 centimetres below the surface. These results appear to contradict those obtained by all the earlier workers who, as a result of panning, reported that they only obtained significant values from the samples taken within a few centimetres of bedrock. Several B-horizon soil samples were taken in a northern part of the area and some carried soil values of 0.5 ppm or more of gold (greater than 100 times background). Biogeochemistry has been successfully used to correlate anomalous concentrations of gold and arsenic in plants with these elements in rocks.

79. Warren, H.V. and Howatson, C.H. (1947): **Biogeochemical Prospecting for Copper and Zinc**; *Bulletin of the Geological Society of America*, Volume 58, pages 803-820.

Britannia, Sullivan, Texada Island, Copper Mountain, Beaverdell camp	Cu, Zn	NTS 92G/6, 82G/11, 92F/9, 82E/6E

Keywords: Britannia, Sullivan, Texada Island, Copper Mountain, Beaverdell, biogeochemistry.

This paper reports on some relationships of plants to ore deposits as revealed by a series of investigations conducted in British Columbia by the authors at five mining camps (Britannia, Chapman, Texada Island, Copper Mountain and Beaverdell). Results indicate that the zinc and copper contents of some trees and lesser plants may reflect, to a striking extent, the presence of zinc and copper concentrations in the underlying soils or rock formations. The ash of a random selection of botanical samples in noncupriferous areas was found to carry 200 to 600 ppm copper with samples over 1000 ppm considered to reflect anomalous copper concentrations. Ashes in areas with zinc concentrations carried more than 1500 ppm zinc, with background values ranging from 700 to 900 ppm zinc.

Some secondary results reported are as follows:

(1) Cones and needles of *Tsuga mertensiana* (mountain hemlock), *Pseudotsuga taxifolia* (Douglas fir), *Larix occidentalis* (larch) and *Pinus contorta* (lodgepole pine) all offer possibilities for detecting unusual concentrations of copper and zinc.

(2) Leaves of *Echinopanax horridus* (devil's club), *Alnus sinuala* (green alder) and *Salix* sp. (willow) all show ability to indicate the presence of abnormal amounts of copper or zinc in their vicinity.

(3) The wood of the various trees carries the least total mineral content and the green leaves or needles the most. The fruit and bark contain amounts between these two extremes.

(4) In the samples examined, zinc seems, on the average, to be twice as abundant as copper.

80. Westervelt, L.A. (1985): **A Computer Facilitated Statistical Analysis of Three Soil Geochemical Grids in the Nakusp Area, South-central British Columbia**; unpublished B.A.Sc. thesis, *The University of British Columbia*.

Nakusp area	*Multi-elements*	*NTS 82K*

Keywords: Nakusp, soil anomalies, statistical analysis, soil geochemistry, graphs, plots.

A computerized statistical analysis of data from more than 1000 geochemical soil samples demonstrates the ease with which the computer can process and display large volumes of geochemical data in a variety of formats. The computer-generated graphs and plots have delineated rock types, lithologic contacts, faults and mineralized zones and have indicated the types of deposits that may be present under the overburden of the three geochemical grids.

81. White, W.H. (1950): **Plant Anomalies Related to some British Columbia Ore Deposits**; *Transactions of the Canadian Institute of Mining and Metallurgy*, Volume 53, pages 243-246.

Copperado property, Bell claim, Mayflower mine, Reeves-	NTS 92J/9E, 82E/6 82F/4W, 82F/3W

Keywords: Copperado property, Bell claim, Mayflower mine, Reeves-MacDonald mine, drift, overburden, biogeochemistry, geophysics.

The value of anomalous metal contents of trees as an aid to the discovery of mineral deposits was tested under field conditions on four known ore deposits. Results indicate that a base metal deposit, or any deposit containing zinc or copper, casts a 'metal shadow' into the overlying soil which remains approximately positioned above the deposit, regardless of the type of overburden or the movement of groundwater. The unusually high content of zinc or copper in trees growing within the limits of this metal shadow constitutes an anomaly which can be detected and plotted in the field. The field kit and certain points of the field technique are described briefly; and the characteristics of plant anomalies and possible limitations of their use are mentioned.

82. White, W.H. and Allen, T. M. (1954): **Copper Soil Anomalies in the Boundary District of British Columbia**; *Transactions of the American Institute of Mining Engineers*, Volume 199, pages 49-52.

Deadwood Camp, Summit Camp, Phoenix Camp	Cu	NTS 82E/2, 3

Keywords: Deadwood, Summit, Phoenix, soil geochemistry, glacial dispersion, float boulders, copper migration.

Copper soil anomalies are valid only when they appear as rational contours on the map of an area that has been sampled systematically. These anomalies must be interpreted with due regard to the geomorphic history of the area. They may correspond closely to the source of the copper, or, alternatively, they may have spread and migrated considerable distances. Probably in the latter instance a tail could be detected leading back to the source of the copper. In the Boundary District of British Columbia, the normal copper content of the soil is less than 100 ppm, averaging 27 ppm. Copper values over 100 ppm can be considered anomalous. A copper soil anomaly does indicate the presence of unusual amounts of copper in the underlying or contiguous bedrock, but it does not necessarily indicate the presence of a commercial orebody. It follows that a strong anomaly is no better indication of an orebody than a weak anomaly.

83. Wilton, H.P. and Pfuetzenreuter, S. (1990): **Giant Copper (09HSW001, 002)**; *in* Exploration in British Columbia 1989, *B.C. Ministry of Energy, Mines and Petroleum Resources*, pages 91-93.

Giant Copper	Cu, Au, Ag, Mo	NTS 92H/3E

Keywords: Giant Copper, soil geochemistry, breccia, Invermay stock, metamorphic halo.

This brief review paper discusses the regional and property geology and makes reference to a soil geochemistry anomaly map, locating the No. 1 Anomaly zone (gold, silver, arsenic, zinc, copper, lead) which is a newly discovered breccia occurring about 300 metres northeast of the AM breccia anomaly (gold, silver, arsenic, zinc, copper, lead). It has very similar mineralization, hostrock lithology and geochemical signature to the AM breccia and probably represents a segment of the AM zone which has been offset by left-lateral movement on a northeast-trending fault. Two other soil anomalies to the north are associated with local mineralization: the Camp Breccia anomaly (silver, zinc) and Cliff anomaly (arsenic, zinc).

84. Witherly, K.E. (1979): **Geophysical and Geochemical Methods Used in the Discovery of the Island Copper Deposit, Vancouver Island, British Columbia**; *in* Geophysics and Geochemistry in the Search for Metallic Ores, Hood, P.J., Editor, *Geological Survey of Canada*, Economic Geology Report 31, pages 685-696.

Island Copper orebody	Cu, Mo	NTS 92L/11

Keywords: Island Copper, aeromagnetic surveys, IP surveys, soil geochemistry, till, glacial overburden.

Several large soil geochemical anomalies were identified within the regional survey block. Testing of geochemical anomalies on the property most often encountered some low-grade copper mineralization in the bedrock. This observation encouraged the reliance upon the geochemical anomalies as a prime source of drilling targets, because, even though much of the glacial till had been transported, a significant amount of the soil at a given site is apparently locally derived. Extensive drilling of the anomaly over the deposit showed, however, that more than 15 metres of overburden could inhibit the surface expression of even subcropping ore-grade mineralization. Of all the survey techniques used in the discovery of the Island Copper deposit, a soil geochemical survey was the most successful due to its advantages of speed, cost and detection of the specific element of interest. The problem of thick overburden subduing the geochemical expression was apparent, but did not present a serious problem. Examination of the geophysical data made subsequent to the discovery of Island Copper show that the geophysical results support and enhance information on structure, alteration and mineralization both in and around the orebody.

85. Young, M.J. and Rugg, E.S. (1971): **Geology and Mineralization of the Island Copper Deposit**; *Western Miner*, Volume 44, pages 31-40.

Island Copper orebody	Cu, Mo	NTS 92L/11

Keywords: Island Copper, soil geochemistry, magnetic surveys, IP surveys, till, soil profiles.

A geochemical soil survey was conducted over the property during January to June 1966. In the area of the orebody, the geochemical anomaly showed a fairly steep gradient from below 100 to above 200 ppm copper. The anomaly defined by the 200-ppm contour is roughly in the centre of the orebody in plan and conforms well with that part of the orebody generally overlain by less than 10 metres of overburden. Soil profiles have been taken at several locations in the vicinity of the orebody. Assays from drill core near the location of the soil profiles indicate the underlying bedrock contains about the average copper content of the orebody. Several other soil profiles taken indicate an anomalous concentration of copper in the red-brown mixed clay, sand and gravel at depths of 60 to 150 centimetres. Geophysical surveys carried out concurrently show that magnetic anomalies in this area are only a rough guide in prospecting because of the ubiquitous character of magnetite in the volcanics. Induced polarization surveys did not directly locate the mineralized bedrock deposit.

TABLE 27-1
SUMMARY OF DRIFT PROSPECTING PUBLICATIONS IN BRITISH COLUMBIA

Citation	Deposit/ Region	NTS	Metals	Geological (Quaternary)	Geochemical	Geophysical
1	Chappelle deposit	94E/6	Au, Ag		X	X
2	Highland Valley Copper mine	92I/6, 7 10 and 11	Cu	X		
3	Lornex deposit	92I/11	Cu	X	X	X
4	Capoose batholith	93F/6	Cu, Mo	X	X	
5	Newman (Bell) Cu deposit, Boss Mt. deposit, Cariboo-Bell deposit	93L; 93A/2; 93A/12	Cu, Mo, Au	X	X	
6	Cariboo-Bell deposit	93A/12	Cu, Mo, Au	X	X	
7	Canadian Cordillera	Various NTS regions	Cu, Zn, Pb, Mo, Au, Ag		X	
8	Island Copper deposit	92L/11	Cu, Mo	X	X	X
9	Cariboo-Bell deposit	93A/12	Cu, Mo, Au		X	
10	Afton Cu deposit	92I/10E	Cu		X	
11	Afton Cu deposit	92I/10E	Cu	X	X	X
12	Morrison deposit	93M/1W	Cu	X	X	X
13	Cinola deposit	103F/9	Au		X	
14	Buttle Valley, St. Elias Mountains	92F/12; 114P/12	Cu, Zn, Au, Ag	X	X	
15	Grasshopper Mountain	92H/10	Pt	X	X	
16	Grasshopper Mountain	92H/10	Pt	X	X	
17	Congress property	92J/15	Au, Ag	X	X	
18	Sheslay prospect	104K	Cu, Mo		X	
19	Ingerbelle deposit	92H/7	Cu	X	X	
20	Rea Gold deposit	82M/4	Au, Ag, Pb, Zn, Cu		X	
21	East Arm Glacier, Windy Craggy deposit	114P/12	Cu, Co, Zn, Ag, Au	X	X	
22	Tsowwin River, Franklin River, Harris Creek, Watson Bar Creek	82L/2; 92E/15; 92F2,3,4; 92F3,4	Au		X	
23	East Arm Glacier, Windy Craggy deposit	114P/12	Cu, Co, Zn, Ag, Au	X	X	
24	Shasta deposit	94E/6	Au, Ag	X	X	X
25	QR deposit	93A/12	Au	X	X	X
26	Franklin Camp, Tulameen, Scottie Creek	82E/9; 92H/7,10; 92I/14	Pt, Pd	X	X	
27	Quesnel River gold deposit	93A/12	Au	X	X	
28	Mount Milligan deposit	93N/1E; 93O/4W	Cu, Au	X	X	
29	Whipsaw Creek	92H/7	Cu, Mo	X	X	X
30	Buttle Valley	92F/12	Cu, Zn, Pb	X	X	
31	Cariboo-Bell deposit	93A/12E	Cu, Au	X	X	X
32	Rayfield River property	92P/6	Cu	X	X	
33	McConnell Creek area	94D	Cu, Au	X	X	
34	Dansey-Rayfield River	92P/6	Cu	X	X	
35	Highmont property	92I/7	Cu, Mo	X	X	
36	Various properties in B.C.	92F,92H,92P, 93E,93K	Cu, Mo	X	X	
37	Lucky Ship deposit	93L/3, 4	Mo	X	X	X
38	Huckleberry Mountain	93E/11	Cu, Mo	X	X	X
39	Nechako Range		Ba, Sr, Pb, Ni, Mn		X	
40	Mount Milligan, Johnny Mountain	93N/1E; 93O/4W, 104B/6E, 7W, 10W, 11E	Cu, Au	X	X	
41	Galaxy property	92I/9	Cu, Au	X	X	
42	Quatsino	92L/12	Multi-elements	X	X	
43	Endako deposit	93K/3E	Mo	X	X	
44	Bell Copper deposit	93L/16	Cu	X	X	
45	Central bog, Whipsaw Creek	92H/7	Cu, Co, Ni, Zn	X	X	

46	North Wow Flats,					
	Covert Basin,					
	Prairie Flats	82E/4, 5, 12	U, Th, Ra, Pb	X	X	X
47	Old Fort prospect,					
	Bell Copper deposit,					
	Granisle Copper deposit	93L/16; 93M/1	Cu, Zn, Mo	X	X	
48	Catface deposit	92F/5W	Cu, Mo		X	
49	Chutanli prospect	93F/7	Mo	X	X	
50	Central Interior of B.C.		Mo	X	X	
51	O.K. property	92K/2E	Cu	X	X	X
52	Maggie deposit	91I/14W	Cu, Mo	X	X	
53	Ashnola copper prospect	92H/1W	Cu, Mo		X	X
54	Sam Goosly deposit	93L/1	Cu, Ag	X	X	X
55	Whipsaw Creek property	92H/7	Cu, Mo	X	X	X
56	Babine Lake area		Cu, Zn, Mo, Fe, Mn	X	X	
57	Red-Chris deposit	104H/12	Cu, Au	X	X	
58	Clusko River,					
	Toil Mountain	93C/9, 16		X	X	
59	Highmont deposit	92I/7W	Cu, Mo	X	X	X
60	Fraser Valley,					
	Peace River	92G, 94A	Ca, Mg, Na, K, Si	X	X	X
61	Poison Mountain deposit	92O/2W	Cu, Mo		X	X
62	Nickel Plate mine	92H/8	Au, Ag	X	X	
63	Nickel Plate mine	92H/8	Au, Ag	X	X	
64	Pellaire prospect	92O/4E	Au	X	X	
65	Kemess South deposit	94E/2E	Au, Cu	X	X	
66	Brenda Cu-Mo deposit	82E/13	Cu, Mo	X	X	
67	Boss Mountain Mo deposit	93A/2	Mo	X	X	
68	Ten properties in					
	Central B.C.	103I; 93K,L,N	Hg, Mo	X	X	
69	Five regional	Various				
	tectonic belts	NTS regions	Cu, Zn, Mo, Pb, Ni, Ag		X	
70	Sam Goosly deposit	93L/1	Cu, Ag, Zn	X	X	
71	Island Copper deposit	92L/11W	Cu, Mo	X	X	
72	Huckleberry Cu-Mo deposit	93E/11	Cu, Mo	X	X	
73	Stirrup Creek	920/1	Au		X	
74	Sullivan mine,	82G/12,				
	Britannia mine	92G/11	Pb, Zn, Ag		X	
75	Unnamed nickel deposit					
	Coast Range Mountains	92H	Ni		X	
76	Windpass	92P/8E	Co		X	
77	Bethlehem deposit,	92I/11;				
	Afton deposit,	92I/9;				
	Dutchman	92H/15	Cu, Zn	X	X	
78	Stirrup Creek area	92O/1	Au		X	
79	Britannia mine,					
	Sullivan mine,	92G/6				
	Texada Island,	82G/11				
	Copper Mountain deposit,	92F/9				
	Beaverdell camp	82E/6E	Cu, Zn		X	
80	Nakusp area	82K			X	
81	Copperado property,	92J/9E				
	Bell claim,	82E/6				
	Mayflower mine,	82F/4W				
	Reeves-MacDonald mine	82F/3W	Cu, Ag, Au, Zn		X	
82	Deadwood Camp,					
	Summit Camp,					
	Phoenix Camp	82E/2	Cu	X	X	
83	Giant Copper	92H/3E	Cu, Au, Ag, Mo		X	
84	Island Copper deposit	92L/11	Cu, Mo	X	X	X
85	Island Copper deposit	92L/11	Cu, Mo		X	X

TABLE 27-2
CROSS-INDEX BY NTS

NTS	Citation
82E/2	82
82E/4	46
82E/5	46
82E/6	79, 81
82E/9	26
82E/12	46
82E/13	66
82F/3, 4	81
82G/11	74, 79
82G/12	74
82K	80
82L/2	22
82M/4	20
92E/15	22
92F	36
92F/2, 3, 4	22
92F/5W	48
92F/9	79
92F/12	14, 31
92G	60
92G/6	79
92H	36, 75
92H/1W	53
92H/3E	83
92H/7	19, 26, 29, 55
92H/8	62, 63
92H/10	15, 16, 26, 45
92H/15	77
92I/6	2
92I/7W	59
92I/7	2, 35
92I/9	41, 77
92I/10E	11
92I/10	2, 10
92I/11	2, 3, 77
91I/14W	52
92I/14	26
92J/9E	81
92J/15	17
92K/2E	51
92L/11	8, 71, 84, 85
92L/12	42
92O/1	22, 73, 78
92O/2W	61
92O/4E	64
92P	36
92P/6	32, 34
92P/8E	76
93A/2	5, 67
93A/12E	31
93A/12	5, 6, 9, 25, 27
93C/9, 16	58
93E	36
93E/11	38, 72
93F/6	4
93F/7	49
93K	36
93K/3E	43
93K/3	68
93K/8	68
93K/9	68
93L	5
93L/1	54, 70
93L/2	68
93L/3	37
93L/4	37, 68
93L/10	68
93L/12	68
93L/14	68
93L/16	44, 47
93M/1W	12
93M/1	47
93N/1E	28, 40
93N/11	68
93O/4W	28, 40
94A	60
94A/6	1
94D	33
94E/2E	65
94E/6	24
103F/9	13
03I/9	68
104B/6E, 7W, 10W, 11E	40
104H/12	57
104K	18
114P/12E	14, 21, 23

TABLE 26-3
CROSS-INDEX BY SELECTED KEY WORDS

Key words	Citation Number
Afton deposit	10, 11, 77
alpine glaciation / glaciers	6, 33, 57
Ashnola porphyry copper	53
Babine Lake	56
basal till	*see* till
Beaverdell	79
Bell claim	81
Bell Copper	44, 47
Bethlehem	77
biogeochemistry	4, 7, 8, 17, 25, 32, 37, 38, 41, 53, 73-79, 81
Boss Mountain Mo deposit	67
boulder clay	*see* till
boulder trains / tracing	21, 23, 27, 32-34, 40, 43, 82
Brenda Cu-Mo deposit	66
Britannia mine	74, 79
Buttle Valley	14, 30
Capoose batholith	4
Cariboo Bell	6, 9, 31
Catface	48
Centennial	68
Chappelle	1
Chutanli	49
Cinola deposit	13
cirque	64
Clusko River	58
colluvium / colluvial dispersion	3, 15, 16, 20, 25, 27, 28, 44, 49, 64
Congress property	17
Copperado property	81
Copper Mountain	79
Covert Basin	46
Dansey - Rayfield River	34
Deadwood Camp	82
dispersal trains	*see* glacial dispersion
down-slope dispersion	*see* colluvium
Dutchman	77
East Arm Glacier	21
Endako	43, 68
Erratics	*see* boulder trains
Equity Silver	54, 70
felsenmeer	3
float boulders	*see* boulder trains
fluvial-glacial	*see* glaciofluvial sediments
Franklin Camp	26
Franklin River	22
Fraser Valley	60
Galaxy	41
gaseous dispersion	3
geochemical anomalies / dispersion	*see* soil geochemistry
geophysics	11, 12, 25, 31, 51, 55, 59, 61, 81
Giant Copper	83
glacial deposits / drift / overburden	*see* till
glacial dispersion / dispersal trains	11-15, 24, 25, 27-32, 34, 35, 40, 41, 43, 47-50, 55, 56, 59, 62, 63, 67, 70, 82
Glacier Gulch	68
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