QUATERNARY GEOLOGY AND DRIFT EXPLORATION AT MOUNT MILLIGAN (93N/1E, 93O/4W) AND JOHNNY MOUNTAIN (104B/6E, 7W, 10W, 11E), BRITISH COLUMBIA

885753

(Fig. B1, No. 7)

By D.E. Kerr and P.T. Bobrowsky

INTRODUCTION

An integrated research program in Quaternary mapping and drift prospecting in areas of high mineral potential was initiated in 1990 by the Geological Survey Branch. The long-term objective of the program is to illustrate the utility of surficial geological methods and techniques of analysis applied to the detection of mineral deposits in drift covered areas. Interpretive drift-exploration models applicable to British Columbia will be produced based on types of landforms, sediments and depositional environments.

All areas of British Columbia have been subjected to one or more glaciations. Local topography, style of glacial erosion and deposition and the geologic history of post-glacial events influence the type of sediment present, the thickness of the deposits over bedrock and the stratigraphy of an area. Collectively, these factors affect the nature of the surface expression (geochemical anomalies) of the underlying mineral occurrences. In many areas of the province, mineral exploration is hindered and often unsuccessful in dealing with complex and thick Quaternary successions of tills, debris-flow deposits, outwash sand and gravel, lake deposits and colluvium. Quaternary geology can be used as an aid to mineral exploration through the application of drift-prospecting techniques. Proper interpretation of surface geochemical results requires a clear understanding of the Quaternary geology to ensure success in the identification of hidden mineral deposits.

Drift prospecting has proven to be an invaluable tool for mineral exploration in many regions of Canada (Shilts, 1975, 1984), and we believe it can be successfully applied to broad areas of drift-covered or mountainous terrain in British Columbia. Drift-prospecting research was undertaken in two areas of the province during the summer of 1990 (Figure B-7-1):

- the Mount Milligan property north of Prince George, a copper-gold alkali porphyry deposit in the Quesnel trough, and
- the Johnny Mountain property in the northwest, a mesothermal gold-silver vein deposit in the Golden Triangle region.

The approach entailed air-photo interpretation and ground follow-up to produce 1:50 000-scale surficial geology maps for each study area. Detailed maps (1:10 000 and 1:14 000), illustrating the local Quaternary geological features, further assisted in the interpretation of geological and geochemical data. Stratigraphic studies of natural and man-made exposures, as well as overburden drill-hole logs, provided important information as to the composition and nature of the surficial deposits. Pebble-fabric measurements and other paleocurrent determinations were obtained in a variety of sediments to assist in the interpretation of sediment genesis and paleoflow. Pebble counts (lithologic determination) of clasts within sediments helped to confirm ice-flow patterns in relation to mineralized sources. Geochemical soil-profile sampling of pits and trenches at Mount Milligan (Gravel and Sibbick, 1991, this volume) was carried out to illustrate trends in the distribution and concentration of economic elements in different types of surficial materials. Geochemical data previously collected by Continental Gold and Skyline Gold Corporations were reinterpreted using the geological data resulting from this study.

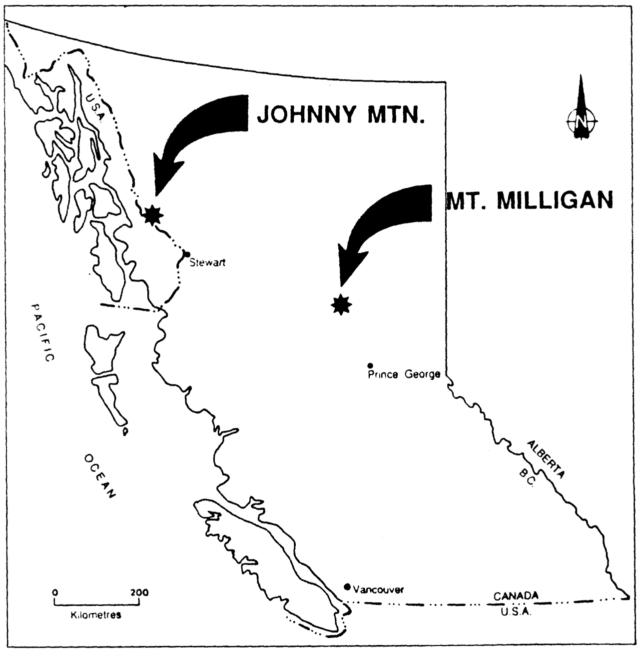


Figure B-7-1. Location map of drift prospecting studies. Mount Milligan in north-central and Johnny Mountain in northwestern British Columbia.

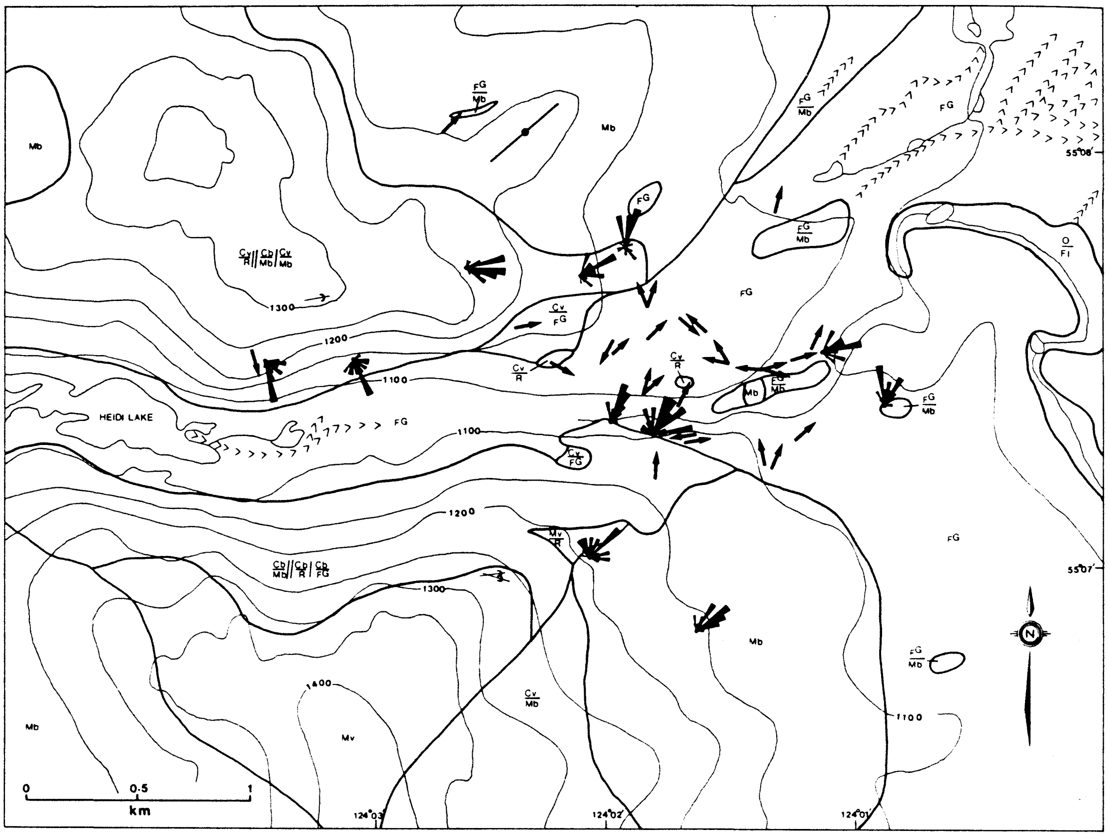


Figure B-7-2a. Detailed surficial geology map of the Mount Milligan property area. Paleocurrent symbols include rose histograms for pebble fabrics, arrows for sand/gravel crossbedding, open-checks for eskers and the standard crossed-line symbol for striations. Map units include Cv (colluvial veneer), F^G (glaciofluvial), Mb (morainal blanket), Mv (morainal veneer), O (organics) and R (bedrock).

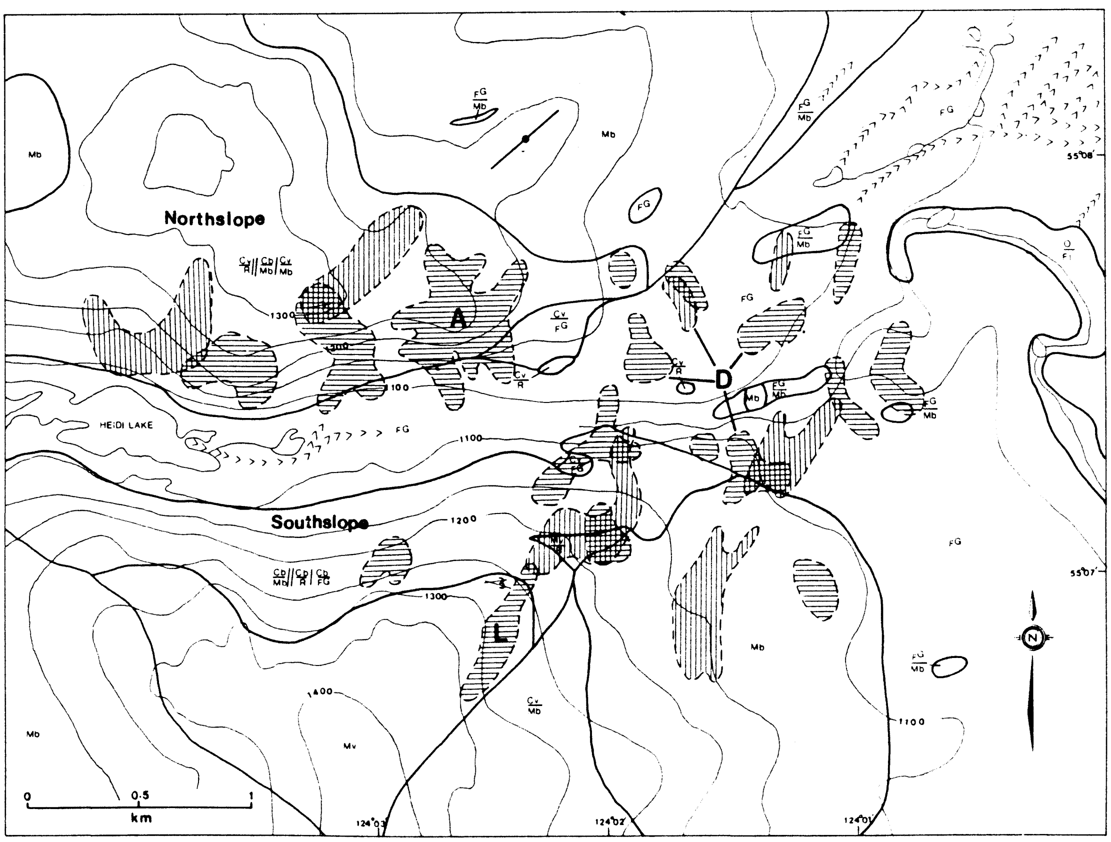


Figure B-7-2b. Illustrated soil anomalies consist of Cu at 150 ppm (vertical lines) and Au at 80 ppb (horizontal lines). Modified from unpublished Continental Gold data. Map units same as in Figure 2a. See text for explanation of letters A, L and D.

RESULTS

MOUNT MILLIGAN

The Mount Milligan property lies approximately 160 kilometres north of Prince George. Situated within the early Mesozoic Quesnel trough, this copper-gold alkali porphyry deposit comprises a series of biotite quartz monzonite, monzonite porphyry and diorite stocks which intrude augite plagioclase porphyries, bedded tuffs and porphyritic agglomerates. The geology of Mount Milligan and surrounding area has been described by Armstrong (1949), DeLong *et al.* (1991), Faulkner (1986, 1988), Faulkner *et al.* (1990), Nelson *et al.* (1991a, 1991b), Rebagliati (1990), Tipper *et al.* (1979), as well as in a number of unpublished assessment reports.

SURFICIAL GEOLOGY

The last glacial episode in the Mount Milligan region probably occurred some 20 000 to 10 000 years ago during the Late Wisconsinan (Fraser Glaciation). Regional ice movement during this final 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 and on unconsolidated sediments (Kerr, 1991a). This observation of regional flow is in accordance with earlier studies by Armstrong (1949) to the north, west and south of the Milligan area, as well as those of Plouffe (1991) in the Stuart – Fraser Lakes area to the southwest. Southeast of the study area, in the McLeod Lake region, Struik and Fuller (1988) mapped the extent of glacial lake deposits and noted the presence of mineralized clasts in morainal deposits. Previous glacial episodes also affected the study area, but the conditions surrounding these older events can only be interpreted from deeply buried deposits preserved in bedrock depressions.

Surficial sediments identified in the Mount Milligan study map area include diamicton (till and debris-flow deposits), glaciofluvial and fluvial sand and gravel, glaciolacustrine sand, silt and clay, colluvium and organic materials (Kerr, 1991a and Plate B-7-1). Hummocky and drumlinized till deposits are widespread throughout the area, occurring primarily as a blanket along the east half of the map sheet from south of Philip Lakes north to the Nation River. Drift cover is highly variable, ranging from 1 to more than 90 metres in thickness. Drill-hole data show that significant thicknesses of unconsolidated sediments in excess of 100 metres are common directly west of Mount Milligan, and in excess of 200 metres in the Nation Lakes area farther west (Ronning, 1989). For most areas, the till is compact, very poorly sorted and consists of angular to well-rounded pebbles to boulders in a sand-silt-clay matrix (Plate B-7-2).

Drumlinized features, often occurring in "drumlin fields", are restricted to till plains and are best developed in the northern and southeastern parts of the map area. The shape and size of the flutings are variable, and some are more evident on air photos than at ground level. Although the dominant trend of these landforms is to the northeast, easterly oriented features paralleling the Nation River are present in the northeast part of the map area.

A northeast-trending belt of glaciofluvial sediments occurs in the western part of the map area along Fort St. James Highway #27. A second belt, trending east, borders the Nation River to the north, and a third concentration of glaciofluvial sand and gravel dominates the central part of the map directly east of the Mount Milligan property. These sand and gravel deposits consist of sinuous esker ridges, kame deposits with some kettle lakes, and broad overlapping outwash fans (Plate B-7-3). They attain 30 kilometres or more in length and 6 to 8 kilometres in width. Several smaller glaciofluvial corridors occupy the narrow east-west oriented valleys between high-points south of Mount Milligan.

Stratified glaciolacustrine sediments consisting of interbedded rhythmites of sand, silt and clay occur as isolated deposits (Plate B-7-4). The most extensive deposits (>20 m thick) are exposed in sections along the Nation River (elevation of 850 m) and appear to be confined to the river valley. Elsewhere, such as along tributaries of Rainbow Creek, thin (2-5 m thick) planar and cross-stratified sand and silty clay, glaciolacustrine sediments are evident (elevation of 1025 m). There does not appear to be any spatial relationship between these deposits and the more extensive glacial lake sediments in the Fort St. James basin to the south (Armstrong, 1949).

Holocene postglacial drainage is responsible for the braided and meandering river deposits occurring along the major water courses and tributary streams. Many low-lying and poorly drained areas are now occupied by organic accumulations in bogs, most commonly associated with glaciofluvial and morainal deposits. Colluvium deposits frequently mantle the steeper slopes of hills and valleys and mainly occur directly north and south of Heidi Lake.

A detailed surficial geology map (1:10 000 scale) of the Mount Milligan property was compiled from various data obtained during this investigation, as an aid to reinterpretation of geochemical data (Figures B-7-2a, b). The surficial deposits consist predominantly of diamictons in the form of a till blanket which varies in thickness from 0.5 metre to over 30 metres. A belt of glaciofluvial sand and gravel is confined to the Heidi Lake valley in the west, but fans out to the east over the MBX stock and beyond. Colluvium derived from till and bedrock weathering dominates the hills north and south of Heidi Lake. An approximation of the stratigraphy in the area of the MBX stock

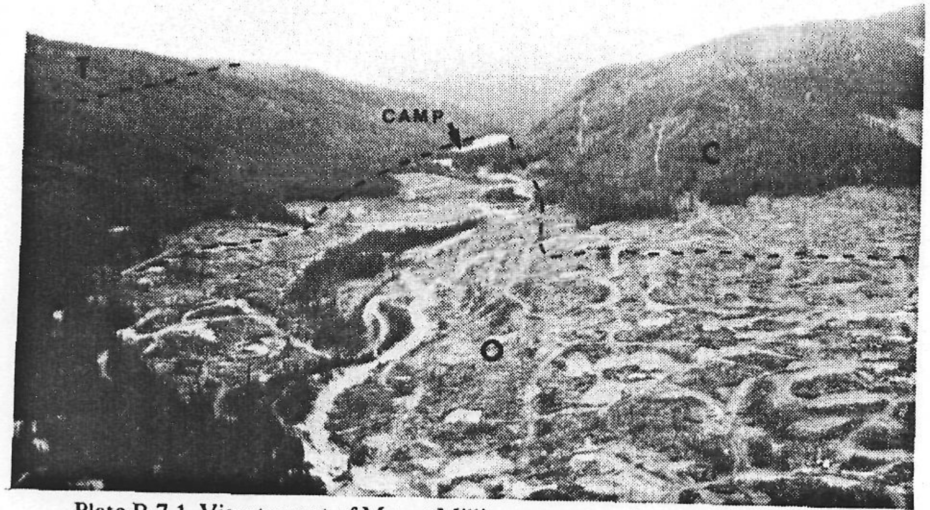


Plate B-7-1. View to west of Mount Milligan property. Symbols include T (till), C (colluvium) and O (outwash). Camp in background is near Heidi Lake.

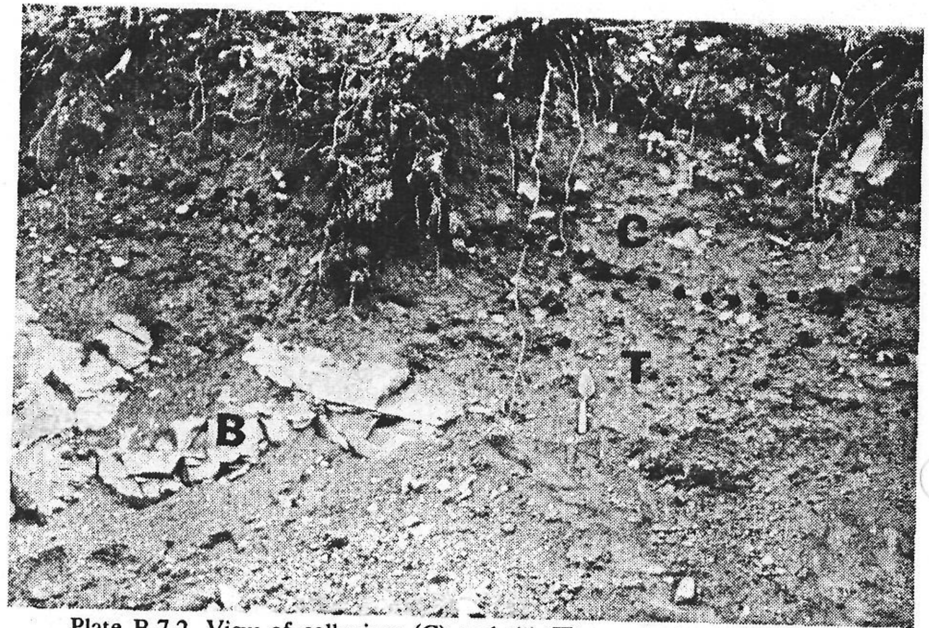


Plate B-7-2. View of colluvium (C) and till (T) over bedrock (B) at Mount Milligan. Dotted line marks approximate transition between the two diamictons. Note trowel near letter T for scale.

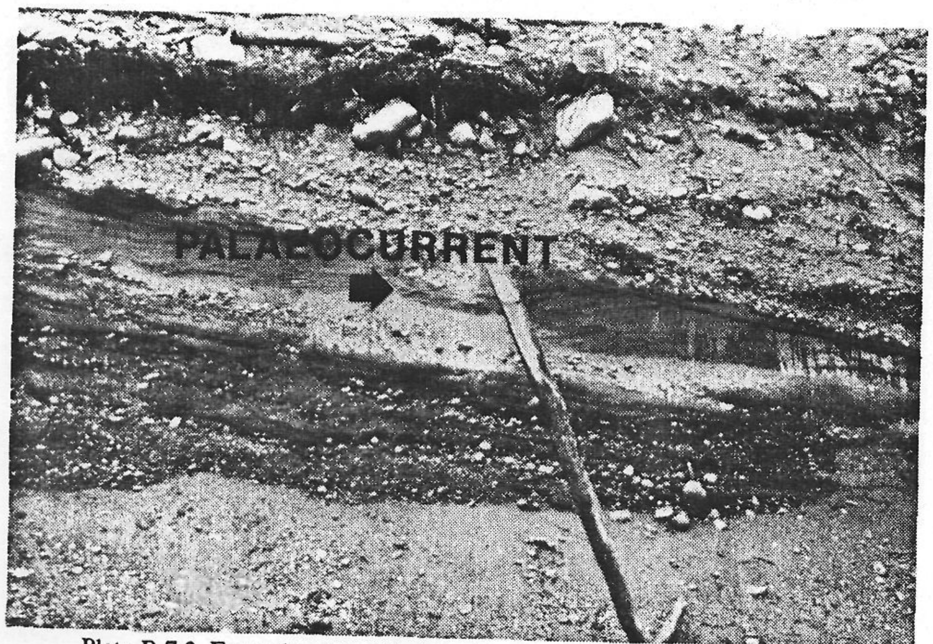


Plate B-7-3. Example of stratified sand and gravel comprising the outwash plain at Mount Milligan. Paleocurrent illustrated.

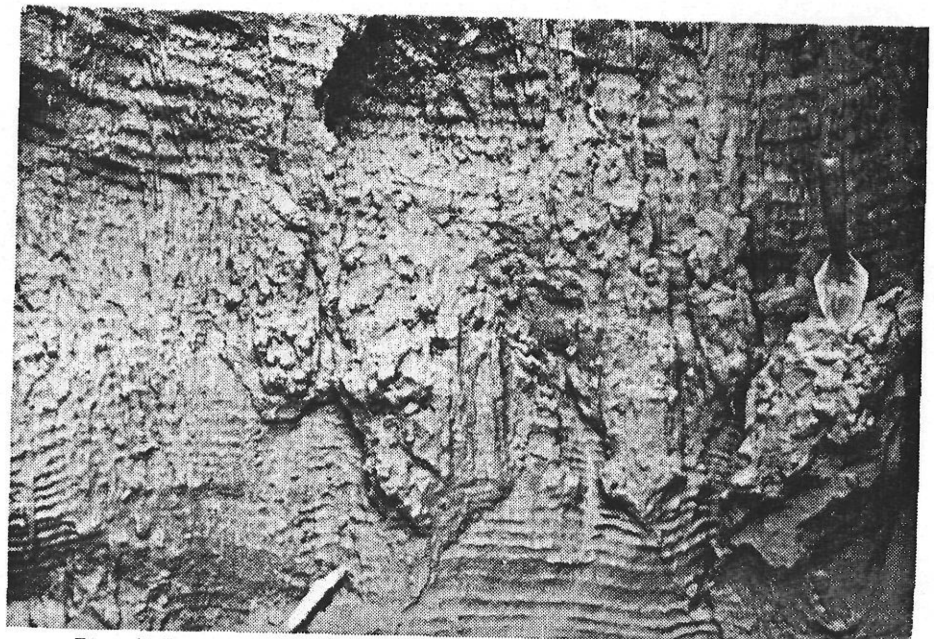


Plate B-7-4. View of deformed sand, silt and clay glaciolacustrine rhythmites directly east of Mount Milligan property.

was interpreted from the drill-hole logs (Figure B-7-3). Although generalized, this interpretation illustrates the stratigraphic complexity of the unconsolidated sediments over very short distances. Noteworthy is the high paleotopographic relief of the underlying bedrock surface.

Striated bedrock and pebble fabrics determined from till indicate that during the last glaciation, ice was deflected locally by hills and funnelled through the small valley now occupied by Heidi Lake. Fabrics indicate initial southeasterly, easterly and northeasterly ice-flow directions in the early stages of ice advance (Figure B-7-2a). This was followed by a predominant northeasterly flow during full glacial conditions as indicated by striae on hill tops and by drumlins (Figure B-7-4). Pebble counts (Figure B-7-5) in till reflect local lithologies (porphyries, monzonite, tuff). These data suggest basal transport in the ice, as well as a proximal origin for the source materials of the till. In only one locality at the northern extremity of the Southern Star stock, a few clasts of rock types outcropping about 30 kilometres to the west were observed, suggesting that a very small fraction of exotic material has been incorporated with the locally derived drift. Deglaciation took place by down-wasting and ice stagnation, and was accompanied by intense glaciofluvial meltwater activity. This is evidenced by extensive well-stratified sand and gravel deposits. Paleocurrent measurements derived from crossbedding and ripple marks exhibit variable flow directions (Figure B-7-2a) which is typical of deglacial outwash sediments. However, the general trend is towards the northeast as indicated by esker ridges and other large-scale sedimentary structures.

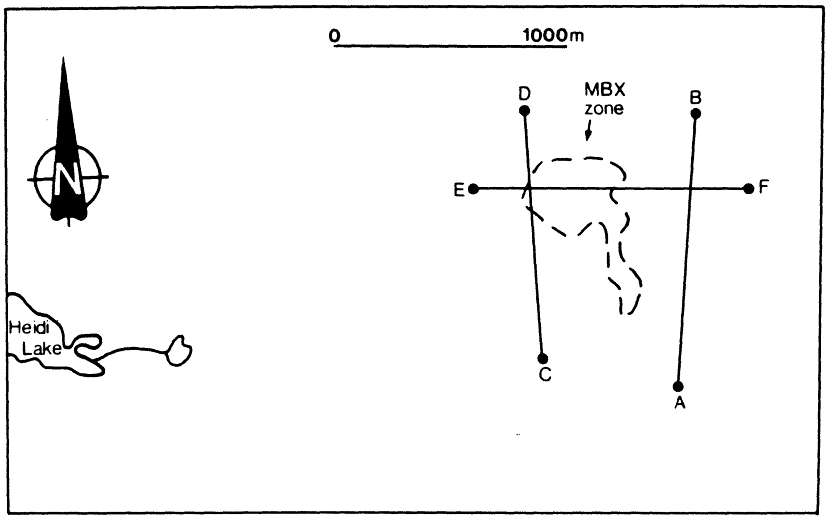
DISCUSSION

The Mount Milligan property provides an excellent example of the importance of surficial geology in drift prospecting surveys because of its known geological setting, the size of the mineralized zones, variable drift thickness and abundance of geochemical data. The complexity of the stratigraphic record for surficial deposits is illustrated in a series of cross-sections (Figure B-7-3). Drill-hole information indicates that the unconsolidated cover of sediment in the Mount Milligan area consists of alternating beds of clay, sand, gravel, boulders and till. Considerable vertical and lateral variation in texture and character of the deposits exists over the entire area. This variability, together with significant changes in drift thickness over short distances (Section E-F), makes correlation of units difficult. It remains unclear if more than one glaciation is recorded in these deposits, as no datable organic material was observed in sections. However, a diamicton interpreted as a second till was encountered east of the property during drilling operations. This till was overlain by a basalt bed and may represent a pre-Late Wisconsinan glacial event.

In areas of relatively thin drift cover, an evaluation of new and existing soil geochemical data was undertaken to study the development of mineralized dispersal trains within various types of surficial sediments (Gravel *et al.*, 1991; Gravel and Sibbick, 1991). Soil geochemistry for copper and gold, as well as other pertinent surficial geology features are summarized in the detailed surficial map.

In the Mount Milligan area, soil geochemical anomaly patterns can be classified into three which in turn, can be related to overburden type as seen in Figure B-7-2b: amorphous-shaped (A), linear or ribbon-shaped (L) and discontinuous or fan-shaped (D). Copper (> 150 ppm) and gold (> 80 ppb) soil anomalies occur as broad amorphous zones covering 100 000 square metres downslope from source areas in thin colluvium and till veneers over the North Slope and South Slope mineralizations. Linear dispersal trains, some approaching 1 kilometre in length, are associated with till in the Southern Star area. Linear anomalies in till parallel the dominant ice-flow direction to the northeast. Shorter, dispersed anomalies occur in glaciofluvial sand and gravel. Although the latter anomalies trend in the paleocurrent directions of the outwash deposits, their form is discontinuous.

Determining the direction and source of till provenance, as well as the direction of transport of outwash sediments helped to resolve the mineralized source location of anomalies. A local mineralized bedrock source is inferred for the colluvium anomalies as this material appears to be locally derived. Soil anomalies in till are likely associated with the Southern Star stock (SS in Figure B-7-6), although smaller anomalies up-ice (south) of the Southern Star deposit suggest that there may be additional mineralization as yet undiscovered in this area. The discontinuous anomalies in glaciofluvial deposits are a result of a combination of meltwater erosion of mineralized bedrock in the Esker Zone (EZ) and Creek Zone (CZ), and reworking of locally derived till from the MBX and Southern Star stocks. This relationship has been established using boulder tracing. Mapping of mineralized float lithologies and relative abundance approximations was conducted using test pits over the MBX and Southern Star deposits (Figure B-7-6). The resulting patterns may then be used for determining transport directions and distances. At a local scale, abundant float of easily comminuted, oxidized supergene ore was encountered at a depth of less than 2 metres. The underlying till exceeds 25 metres in thickness. The nearest subcrop of supergene material lies approximately 90 metres up-ice, indicating that some surficial deposits overlying the mineralized zones are proximally derived. On a more regional scale (Figure B-7-6), a greater concentration of mineralized clasts was observed in areas of thin overburden and closer to various mineralized sources. Further proven-



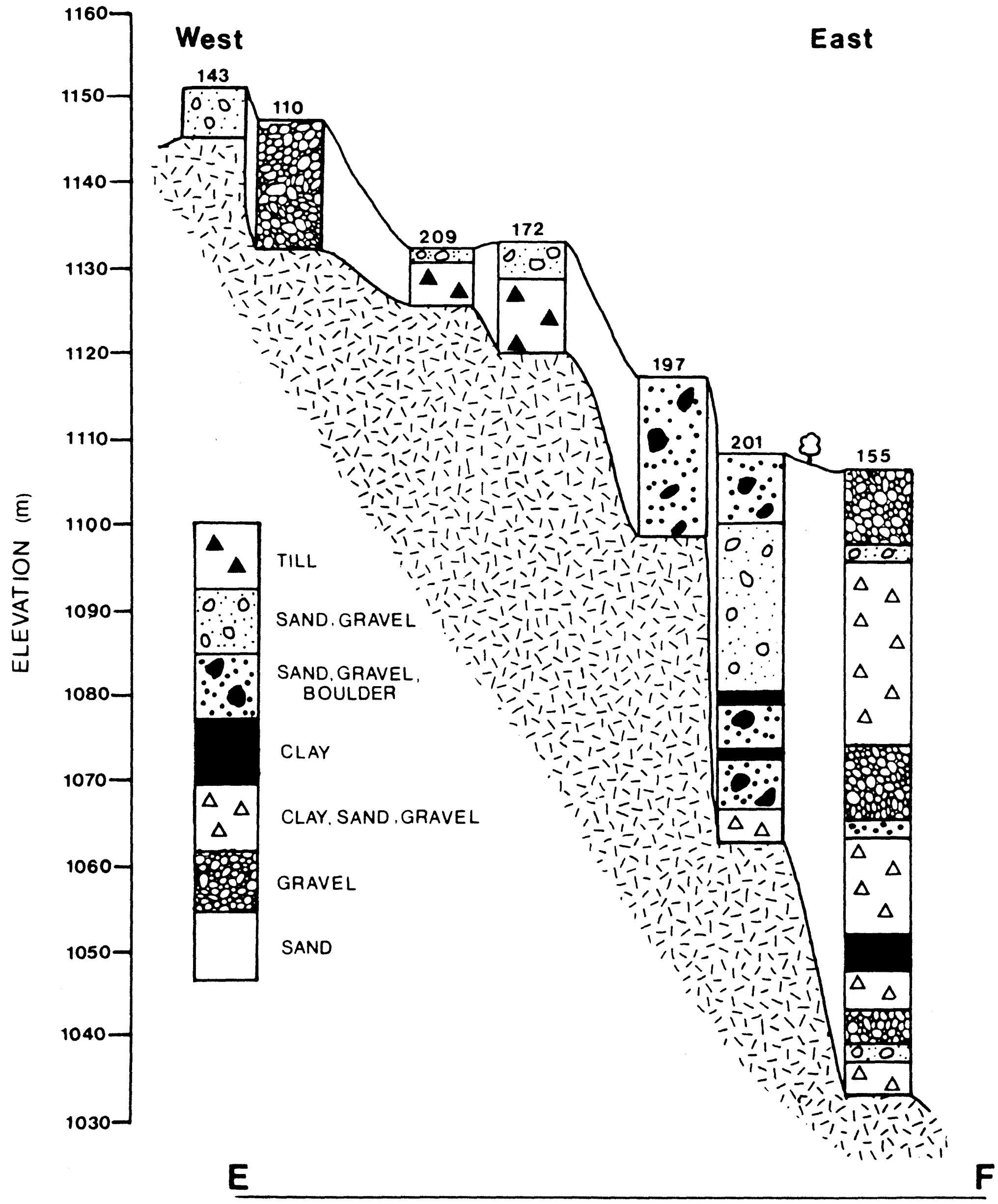
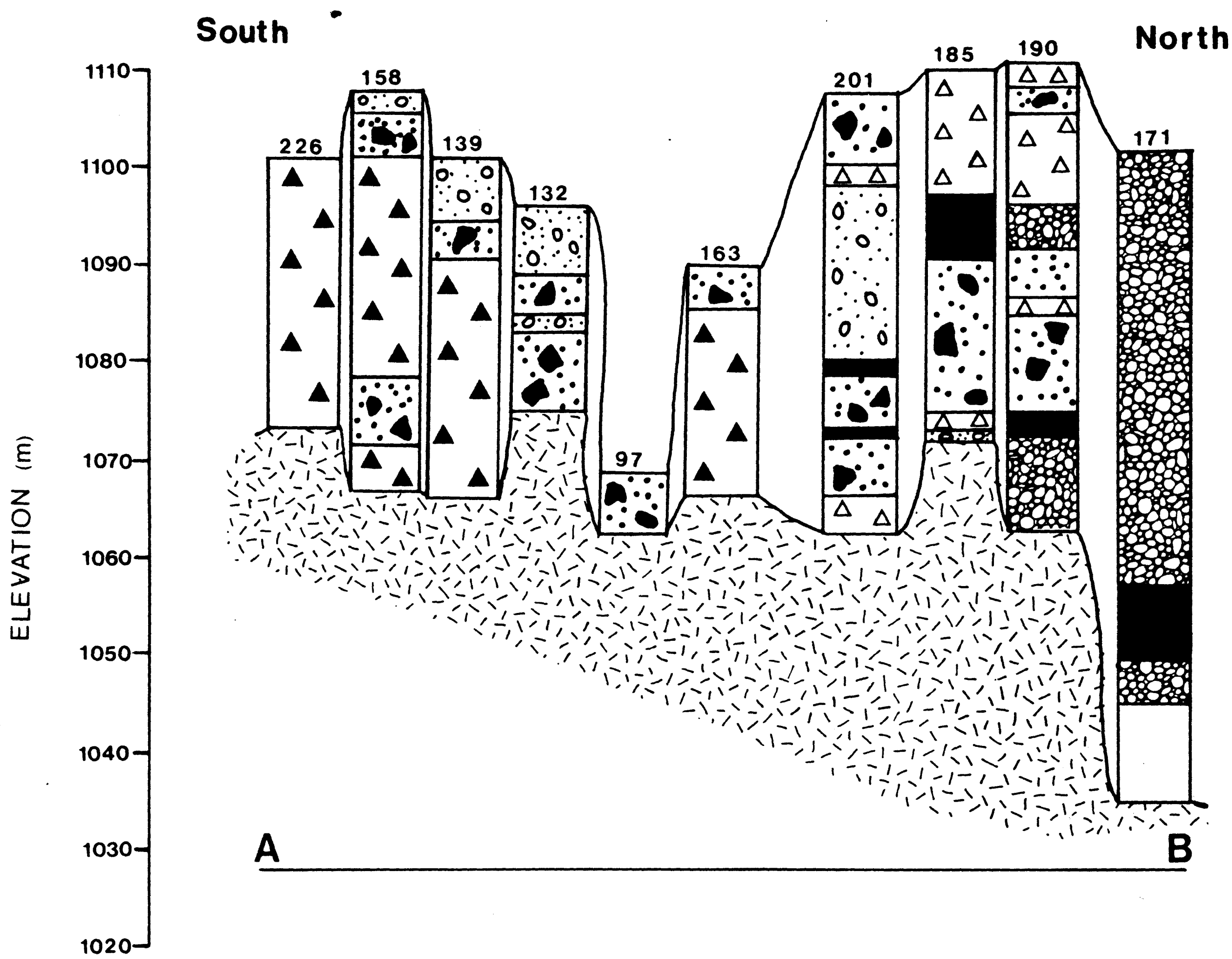
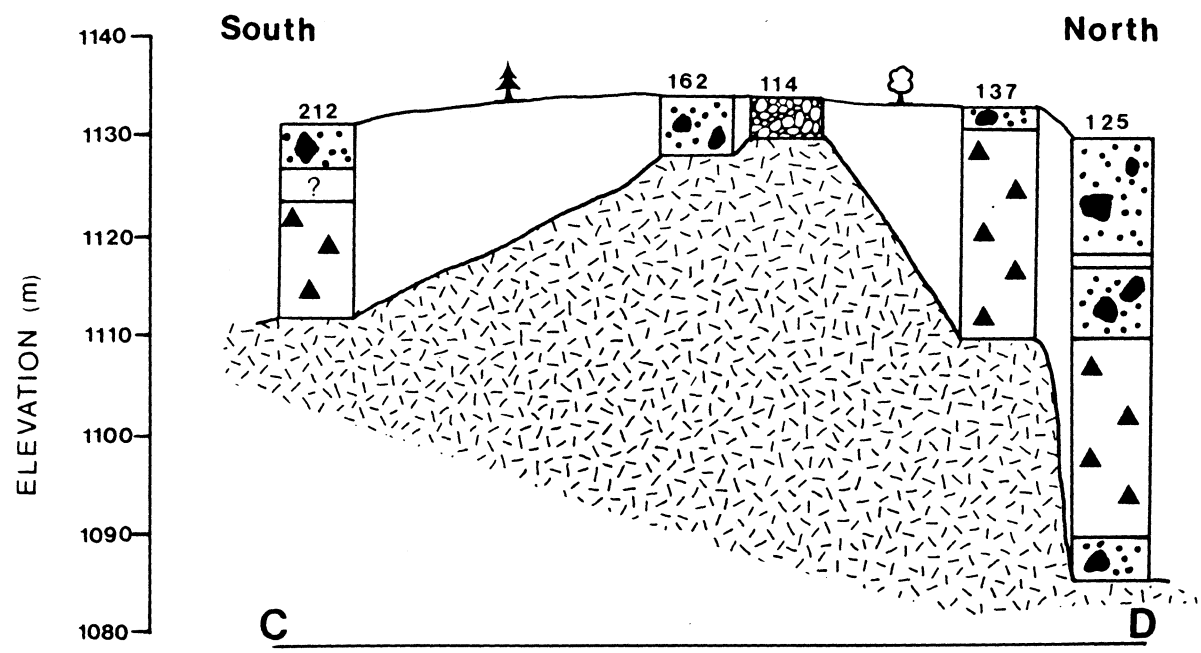


Figure B-7-3. Location map and Stratigraphic cross-sections of the surficial geology over the Mount Milligan deposit. Sections are based on drill hole data; (continued on facing page).



South
North
1110
1100
1090
1080
1070
1060
1050
1040
1030
1020
ELEVATION (m)
226
158
139
132
97
163
201
185
190
171
A
B



South
North
1140
1130
1120
1110
1100
1090
1080
ELEVATION (m)
212
?
162
114
137
125
C
D

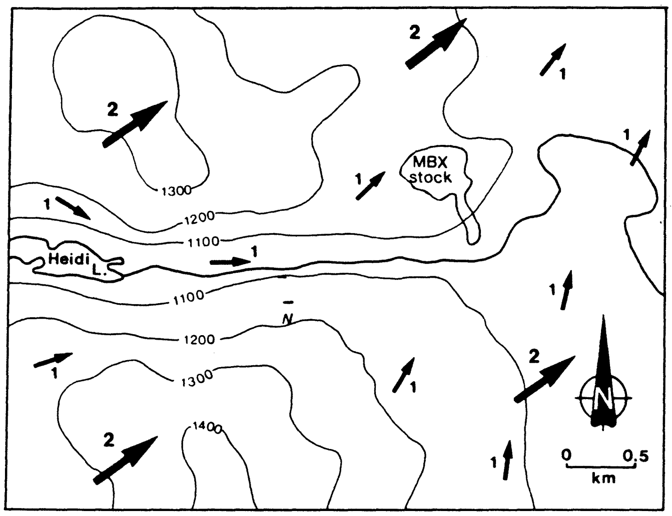


Figure B-7-4. Generalized glacial-flow history for the Mount Milligan area. Small arrows (1) illustrate first phase of local ice flow which was topographically controlled and larger arrows (2) illustrate a later stage of regional ice-sheet flow.

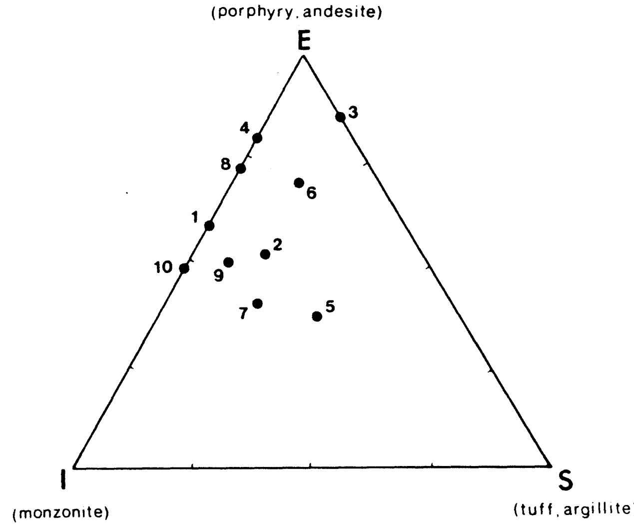


Figure B-7-5. Ternary plot of pebble lithologies for the Mount Milligan area. S-sedimentary, I-intrusive and E-extrusive rocks. Numbers refer to separate sample locations.

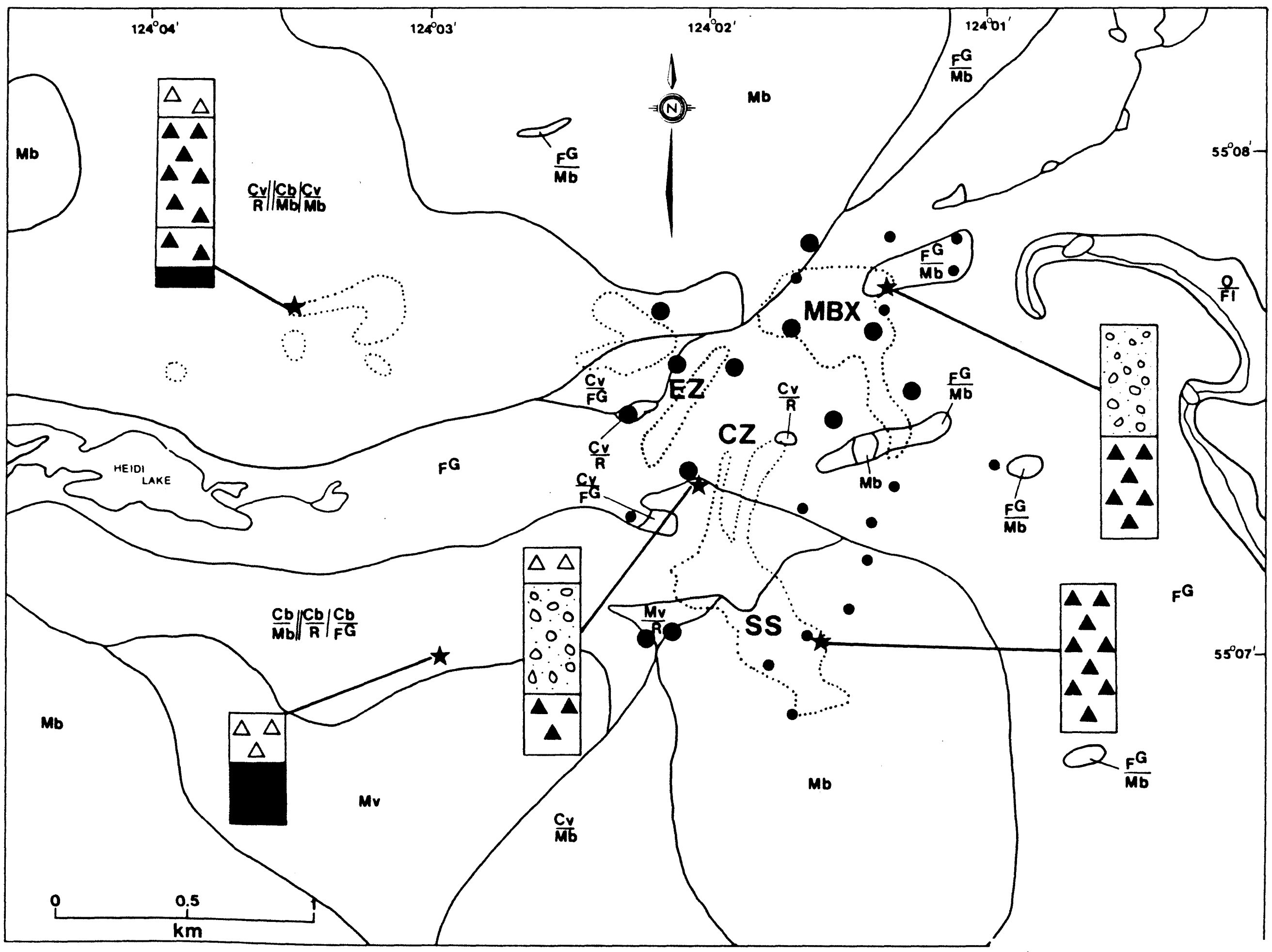


Figure B-7-6. Distribution of sulphide bearing clasts in test pits over the MBX zone, Southern Star (SS) zone, Esker Zone (EZ), Creek Zone (CZ) and other mineralized zones (shaded): large dots represents 5% mineralized clasts, small dots %; Generalized overburden stratigraphy throughout the study area is also presented: black = bedrock (R), black triangles = till (Mb, Mv), open triangles = colluvium (Cb, Cv), stippling = glaciofluvial deposits (F^G).

ance studies over a broader area down-ice would be needed to determine if boulder concentration increases in an up-ice direction, that is close to the mineralized stocks.

CONCLUSION

An understanding of the regional and local surficial geology of the Mount Milligan area is the major controlling factor in successful application of drift-exploration techniques. A conceptualized flow chart clarifies the relationship between anomaly form and surficial sediment type in the study area (Figure B-7-7. During glaciation, mineralized bedrock may be eroded and incorporated into glacier ice. The sediment in the ice is eventually deposited in a variety of forms such as till, outwash sand and gravel, or debris-flow deposits. The characteristics of the mineralized bedrock, as expressed by the geochemical anomalies differ depending on the depositional history of the elements. Linear-shaped geochemical anomaly patterns represent minimally altered proximal mineral indicators and occur most commonly in deposits such as till. Amorphous or discontinuous patterns represent moderately altered distal indicators and are generally observed in outwash deposits. Subsequent modification of these two types of sediments through colluviation further complicates the geochemical anomalies resulting in discontinuous patterns. However, if the colluvium is a product of weathered bedrock, the resulting anomaly pattern is amorphous and represents a proximal indicator.

Morainal deposits (till) over the Southern Star are predominantly locally derived, as evidenced by pebble lithologies and boulder trains. Till deposits in this area are characterized by linear geochemical anomalies which primarily reflect the underlying mineralization. However, some of the anomalies near Southern Star cannot be associated directly to known mineralization. Glaciofluvial deposits over the MBX stock exhibit discontinuous anomalies parallel to paleocurrent directions. The anomalies result from erosion of local bedrock, reworking of underlying till and melting of sediment-laden glacier ice. The broad amorphous anomalies in colluvium over the North Slope suggest local point-sources of mineralization and not a second stage of resedimentation of pre-existing till or outwash.

Elsewhere in the area, where the sediment cover is thicker, greater attention must be given to documenting the types of surficial deposits present. The complexity of the stratigraphic record and the large variations in drift thickness (< 1 m to > 30 m) over lateral distances of tens of metres directly influences the application and interpretation of geochemical exploration programs. A greater effort to describe overburden encountered during drilling facilitates subsequent interpretation and represents a cost-effective exploratory technique. An understanding of the nature and origin of stratigraphic units is essential in the interpretation stages; soil sampling should be directed toward particular materials which, in order of sampling priority, are bedrock-derived colluvium, till, outwash, and other colluviated surficial deposits.

JOHNNY MOUNTAIN

The Johnny Mountain gold mine lies approximately 100 kilometres northwest of Stewart, within the Boundary Ranges of the Coast Mountains physiographic belt (Figure B-7-1). This mesothermal vein deposit, in British Columbia's Golden Triangle, is part of a volcanic package consisting of interbedded andesite and dacite volcaniclastics and volcanic sediments ranging from mudstones to conglomerates. The geology of the Johnny Mountain deposit and the Snippaker Creek map area is described in Alldrick *et al.* (1989, 1990), Anderson (1989), Britton *et al.* (1990), Fletcher and Hiebert (1990), Kerr (1948), Lefebure and Gunning (1989), Read *et al.* (1989) and Souther *et al.* (1979).

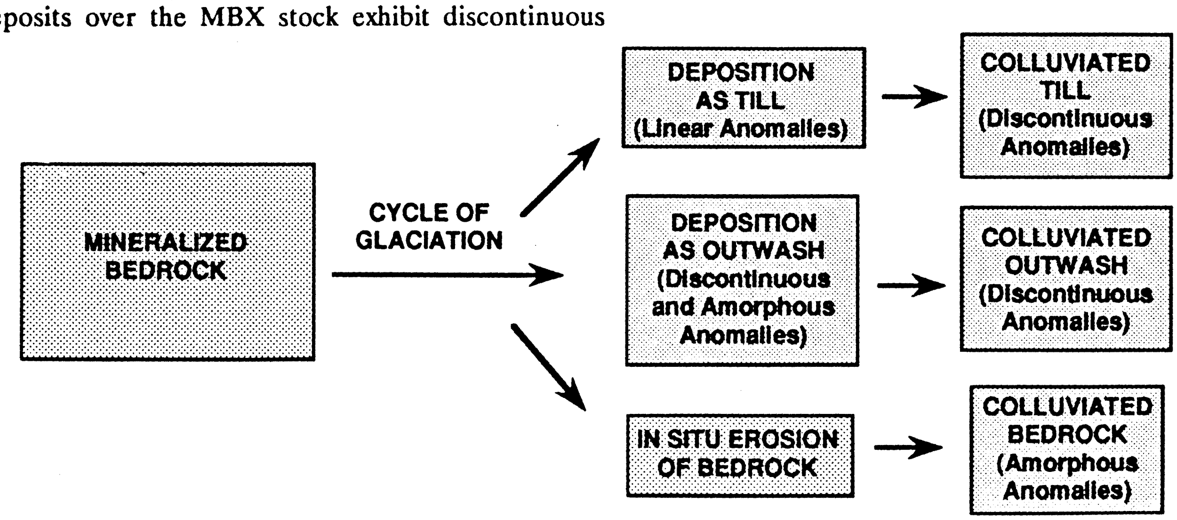


Figure B-7-7. Mount Milligan flow chart illustrating relationship of geochemical anomaly patterns to types of surficial sediments.