Section C

THE CANADIAN SHIELD

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INTRODUCTION

Discussion in this section is confined to the Canadian Precambrian Shield. This entire area has suffered continental glaciation of a more widespread and continuous nature than was the case in the valley glaciated areas of the Canadian Cordillera. As a result of this, the glacial processes, although the same in mechanism of formation of glacial drift as for the Canadian Cordillera, were generally more intense and consequently have had a more profound effect on geochemical dispersion. In particular, within the Canadian Shield the occurrence of stratified drift is far more common than within the Cordillera, and it is this overburden which creates the greatest problem for the exploration geochemist. However, methods of successfully using geochemistry within these overburden conditions have been established and they are included in this section.

Because formation of geochemical anomalies in the Shield is generally more complex, and their interpretation requires greater attention to detail than in the Cordillera, the reader is advised to study Section B prior to this section. On the whole the processes which apply in the Canadian Cordillera also apply in the Shield, but in places with added complications. In addition, there are no residual soil areas within the Canadian Shield as is the case in the Cordillera. It is these residual soil areas which are the simplest and most straightforward to understand and therefore should be studied first. In much the same way as metamorphic petrology should be studied after igneous and sedimentary petrology, exploration techniques in glaciated areas follow on as a natural progression from residual soil areas. These can therefore be profitably studied first, even if exploration is not being conducted there.

Within the Canadian Shield there are a number of different geochemical environments. These have resulted largely from the combined effects of differing glacial histories, which in turn have modified the physiography. These two variables have greatly influenced the geochemical dispersion patterns of the elements in the secondary environments. This section outlines the broad

geochemical dispersion characteristics which can be expected under the different environmental conditions found within the Shield. However, prior to discussion of the geochemistry, mineral zoning, Pleistocene geology, physiography and soils are discussed, particularly as they affect geochemical exploration. In addition, a detailed description of the common glacial sediments, their properties and distribution and use in exploration geochemistry are given in the Appendix to this section (p.189).

Mineral zoning and distribution of mineralization

The Canadian Shield is divisible into seven structural provinces (Fig.62) — Superior, Slave, Bear, Churchill, Southern, Grenville, and Nutak — and the rocks are generally subdivided into two eons, the oldest being represented by the Archean and the youngest by the Proterozoic. These rocks have been affected by four major orogenies (Table XXII).

The Archean rocks of the Canadian Shield are characterized by thick sequences of volcanic flows and various intrusions of basic, intermediate, and acidic composition, all generally referred to in the older literature as Keewatin. In places the volcanics are interbedded with iron formation and pyritic sediments. These sequences are interbedded with or overlain, often conformably, by great thicknesses of greywackes, siltstones and shales commonly referred
TABLE XXII

Precambrian time-stratigraphic classification in relation to orogenies of the Canadian Shield (after Stockwell, 1970)

<table>
<thead>
<tr>
<th>Eon</th>
<th>Era</th>
<th>Sub-era</th>
<th>Orogeny (mean K–Ar mica age, m.y.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hadrynian</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neohelikian</td>
<td></td>
<td>Grenvillian (955)</td>
</tr>
<tr>
<td>Proterozoic</td>
<td>Helikian</td>
<td></td>
<td>Elsonian (1370)</td>
</tr>
<tr>
<td></td>
<td>Paleokelikian</td>
<td></td>
<td>Hudsonian (1735)</td>
</tr>
<tr>
<td></td>
<td>Aphebian</td>
<td></td>
<td>Kenoran (2480)</td>
</tr>
<tr>
<td>Archean</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

to in the older literature as Temiskaming-type sediments. The Archean volcanic terranes have been much studied over the last 75 years. They apparently differ little from eugeosynclinal terranes of more recent vintage. All of the Archean rocks were folded, sheared, faulted, metamorphosed, granitized, and intruded by granitic rocks during the late Archean Kenoran orogeny. The Archean rocks are best preserved in the Superior and Slave provinces but have also been recognized in parts of the Grenville, Churchill, Southern, and Nutak provinces.

The Proterozoic rocks of the Canadian Shield are quite varied and few generalizations can be made about them. In most regions they comprise conglomerate, quartzite, greywacke, arkose, shale, stromatolitic limestone, and other allied sedimentary rocks. In other regions these rocks are present in addition to basic volcanic flows and sills, acid pyroclastics, iron formation, limestone (marble), and other allied rocks. Some Proterozoic rocks are relatively flat lying and undisturbed by faulting as in the Cobalt area of Ontario; others are highly folded, faulted, sheared, metamorphosed, granitized, and intruded by granitic rocks during the Hudsonian, Elsonian, and Grenvillian orogenies.

The principal types of mineral deposits in the Canadian Shield are listed below (details should be sought in the volume edited by Douglas, 1970):

**Carbonatites.** These have a widespread distribution in the Canadian Shield. Most are characterized by the presence of alkali syenites and masses or disseminations of magnetite, apatite, fluorite, and carbonates. Fenitization is common in the wall rocks of carbonatites. The elements markedly enriched include K, Na, Fe, P, F, Cl, CO₂, Zr, and Nb. Elements enriched to varying degrees in some deposits include S, Li, Sr, Ba, Ti, Cu, Ag, Zn, Ta, U, Th, and rare earths. Examples are Oka, Quebec, and Nemegis, Ontario.
Pegmatites. These deposits invariably occur in high-grade metamorphic terranes or in the associated granitic intrusions. Three types of pegmatites are recognized — granite, syenite, and basic or gabbroic. The last is of no particular interest in the Canadian Shield. The granitic variety are mined for feldspar, quartz, and other ceramic materials. They also yield tantalite-columbite, lithium minerals, molybdenite, etc. Some granitic pegmatites are characterized by enrichments of one or more of Li, Rb, Cs, Be, B, Sc, Y, La, Ce and rare earths, Sn, Ti, Zr, P, As, Nb, Ta, Mo, W, F, Th, and U. Examples occur in the Bernic Lake area, Manitoba, and the Yellowknife area, Northwest Territories. The syenitic type of pegmatites are common in the Grenville province. They are characterized by enrichments of Be, B, Ti, Zr, La, Y, Ce and other rare earths, Th, U, Cl, and F. Examples occur in the Bancroft area, Ontario, and Buckingham area, Quebec.

Ni—Cu—Fe sulphide deposits. These are commonly associated with basic intrusions or basic volcanics. The deposits are massive or disseminated epigenetic bodies composed essentially of pyrite, chalcopyrite, pentlandite, and pyrrhotite. Extensive gossans are developed on some of the bodies. The elements greatly enriched in the deposits include: Fe, S, Ni, Cu, and Co. Elements exhibiting minor enrichments are: Pt and other platinoids, Ag, Au, As, Sb, Bi, Se, and Te. Examples are Sudbury, Ontario, and Lynn Lake, Manitoba.

Skarn deposits. These are found mainly in terranes containing regionally metamorphosed carbonate rocks, commonly near intrusive granitic bodies but also in zones well removed from such bodies. Most of the deposits in skarn in the Canadian Shield occur in the Grenville province. Several types of skarn deposits are recognized, viz. iron (magnetite) deposits; Cu—Zn—Pb deposits; graphite deposits; and arsenopyrite-pyrite-gold deposits.

The skarn iron deposits contain essentially massive or disseminated magnetite or magnetite-ilmenite in a gangue of Ca—Mg—Fe silicates. The principal element enriched is iron with titanium to a less degree. Examples are Marmora, Ontario, and Bristol iron mine, Quebec.

The Cu—Zn—Pb deposits are mainly composed of disseminated to massive pyrite, pyrrhotite, chalcopyrite, galena, sphalerite, and minor sulphosalts in a gangue of Ca—Mg—Fe silicates. The elements greatly enriched are Fe, Cu, Pb, Zn, Cd, and S. Those exhibiting minor enrichment in some deposits include: Ag, Au, As, Sb, and Bi. Examples are Calumet Island and Tetreault mines, both in Quebec.

The graphite deposits contain only graphite as a commercial mineral. Some deposits contain minor amounts of pyrite and pyrrhotite.

The skarn-type gold deposits are relatively rare. They contain essentially native gold in a gangue of Ca—Mg—Fe silicates with some pyrite, pyrrhotite, and arsenopyrite. Uranium minerals such as uraninite and brannerite have been recorded in these deposits. The elements exhibiting enrichments include: Au, Ag, Fe, S, As, U, and Th. An example is the historic Richardson mine at Eldorado, Ontario.
Massive Cu—Zn sulphide deposits. These have a widespread distribution in the Canadian Shield occurring mainly in Archean volcanic sequences but also in Archean sedimentary piles. Most are massive and heavily disseminated bodies of pyrite and pyrrhotite with chalcopyrite, sphalerite, and generally minor galena. The elements strongly enriched are Fe, S, Cu, and Zn. Some show marked enrichments of silver and gold. Others contain only minor enrichments of these two precious metals. Many are slightly enriched in one or more of Cd, Hg, In, Tl, Sn, Pb, As, Sb, Bi, Se, and Te. Examples are Flin Flon, Manitoba, Kidd Creek, Ontario, and Noranda, Quebec.

Native copper deposits. The best known and only economic example of this type of deposit is in the Keweenawan peninsula in Michigan, U.S.A. Occurrences are known in the Coppermine district, Northwest Territories, Michipicoten Island, Ontario, and Seal Lake, Labrador. The deposits occur in amygdaloidal basalts (copper amygdaloids) or in associated conglomerates (copper conglomerates) of Proterozoic age. The ore mineral is essentially native copper. The major enrichment is copper with minor enrichments of Ag, As, Sb, and B in some deposits.

Gold-quartz deposits. These comprise veins, stockworks, and silicified bodies of rock in fractures, faults, shear zones, drag folds, etc., mainly in Archean volcanic and sedimentary rocks. The elements extensively enriched are Si, Fe, S, As, Sb, Au, and Ag. Minor enrichments of Cu, Zn, Cd, B, Pb, Bi, Mo, W, and Te occur in some deposits. Examples are widespread from Yellowknife, Northwest Territories, to Val d’Or, Quebec.

Native silver and Ni—Co arsenide deposits. These are generally narrow veins in various Proterozoic rocks, richly mineralized with carbonates, Ni—Co arsenides and native silver. Pitchblende occurs in some deposits (Great Bear Lake area). The elements strongly enriched in these deposits include Ni, Co, Fe, As, Sb, Bi, Ag, Hg, and locally U, Cu, Zn, Cd, Mo, and Pb. The best known examples of these deposits are found in the Great Bear Lake area, Northwest Territories, on Silver Islet, Ontario, and the Cobalt area, Ontario.

Uranium deposits. Four common types can be recognized; all are probably of Proterozoic age:

(1) Vein and disseminated deposits mineralized essentially with pitchblende; also in some cases with Ni—Co arsenides and native silver. Examples of the first are found in the Beaverlodge area, Saskatchewan; the second are common in the Great Bear Lake area, Northwest Territories. The elements enriched in the simple vein type are mainly uranium and iron (hematite); some veins exhibit moderate enrichments of vanadium, copper and selenium. The veins mineralized with Ni—Co arsenides exhibit the same enrichments as those noted above for the native silver and Ni—Co arsenide deposits.

(2) Pegmatites and granitic bodies containing disseminated uraninite and other U—Th minerals. The elements enriched include U, Th, Zr, P, F, Mo, and various rare earths. The best examples of these deposits are found in the Bancroft area of Ontario.
(3) Calcite-fluorite lenses and irregular bodies. These occur entirely in the Grenville province and comprise masses of calcite with fluorite, apatite, biotite, and pyroxenes. The elements enriched include Ca, F, P, U, Th, and various rare earths.

(4) Pyritiferous quartz pebble conglomerates.

The best known examples of these deposits are found in the Elliot Lake area of Ontario where the orebodies are constituted of gently dipping beds and lenses of pyritiferous quartz pebble conglomerates and quartzites mineralized with uraninite, brannerite, monazite, zircon and a variety of other minerals in small amounts. The elements enriched in the deposits are Fe, S, U, Th, Zr, P, and rare earths (mainly Y group).

Polymetallic veins and lodes. These comprise veins, lodes, stockworks, and disseminations of pyrite, pyrrhotite, arsenopyrite, sphalerite, galena, chalcopyrite, stibnite, and various sulphosalts. The gangue is usually quartz or carbonates. These deposits occur in all ages of Precambrian rocks. The elements enriched include one or more of Fe, S, As, Sb, Cu, Pb, Zn, Cd, Au, Ag, Ba, Sr, Mo, W, Co, Ni, Hg, Bi, Se, and Te. Examples are widespread throughout the Canadian Shield, but few deposits are large and economic.

Disseminated copper and/or molybdenum deposits. These constitute the so-called “porphyry copper and/or molybdenum” type of deposit. Known deposits of economic stature are rare in the Canadian Shield, but the possible presence of such deposits should always be kept in mind during prospecting. An example of an economic porphyry copper deposit occurs in the McIntyre mine at Timmins, Ontario. Other occurrences are widespread in porphyritic and granitic bodies in the Canadian Shield. The elements commonly enriched in these deposits include Fe, S, Cu, Mo, Ag, Au, and Te.

Sedimentary iron deposits. Two types are recognized — Algoma and Superior. The Algoma type is restricted to Archean greenstone and sedimentary belts and the Superior type to Proterozoic sedimentary formations. Both are characterized by cherty bands with iron-rich layers (banded iron formation). The principal elements enriched are Si, Fe, and Mn in places. The sulphide facies of some iron formations contain considerable amounts of pyrite and pyrrhotite; also minor amounts of the base-metal sulphides.

Copper shales. The only economic example of this type of deposit occurs at White Pine, Michigan, U.S.A. There the deposits are disseminated copper minerals, mainly chalcocite and native copper, in flat-lying Nonesuch (Proterozoic) shale. The elements enriched include Cu, Ag, and S.

Miscellaneous deposits. These include a wide variety of industrial mineral deposits among which may be mentioned: ilmenite deposits associated with anorthosites in eastern Quebec; various titaniferous magnetite deposits in the Grenville province; chromite deposits associated with ultrabasic igneous rocks as in the Bird River area of Manitoba; magnesium deposits in dolomite and brucitic limestone in the Grenville province in eastern Ontario and at Wakefield, Quebec; apatite deposits in the Grenville province; asbestos deposits at Matheson, Ontario; nepheline syenite at Blue Mountain, Ontario; fluorite
deposits at Madoc, Ontario; talc deposits at the same place; corundum and kyanite deposits mainly in the Grenville province, and silica deposits in many parts of the Shield.

Pleistocene geology

The Canadian Shield was almost completely glaciated during the Wisconsinan stage. The mainland part of the Shield was probably covered by glacier ice for most of the past 100,000 years (McDonald, 1971); the last glacial ice probably melted from the Keewatin and Labradoran ice divides as recently as 6,000 to 7,500 years ago. The central part of the Shield was isostatically depressed by the ice sheets so that much of the low-lying terrain adjacent to Hudson Bay and to the Arctic Ocean was inundated temporarily by marine waters of the Tyrrell Sea (Lee, 1959; Craig, 1969). Isostatic rebound has now compensated for most of the depression, but the Shield in the vicinity of Hudson Bay is probably still rebounding slowly.

The early glacial history of the Shield has been largely obscured by erosional and depositional effects of the last major glaciation that took place in the Wisconsinan stage. However, in Paleozoic terrains at the southern, western, and northern edges of the Shield, stratigraphic sections indicating a complex glacial history are present and have been extensively studied (McDonald, 1969, 1971; Skinner, 1973). From the study of numerous stratigraphic sections in and near the James Bay Lowlands, Skinner (1973) and McDonald (1969) have described till units representing several Wisconsinan glacial oscillations, apparently emanating from the Hudson Bay basin. Soils, lake sediments, tills, forest beds, and marine sediments buried beneath the youngest glacial deposits indicate that the late Wisconsinan cycle of glacial and postglacial events was only the latest of several such cycles. Glacial deposits of probable Illinoian age lie at the base of the earliest cycles.

Near the southern limits of glaciation, in the midwestern United States, abundant and long-known stratigraphic evidence suggests that at least two major glacial events may have been preceded by those recorded in the James Bay region (Frye, 1973). Deposits or evidence of these very early glaciations have never been reported from the Shield but the Shield, nevertheless, must have spawned the glaciers that penetrated to the southern midwest.

From the preceding discussion it is evident that the Shield has had a complex glacial history and that the glacial deposits that now cover it have been reworked and retransported many times during the Pleistocene. In utilizing Quaternary sediments for exploration purposes, however, many of the principal components of the drift can usually be regarded as having been derived directly from the bedrock during the last glacial event. Complexities of glacial dispersal related to varying ice-flow directions that are demonstrated to have been associated with various glaciations are usually only locally important. Thus, careful mapping of directional features formed during the last phases of glaciation should indicate the general direction of glacial transport.
Most of the glacial and postglacial sediments that now form the surface of the Shield were formed during the latest phases of Wisconsinan deglaciation. A glance at the glacial map of Canada (Prest et al., 1968) plainly shows that late-glacial ice-flow directions over most of the Shield were related to two centres of outflow, the Keewatin Ice Divide and a centre in Labrador (Fig. 63).

Between James Bay and the Keewatin Ice Divide and the Labrador centre, ice flow was extremely variable due to the confluence of ice from the Labradoran and Keewatin centres or to another centre of flow in the Hudson Bay basin. Thus, in the economically important portions of the Shield that lie in this region care should be taken to work out carefully the local variations in ice-flow directions before any geochemical work is undertaken.

As the last ice sheet retreated, major marine and fresh-water flooding took place south and west of Hudson Bay, in the Hudson Bay basin, and in the Great Lakes—St. Lawrence Lowlands. Lakes were formed in drainage basins of rivers that now drain northward or eastward into Hudson Bay. Ice that filled Hudson Bay blocked drainage to the sea and caused the lakes to overflow east, along the southern margins of the ice sheet or south through the Mississippi River drainage system. Although the total area covered by ice-dammed lakes is vast (Prest et al., 1968), the area of lakes at any one time was relatively small, depending on the location and altitude of outlets (Elson, 1967). Thickness of sediment deposited in the lakes varies greatly also. Over most of the regions formerly covered by lakes, sediment thickness is negligible, but locally, as in the Great Clay Belt of Ontario and Quebec, lake sediment may be thick and persistent and a considerable hindrance to conventional geochemical exploration.

Areas adjacent to Hudson Bay, the Arctic Ocean and the St. Lawrence Valley were submerged by postglacial incursions of the sea. The reason for submergence was that the land was temporarily isostatically depressed by the weight of the glaciers. As in areas formerly covered by postglacial lakes, sediment thickness in areas of submergence is variable. The thickest marine sediment is found where major rivers entered the sea, particularly those rivers that were carrying glacial meltwater. Where marine sediment cover is thick it effectively masks surface geochemical effects of underlying mineralization or mineralized drift.

In the zone of continuous permafrost, considerable postglacial modification associated with movement within the seasonally thawed or active layer has taken place. In areas of continuous permafrost, considerable downslope movement of drift may have taken place. For a more complete discussion of the effects of permafrost on drift geochemistry, the reader is referred to Shilts (1973) and Ridler and Shilts (1974).

When undertaking exploration geochemistry in the Shield a knowledge and understanding of the different glacial products is essential. A fairly complete description of the common glacial sediments, their properties, distribution and possible use as geochemical sampling media is given in the Appendix (p. 189).
Late-Glacial ice divides or centres of outflow
Areas inundated by marine waters
Areas flooded by fresh water; only a small portion of area shown flooded at any one time
Generalized glacier flow directions
Generalized boundary of pre-Cambrian outcrop

Fig. 63. Generalized direction of glacier movement and distribution of marine and lacustrine depositional environments in the Canadian Shield.
Physiography, climate and vegetation

The Canadian Shield comprises the vast V-shaped terrain of North America around Hudson Bay within which Precambrian rocks of various ages are exposed over broad areas (Fig.62). The Shield is a peneplain, strongly lineated in many districts and irregularly broken in others by valleys and rocky hills. Elevations are greatly subdued in most regions, altitudes rarely exceeding 2,500 feet, except in Labrador where some of the Torngat Mountains may reach 6,500 feet. Pleistocene glaciation has sculptured the terrain we now observe in the Shield, yielding deeply gouged linear valleys now filled with drift, great areas deeply buried by glacial lake clay, vast boulder fields, extensive till plains, and severely disrupted and disorganized drainage systems marked by innumerable lakes and rivers.

Three climatic zones can be recognized in the Canadian Shield as shown in Fig.64. The Arctic zone is characterized by a harsh climate with long, cold winters and short, cool summers. The Boreal or Northern zone has a more equitable climate; the winters are long and cold and the summers relatively short but frequently quite warm. The Southern zone has a temperate climate with well-marked seasons. The winters are moderately cold and the summers frequently hot. Extremes of −30°F and +95°F in winter and summer respectively are common in the Southern zone for short periods of time. The mean annual total precipitation in the Canadian Shield is shown in Fig.65.
The vegetation regime of the Canadian Shield (Fig. 66) is exceedingly variable. Above the tree line, vegetation is sparse, cold-climate (Arctic) flora predominate in a cold desert (tundra). South of the tree line the amount of vegetation increases, temperate-climate (Boreal) flora predominate, and coniferous forests cover parts of the terrain. Regions underlain by glacial clay and till are flat plains (Little Clay Belt and Great Clay Belt of Ontario). The southern part of the Shield is covered mainly by mixed conifer and hardwood forest. Local areas support some farming. Muskegs (a word derived from the Chippewa Indian language meaning a grassy bog) are a characteristic feature of the Canadian Shield. Composed of much decaying matter they complicate the chemistry of the surface migration of the elements and cause innumerable problems in geochemical prospecting.

Permafrost or perennially frozen ground is defined exclusively on the basis of temperature and refers to the thermal condition of earth materials such as soil and rock when their temperature remains below 32°F continuously for a number of years (Brown, 1967).

In the continuous zone of permafrost (Fig. 67) thickness of permafrost ranges from 200 feet to more than 1,000 feet from the southern to northern parts of the zone. The active layer at the surface which freezes in winter, thaws in summer and usually extends to the permafrost table varies from 1.5 to 3 feet thick.

In the discontinuous zone, particularly near the southern margin, perma-
Fig. 66. Vegetation regions in the Canadian Shield.

Fig. 67. Distribution of permafrost and soil types in the Canadian Shield.
frost occurrences are not common and are generally found in peatlands whereas its occurrence becomes increasingly widespread and in a greater variety of terrain types approaching the zone’s northern margin.

The major factors influencing the occurrence and distribution of permafrost in the Canadian Shield are climate and terrain conditions. For example, near the southern limit of the discontinuous zone, because the climate is too warm, permafrost occurrences are found as scattered islands a few feet across to several acres in extent, predominantly in the drier portions of peatlands. Farther north, approaching the discontinuous/continuous zone boundary, occurrences are increasingly widespread in a larger variety of terrain types as well as on north-facing slopes and in shaded areas.

Soils

The soils of the Canadian Shield (Fig.67) are dominantly regosolic and brunisolic soils in the northern latitudes and podzolic and organic soils in the southern latitudes. The parent materials of the well-developed soils are mainly glacial till and clay. Only rarely are soils developed from bedrock.

A more complete description of soil characteristics and soil classification has already been given in Section B on the Canadian Cordillera.

Format

Although for sampling bedrock, geology is a primary controlling factor, when interpreting geochemical patterns, within the soil-sediment environment the single factor which is of greatest influence in geochemical dispersion patterns is overburden. That is, whether the overburden is residual, transported material of local derivation (i.e. till) or transported material of remote derivation (this includes glaciofluvial and glaciolacustrine deposits, alluvium, volcanic ash, and any other material of remote origin). Consequently different models are drawn for each of these parameters. In addition, there are a number of factors of secondary importance, which are superimposed on these different types of overburden. These include geology, seepage zones, bog developments, elements of different mobility, etc. These various factors have been summarized in Table XXIII. This table is also an index of all the pertinent data related to each individual model. It shows the figure number of each model (or models) field data quoted in this paper, and also the references to any supporting data in the literature.

IDEALIZED MODELS

The idealized models are discussed in order, generally moving from the simplest to the most complex. However, there is also continuity between models presented here and those presented for the Canadian Cordillera. Referring to Table XXIII “Index of examples”, interpretation of geochemical
<table>
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<th>Till</th>
<th>Stratified drift</th>
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<tr>
<td>1. lodgement till</td>
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<tr>
<td>2. ablation till</td>
<td></td>
</tr>
<tr>
<td>3. ice contact</td>
<td>Puskaskwa region</td>
</tr>
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<td>4. outwash</td>
<td>(Wolfe, 1973)</td>
</tr>
<tr>
<td>5. glacial lake marine</td>
<td></td>
</tr>
</tbody>
</table>

### A. General (Mobile elements in thin overburden)

(A1)** Lac Albanel
- Beechey Lake
- Cachau-Herreillat and La Sale (1969)
- Chibougamau area
  - (Ermengen, 1959)
- Cobalt
- Coppermine (Allan et al., 1972)
- Coronation mine
  - (Scott and Byers, 1969)
- Limerick
- Ogden (1954)
- Otelnuk Lake area
  - (Kish, 1968)
- Puskaskwa region
  - (Wolfe and Wright, 1969; Wolfe, 1973)
- Shawinigan (Felder, 1974)
- Cachau-Herreillat
  - and La Sale (1969)
- Lee (1968, 1971)
- Shilts (1973)
- Puskaskwa region
  - (Wolfe, 1973)

(B5) Manitouwadge
- Ogden (1954)
- Setting Net Lake
  - (Wolfe, 1974)
- Puskaskwa region
  - (Wolfe, 1973)
- (B5) Manitouwadge
  - Ogden (1954)
  - Setting Net Lake
    - (Wolfe, 1974)
C. Multiple episodes of glaciation
   (C1) Gleeson and Cormier (1971)
       Kidd Creel
       Louvem (Garrett, 1971)

D. Effect of rock type change
   (D1) Beechey Lake
       Coppermine (Allan et al., 1972)
       Otelnuk Lake area
       (Kish, 1968)
       Shawinigan (Felder, 1974)

E. Chemical mobility
   (E1) Lac Albanel
       Beechey Lake
       Cobalt
       Limerick
       Mattagami
       Wintering Lake

F. Mobile elements in bog
   (F1) Fortescue et al. (1973)
       Gleeson and Coope (1967)
       Limerick
       Ogden (1954)

G. Different soil types
   (G1) Cachau-Herreillat
       and La Salle (1969)
       Cobalt
       Coppermine (Allan et al., 1972)
       Fortescue et al. (1973)
       Otelnuk Lake area
       (Kish, 1968)

*References with author and date refer to literature references given at the back of this volume.
The remainder are case histories given here. Where literature reference only is given, the reference contains examples from several different areas.
**The numbers refer to the idealized models as given.
anomalies generally increases in complexity from left to right and from top to bottom. The formation of anomalies is discussed firstly for till-covered areas and then for areas covered by stratified drift overburden. The same criteria, which apply in the simpler cases (till), also apply in the more complex cases but with added complications. In this way there is a natural progression in discussion of till followed by stratified drift. The Appendix to this section (p.189) should be carefully read before studying this section, as a knowledge of the different types of glacial sediments, their weathering products and distribution is essential.

Within the Canadian Shield the glacial and physiographic conditions cover an extremely wide range. For example, in discussing a variable such as the effects of overburden thickness, available examples may cover the range from 2 to 200 feet. In each case the geochemical anomalies may be marginally different as a result of this variable. Rather than present a large number of idealized models, only the “end member models” are provided. That is, in the example just quoted, for very thin and very thick overburden. Although Table XXIII provides space for examples and models in lodgement till, ablation till, ice contact stratified drift, outwash deposits and glaciofluvial deposits, only the two extreme cases are provided. That is lodgement till and glacial lake and marine deposits. This is largely because the majority of available data falls in these two areas. It is hoped that as further data becomes available it may be possible to reliably complete some of the other models.

Table XXIII provides an index of all the case histories which have been used to support the various idealized models. These case histories are drawn both from the literature and from this volume. In certain cases sufficient case history information is not available to reliably construct an idealized model. In this case no model is given.

When examining the idealized models exactly the same legend is used in each case. This is given in the caption of Fig.68.

A. Mobile elements in thin overburden

Models A1 and A5 (Figs.68 and 69) show the general characteristics which may be expected for mobile elements in both well- and poorly drained overburden with underlying till and underlying glaciofluvial material, respectively. The generalizations regarding geochemical dispersion in these two environments are listed below.

Surface soils. The geochemical anomaly in soil developed on thin till (model A1, Fig.68) occurs virtually directly over the ore deposit, and is spread down-ice by mechanical action, as e.g. at Agnico mines, Cobalt, and at the Kekko deposit, Chibougamau (Ermengen, 1957). The anomaly normally fans outward and becomes weaker and more erratic down-ice. Displacement by downslope creep is also common, even in areas of only moderate topography as for example in the 47-zone, Coppermine area (Allan et al.,
Fig. 68. Model A1 (Shield). Idealized models for geochemical dispersion of mobile elements in areas of thin lodgement till.

Anomaly types: SL(M) = soil anomaly derived by mechanical means, SL(H) = soil anomaly derived by hydromorphic means, SS(M) = stream sediment anomaly derived by mechanical means, SS(H) = stream sediment anomaly derived by hydromorphic means, LS = lake sediment anomaly, SP = seepage anomaly, BG = bog anomaly.

Overburden types: 1 = bedrock, 2 = residual soil, 3 = recent alluvium, 4 = till, 7 = transported overburden of remote origin.

Others: OB = orebody, :::: = the density of dots is proportional to anomaly strength.

1972). The magnitude of the displacement of anomalies and also the magnitude of these anomalies is extremely variable. One of the primary controlling variables, that of overburden thickness is discussed under the B models (Figs. 70 and 71). As a result of the combined effects of glacial action and weathering, the soil surface expression of the underlying mineralization can vary. On one hand it may be only several times larger than the mineralization, as was observed at Agnico mines, Cobalt area, Ontario; at Kekko, a high-grade zinc zone, and at the Portage Island zone in the Chibougamau area, Quebec;
and Beechey Lake, Northwest Territories. On the other it may be very much larger, such as over the Canagau polymetallic deposit in Ontario, where smearing of the anomaly down-ice appears to have been very intense.

In areas covered by moderately thick to extremely thick stratified drift (model A5, Fig.69), there is normally no surface soil geochemical response. For example, over the veins of the Langis deposit at Cobalt, Ontario, no soil response is seen through 90 feet of glacial clay, although other veins in the immediate area covered with till show well-developed soil anomalies. Also, at Kidd Creek approximately 50 feet of glacial till and varved clay blanket out all surface soil response. Similarly in the Flin Flon area stratified drift blocked the surface soil response over four separate deposits, even though this cover was only a few feet thick in places. There are numerous other examples quoted here and in the literature, e.g. in Manitouwadge, Ontario, particularly where the overburden exceeds 5—10 feet in thickness; Louvem, Quebec; and
Mattagami, Quebec. In practise, overburden sampling generally indicates that 5–10 feet of varved clay would normally serve to inhibit surface soil response.

As well as the anomalies derived by purely mechanical means such as glacial smearing and downslope creep, anomalies may also be formed through the process of hydromorphic movement into seepage areas such as over the Campbell-Merritt deposit and other mineralized areas near Chibougamau (Ermengen, 1957). Depending on topography and soil conditions, hydromorphic movement may or may not be an important contributory agent. However, the effects of mechanical movement and hydromorphic movement are commonly seen as additive in a single soil map and the method of formation of a particular anomaly is not obvious. In addition, mechanically moved material may later undergo at least limited weathering and hydromorphic movement, further complicating precise interpretation of the migration path of elements. For example, in the Coppermine area around the 47-zone (Allan et al., 1972) there are good indications of the hydromorphic accumulation of copper at the base of the slope in addition to mechanical movement downslope. At the Canagau deposit, it was concluded from an examination of the mineralogy of the till that the mechanically moved material has probably undergone later leaching with the consequent migration and concentration of some elements on secondary oxides and clays. There is also the possibility in stratified drift-covered areas (model B5, Fig.71) that groundwater movement through material of foreign provenance will establish hydromorphic anomalies in the overlying soil where no mechanically derived anomalies are evident. This appears to be partially true at Setting Net Lake (Wolfe, 1974) where hydromorphic movement from the till-covered upland areas has moved the molybdenum anomaly downslope across the top surface of the clay overburden area for a distance greater than would have been possible by mechanical means. At Mattagami there is also an indication of anomalous hydromorphically dispersed zinc through more than 20 feet of clay and silt. This condition can be anticipated to occur in other areas as well. It also appears probable from the work of Wolfe (1974) that many Quaternary clays are sometimes calcareous and consequently the subsurface waters are commonly alkaline. This reduces the mobility of many elements, reducing the intensity of hydromorphic movement through this type of overburden into the upper horizons. This minimizes the possibility of establishing post-Pleistocene anomalies near surface by hydromorphic means. This was also noted at Manitouwadge where the overburden was a limestone till.

Soil profiles. Details of the effect of different specific soil types (for example, podzols, regosols, etc.) are given with model G (Fig.78). Particular details on the relative responses of individual horizons within these different soil types should be obtained from that section. However, for the present, an average soil condition (immature soil such as a brown earth) is given for the idealized models.
In lodgement till conditions (model A1, Fig.68), the mineralized material is mechanically spread down-ice as already described. In the down-ice direction the anomalous material frequently “rises” in the section so that it progressively becomes further above bedrock in the down-ice direction. In certain cases this vertical rise appears to be very rapid, such as at the North Coppercliff zone in the Chibougamau area of Quebec (Ermengen, 1957). Elsewhere the anomalous material may “rise” through the till profile at an extremely slow rate such as was found to be the case at Manitouwadge, Ontario, and Louvem, Quebec. There appears to be no reliable method at the present time to estimate in detail the path that anomalous material would have taken through the till profile by examining the surface only. However, in all cases reported in the literature to date, the train of anomalous material in till always leads back to the source at the bedrock interface. Consequently, if material is collected at this interface by the processes of overburden sampling at depth, reliable indication of the mineralization in the underlying bedrock can be obtained. This technique is described further in the next section dealing with the effect of overburden thickness.

Sediments. Stream sediment and lake sediment anomalies are also formed by the combined processes of mechanical and hydromorphic movement as already outlined in Section A. In idealized models A1 and A5 (Figs.68 and 69) an attempt has been made to graphically indicate the separate effects of these two processes. In actual practice, as for soils, the anomalies located in the field are not so easily separated into their respective categories.

Within areas of lodgement till (model A1, Fig.68) significant sediment anomalies are normally built up. For example, at Coppermine around the 47-zone a strong copper anomaly in the stream and lake sediments is observed which would appear to be the result of mechanical movement from the mineralization itself. In the Pukaskwa region around the Rawhide “U” Mines Limited soil anomaly described by Wolfe (1973), a relatively strong copper sediment anomaly is observed (Wolfe and Wright, 1969). This anomaly would appear to be formed by hydromorphic as well as mechanical means as the mineralization is largely up-ice in the interfluvial area. Extensive stream sediment anomalies were also reported at Shawinigan (Felder, 1974), and by Kish (1968) in the Otelnuk Lake area of Quebec. In the latter case detailed knowledge is still lacking, but hydromorphic movement appears to have played the dominant role in establishing stream sediment anomalies related to mineralization in interfluve areas. Similar results are also recorded for the Lac Albanel area, Quebec, and Beechey Lake, Northwest Territories.

With respect to seepage anomalies in areas covered by stratified drift (model A5, Fig.69), hydromorphic transport could possibly establish stream sediment anomalies where no surface soil expression is evident directly over mineralization. In addition streams may cut through the transported drift and, by eroding the lodgement till or bedrock, pick up anomalous material. This process was evident at Manitouwadge.
Fig. 70. Model B1 (Shield). Idealized models for geochemical dispersion of mobile elements in areas of thick stratified drift (see Fig. 68 for legend).

B. Effect of variation in overburden thickness

The effect of variation in overburden thickness in strictly residual soils in tropical and sub-tropical areas can be demonstrated to be virtually negligible by quite a large number of published case histories. That is, no matter what the thickness there is always a surface soil expression of the underlying mineralization (although a greater thickness may marginally reduce intensity). Within glacial till- and stratified drift-covered areas, however, variations in overburden thickness can have quite a marked effect on the shape and distribution of geochemical anomalies, as shown in models B1 and B5 (Figs. 70 and 71).

Surface soils and soil profiles. Within till-covered areas (model B1, Fig. 70), the strength of the anomaly normally tends to decrease as the till gets thicker as shown in idealized form in models A1 and A5 (Figs. 68 and 69). As proof of
this when examining these idealized models, A1 and B1 should be compared, as they are both identical except that A1 represents thin till conditions while B1 represents thick till. Similarly with A5 and B5. Scott and Byers (1965), working at the Coronation mine, found quite a strong copper response in the near-surface soil where the till was 5–16 feet thick, but in a second traverse over the same vein where the till was greater than 20 feet thick the surface soil response was very weak. Similarly at Cobalt, where the glacial till averaged 2–8 feet thick, a strong and pronounced anomaly was observed in the surface soils. Where the glacial till over the same deposit averaged 5–20 feet, the anomalies tended to be substantially weaker in magnitude and also showed apparent greater smearing down-ice. A similar conclusion can also be reached from the work of Ermengen (1957a, b) in the Chibougamau area.

Although the three cases just quoted were carried out in different areas, they all demonstrate that in general terms where the till increases in thickness the surface soil response is weaker in magnitude, and also shows greater displacement down-ice.

In stratified drift-covered areas the situation is rather different (model B5, Fig.71). Even reasonably thin stratified drift, particularly if it is fairly impervious glacial lake or marine sediment, will probably blanket out any surface soil response. It is only when this drift is sufficiently thin (as depicted in model B5, Fig.71) for the plant roots to easily penetrate it, that a surface soil anomaly will have developed.

In this case, where a reasonably high proportion of the plants at surface can penetrate the stratified drift and root in the underlying till, or come in direct contact with the anomalous bedrock, a surface soil anomaly will be

![Diagram](image-url)

*Fig.71. Model B5 (Shield). Idealized models for geochemical dispersion of mobile elements in areas of different thicknesses of stratified drift (see Fig.68 for legend).*
established. The plant uptake of anomalous material into its leaf and stem system, followed by shedding of the leaves and build up of surface soil horizons by the normal processes, will establish an anomaly in the surface soils. This was found to be the case at Manitouwadge, where the overburden cover had to be less than 2 feet for a surface anomaly to be observed. No other history is available within the Canadian Shield to demonstrate this point at the present time. However, within the Cordilleran environment several examples of this type of mechanism, where the area has been thinly covered with recent volcanic ash, were shown (see model D3 in Section B). In addition, such very thin drift would normally allow hydromorphic movement through it into the surface environment and so establish sediment anomalies. On the other hand, thick stratified drift will completely mask all geochemical response in surface soils and sediments as already demonstrated with the examples supporting model A5 (Fig.69).

C. Multiple episodes of glaciation

In the previous models only one type and one age of glaciation have been considered. However, it is common within the Canadian Shield to find more than one glacial event superimposed on the other. This may be two different types of glacial sediment associated with the same glacial period, such as glacial lake sediments overlying lodgement till, or it may be two or three

Fig.72. Model C1 (Shield). Idealized models for geochemical dispersion in several ages of lodgement till (see Fig.68 for legend).
ages of glaciation on top of each other, e.g. two or more ages of lodgement till superimposed. In both cases, interpretation of the geochemical response is more complex than the cases already given as the combined effect of both episodes have to be taken into consideration.

Idealized models C1(1) and C1(2) (Fig. 72) show a situation where more than one age of till is superimposed. In model C1(1), the oldest till, which is at the bottom of the profile, relates directly to the underlying mineralization. In this case, the geochemical anomaly will report in the lowermost lodgement till only. If a field examination fails to correctly identify the presence of more than one age of lodgement till, it would not be possible to explain the absence of a surface anomaly. Idealized model C1(2) illustrates a situation where a second younger age of till has transported anomalous material over the oldest till layer. No case history is available within the Canadian Shield to demonstrate this point, although results of exactly this type were encountered by Shilts (1973) in the southeast Quebec. There, younger lodgement till carrying anomalous material derived from ultrabasics to the north, overrode an older till sheet which advanced from the northeast and was lower in nickel and copper. Consequently, analysis of material down through the profile indicated a Ni–Co anomaly in the upper till horizon only. In either of the cases quoted it is absolutely essential to correctly establish the existence of more than one age of glacial till. If only one age of till is present, a soil geochemical anomaly can be expected at surface, even through a moderate thickness of till. If, however, two ages or more are present the surface soil response can be either masked completely, or the soil anomaly may be encountered several miles down-ice from its actual sub-outcrop.

A very common condition encountered in the Canadian Shield is stratified drift, such as glaciolacustrine deposits, overlying lodgement till, which in turn overlies bedrock. When this condition is encountered, as depicted in idealized model C5(1) (Fig. 73) a geochemical anomaly in the basement till is found in the normal way and fans out down-ice, as already described. However, the overlying stratified sediments normally completely restrict all surface geochemical response (with the possible exception of the case where this drift is extremely thin). This condition was encountered by Fortescue and Hornbrook (1969) over the Kidd Creek (Texas Gulf Sulphur) deposit at Timmins, Ontario. Here the surface soil showed no response to underlying mineralization, while samples taken from the till at depth reflected the presence of the ore deposit quite faithfully, fanning out for some distance down-ice. A similar situation was found by Garrett (1971) at the Louvem deposit at Val d’Or, Quebec, and also by Gleeson and Cormier (1971) at four different locations in the Matagami–Val d’Or area. It has also been found at Consolidated Mogador, Mattagami and Wintering Lake. In all these cases samples of the lodgement till were collected at depth using some type of powered deep-sampling device. This technique, although relatively expensive compared to surface soil sampling, is still very cost effective when compared to diamond drilling. Collection of samples at depth normally costs in the order of $2.00 to $4.00 per foot. Consequently,
one of the best applications of this technique has been to examine specific geophysical conductors or other restricted targets. One of the advantages of this technique is that it is normally possible to determine the mineralogy of the source material at depth. In this way if a geophysical conductor is being drilled it should be possible to establish the cause of this conductor by mineral identification of graphite, barren sulphides or sulphides with economic potential. It is also normal practice to analyze the samples geochemically in order to also detect any additional metal which may have been pulverized to too fine a grain size for visual identification, or weathered to form unidentifiable products during transport in the till. In this regard, the heavy-mineral fraction generally provides the best anomaly as shown in most of the examples just quoted.

If, however, the rock surface is swept clean of lodgement till and covered only with stratified drift of foreign provenance, then no anomaly even directly above the bedrock surface can be expected. In a condition such as this, anomalous material will only be encountered if drilling is sufficiently powerful to collect the top half inch or inch of bedrock.

D. Effect of rock type changes

Rock units with abnormally high metal content may cause sediment or soil anomalies in exactly the same way as does mineralization. Normal weathering of bedrock results in trace as well as major elements being incorporated in the overlying material. The degree of hydromorphic movement of elements away
from rock units with high metal content is generally lower than from mineralization, because there are less sulphides to weather and lower the pH. However, the effect of mechanical movement is exactly the same as that for mineralization. In addition, the volume of material incorporated from mechanically eroded rock types is much higher than for mineralization, because of the greater areal extent. Consequently, the effect of sub-outcrop lithology on the trace element content of the overlying till and sediments is not uncommonly observed where rock types of contrasting trace metal content are situated close together. Idealized models D1 and D5 (Figs. 74 and 75) show the effects which can normally be anticipated in till- and stratified drift-covered areas, respectively.

Surface soils. Where the area is covered with only one age of lodgement till increased metal levels in surface soil over the rock type higher in trace metals can be expected (model D1). For example, Felder (1974) working in the Shawinigan area outlined both a nickel and copper soil geochemical anomaly which responded not only to Ni–Cu mineralization, but also indicated the

Fig. 74. Model D1 (Shield). Idealized model showing the effect of rock-type change on glacial dispersion for mobile elements in stratified drift-covered areas (see Fig. 68 for legend).
broader area of the ultramafic intrusion. This effect was also seen at Beechey Lake where copper and zinc are generally twice as high in soils over the volcanics compared with the adjacent slates.

Sediments. The effect of rock type change is normally more obvious in sediments than in soils, largely because sediments cover a larger area and more commonly encounter rock types of contrasting trace element content. For example, work on the copper content of lake sediments in the Coppermine River area faithfully reflects the presence of the underlying upper basalt member which is relatively rich in copper with respect to the other members of the Coppermine River group. Working with stream sediments, a similar feature was also found at the Mount Otelnuk area (Kish, 1968).

In areas covered with thick stratified drift no sediment reflection of the bedrock change can be expected, as already indicated in idealized models A5 and B5 (Figs. 69 and 71). However, where the stratified drift is relatively thin, the bedrock change should be reflected in the overlying sediments as indicated in B5. In actual practice over an area of any substantial size, the overburden cover is never uniform and may vary from till to thin stratified drift to thick stratified drift. This was the condition encountered by Wolfe (1973) in the study of the Pukaskwa region, Ontario. In an area of 1200 square miles the distribution of mafic volcanic rocks was reliably reflected by the pattern of nickel variation in bedrock. However, the nickel content of the stream sediments showed highs over parts of the mafic greenstone belts but lows in other parts. When superimposed on a map of the regional Pleistocene geology, it is
evident that the high nickel content in stream sediments is a reliable indicator of mafic bedrock only in those places where thick Pleistocene outwash and deltaic deposits (sand and gravel) are absent. In places where the drift is absent or is less than 25–50 feet thick, the sediments reflect both geological bedrock change and also mineralization. Where it is thicker than 50 feet there is no reflection in the sediments. This was found for nickel, copper and zinc. Consequently, it is most important when undertaking a sediment survey of this type to recognize those areas where stream sediment response can be anticipated to be blank, regardless of the underlying bedrock or mineralization. During interpretation these areas should be treated as having no data, rather than having negative data indicating the absence of mineralization.

E. Chemical mobility

As already described in Section A under “General principles of geochemical migration” (p.12), both sediments and soils are built up by two processes, one mechanical and the other hydromorphic. The former is a purely physical function and the solubility of metals or compounds is of minor importance. However, the degree of hydromorphic movement is directly dependent on the extent to which metals are soluble and consequently mobile in water. This solubility is a direct function of Eh and pH, but is also dependent on other variables such as rainfall, iron and manganese content of the waters, humic acid content, etc. As a result of the additive effects of these factors, various elements are mobile (i.e. soluble) while others are immobile (i.e. insoluble). Making generalizations and accurate predictions, however, is complicated by the fact that the mobility of an element can change as one or more of the parameters already listed changes. Consequently, an element may be found to be quite mobile in one area and only partially mobile in an adjacent environment. Although the effects of Eh and pH are fairly well documented, and can be accurately predicted by use of phase stability diagrams, the other factors are not nearly as well understood. As a result, the generalizations made here are valid for the majority of cases, but reversals of the mobilities mentioned may be found in special instances. The hydromorphic movement through stratified drift is exactly the same in mechanism as for till and consequently only the cross section for till conditions is given model E1 (Fig.76).

Surface soils. The relative mobility of different elements in surface soils is best observed by comparing hydromorphic dispersion away from the same deposit. In this way all parameters are the same for all the elements being studied. At Manitouwadge, for example, the hydromorphic dispersion was found to be slightly greater for zinc than for copper. At Cobalt, there is a generally strong indication of hydromorphic movement of zinc, intermediate for silver and low for lead. At Limerick, both copper and nickel behave in a very similar fashion in seepage areas. At Mattagami there is weak indication of a hydromorphic anomaly of zinc reflecting mineralization (1½ times back-
Fig. 76. Model E1 (Shield). Idealized model showing the effect of differing chemical mobility of elements on this dispersion pattern in till-covered areas (see Fig. 68 for legend).

ground) but no indication of anomalous hydromorphic dispersion of copper. From data elsewhere, it can be anticipated that virtually insoluble metals such as gold and tin, and to a lesser extent tungsten, will show essentially no hydromorphic movement. However, at present there are no data available within the Canadian Shield to demonstrate this point.

In addition to mobility controlled by hydromorphic movement, there is the special case of gaseous movement. Of the elements which are capable of moving in the gaseous state, only mercury and radon have been studied in any detail. Direct analyses of soil, air and free air do have application in exploration but is outside the scope of this paper. Several examples of the detection of mercury in soils which has probably moved gaseously are, however, given. For example, in the Flin Flon area anomalous levels of mercury were found over the Keg Lake, Pitching Lake and Schist Lake deposits when no equivalent anomaly was found for copper or zinc. Similar findings were observed at Troilus. In all these cases it is very important to have a strict control on the horizon sampled as there can be large differences in background values between horizons.

Sediments. As for soils, mobility of different elements is shown by the length and strength of hydromorphic movement, and the relative order of mobility is exactly the same. For example, at Beechey Lake zinc and copper show quite marked hydromorphic dispersion, while lead and silver are quite restricted. At Lac Albanel, mineralization in the interfluvial areas is more readily detected in stream sediments by the more mobile zinc and copper compared with the less mobile lead. At Wintering Lake the mobility of copper and nickel appear about equal.
Swamps and bogs are very common in the Canadian Shield, and may be of large areal extent. Largely due to the high organic content, which provides very large surface areas for "scavenging" of metals, these bogs frequently are high in base metals. Accumulation in bogs normally takes place as a result of lateral hydromorphic transport from the surrounding higher ground into the swamp areas. Because of this, very weakly mineralized or even background rocks which show no surface soil anomaly in the well-drained upland ground, may produce substantial build-up of the base metals in bogs. This is particularly true for the more mobile elements such as copper and zinc.

Bog surface. Idealized model F1 (Fig. 77) shows the distribution of metal in a bog close to mineralization, and also one well removed from mineralization. Because of the "scavenging" effect already referred to, even bogs well removed from mineralization normally have higher base-metal content than

Fig. 77. Model F1 (Shield). Idealized model for geochemical dispersion of mobile elements in bogs overlying till (see Fig. 68 for legend).
the surrounding well-drained soils. For example, in an unmineralized area at Dorset, Ontario, a ten-fold increase in copper, lead and zinc was observed in surface bog samples with respect to well-drained soil on the margin. However, this condition may not always be the case, as Gleeson and Coope (1967) found that the surface bog samples in unmineralized areas were generally fairly low in copper, lead and zinc, showing approximately the same metal levels as well-drained soils.

Where mineralization occurs to one side of a bog normally the surface bog samples, particularly on the same side as the mineralization, are extremely high in metal, normally much higher than the well-drained soils directly over the ore. This was found to be the case at the Cu–Ni deposit in Limerick Township, southern Ontario. It was also found by Ogden (1954) for very weak mineralization in Dollier Township, Quebec.

Soil profiles. The metal content of bog material normally decreases downwards in background bogs, as for example at Dorset. However, in the basal mineral layer at the bottom of the bog, either stratified drift or till, the metal value frequently rises again. This was found by Gleeson and Coope (1967) for background bogs.

Model F1 refers specifically to the case where the mineralization lies to one side of the bog. Where the mineralization lies directly underneath the bog it can be anticipated that: (1) the values will be very high in the overlying bog (provided there is no impermeable stratified drift layer between the mineralization and the bog bottom), and (2) that the metal values will probably stay the same or increase with depth down the bog. No case histories are available within the Canadian Shield to demonstrate this point, but studies by Gunton and Nichol (1974) in the Hipsaw Creek area in southern British Columbia demonstrated this feature in valley glaciated areas.

G. Different soil types

A summary of the soil conditions found in the Canadian Shield has already been given. Of the eight soil orders which occur within the Canadian system of soil classification, four occur reasonably frequently in the Shield. These are: regosols, brunisols, podsols and organic (bog). The characteristics for each of these soil orders have been given in the earlier section on soils.

An average soil profile for each one of these classifications is given in model G1 (Fig.78). Because of the normal variations found in nature any individual profile may deviate from the ideal quite significantly. However, the patterns of trace element distribution should approximate those shown here. Well-documented profiles are not common in exploration case histories. However, from the data available the following generalizations may be made:

Brunisols. In this soil type the metal concentration in background areas normally stays fairly uniform with depth. Work undertaken in the Coppermine area directly over mineralization and just to the one side on the edge of a slope, showed that the B horizon was higher than the A humus layer (Allan
et al., 1972). In other words, metal values can be expected to increase down the profile as the mineralization is approached. On the other hand at some distance downslope, particularly at the base of slope where a strong anomaly is developed in the humus layer, the values in the B horizon are lower indicating a decrease in metal content with depth away from mineralization.

*Podsols.* Podsols by nature are quite well differentiated and show a fairly distinct chemical and physical zonation between the various horizons. In background profiles the LH and Ah horizons normally contain slightly higher metal contents on average than the underlying horizons, but very characteristically have a much greater range in values. For example, Scott and Byers (1965) working over the Coronation mine, showed that for 204 background samples zinc in the LH horizon varied by a factor of 200 and in the B and C horizons by a factor of only 5. Equivalent figures for copper are 18 and 10. In other words the normal background trace-metal concentration for the LH horizon shows quite considerable fluctuation making it more difficult to select a reliable threshold value. In addition, threshold must inevitably be selected higher than for the B and C horizons making selection of genuine anomalies difficult. The Ae horizon on the other hand is a zone of chemical leaching and consequently the metal content is normally lower than for any other horizon. While Scott and Byers (1965) did not find this very evident, work at the Dorset area, Ontario, shows this quite clearly. Below the A horizon the B and C layers tend to remain roughly constant with depth.

Directly over mineralization the metal content tends to increase consistently with depth from the A horizon through the C. This was found for example by Ermengen (1957) over the Campbell-Merrill ore zone and over a high-grade zinc zone both in the Chibougamau area of Quebec. A very similar type of
distribution was also observed by Scott and Byers (1965) at the Coronation mine. However, an inverse relationship was noted in the Cobalt area of Ontario where the A horizon is commonly enriched.

Where it is well developed the Ae horizon normally shows no anomaly at all, even directly over mineralization. For example, the soil profiles found by Ermengen over the high-grade zinc zone at Chibougamau, although showing a strong anomaly in the AH and B horizons, showed at best only a very weak response in the Ae horizon.

In podsol soil, profiling to one side of mineralization, it is normal to observe a steady decrease in metal content with depth. This was observed for instance by Ermengen (1957) to one side of the Campbell-Merrill zone where high levels of zinc and copper were detected in the A horizon in a seepage anomaly downslope, but the underlying B–C horizon contained only background level of these metals. A similar feature is observed in the Cobalt area, although the results here are ambiguous as the A horizon is consistently higher than the C, either away from mineralization or directly over it.

Organic. The idealized model of variation in metal content down bog profiles is depicted in model G1 (Fig. 78). However, the details of the down profile distribution of metals in bogs has already been fully covered for model F1 (Fig. 77).

CASE HISTORIES

Introduction

This section is an integral part of this volume and provides the support and confirmation of the conclusions expressed in the idealized models. It is considered an essential part of this study that no idealized model be drawn without at least one corroborative piece of field data, and in most cases several. (For geographic location of case histories given see Fig. 79.) In some instances all or part of a case history which has appeared in print before has been reproduced here. There are several reasons for this. In some cases, data has been redrafted so that it can be more easily compared with the other data presented here and its pertinence to the present study becomes more obvious. In certain cases the original data were published some time ago in journals without wide circulation and so are not now readily available to many readers. In addition, certain data were considered so critical to the support of a particular model that they were included. However, a great deal of data in this section has not been published before.

An attempt has been made to reduce all the data in this section to a common format, and in particular to standardize the presentation of the data. This has not been possible in every case by any means, particularly because information presented here was collected with no particular view to standardization. It is hoped that future work will be collected with this format in mind, as set out in the section on suggestions for an orientation survey (section D).
The individual case histories are given in alphabetical order according to property name.

The details of the size and strength of the anomaly for each area is summarized on Table XXVIII after the last case history. This table is set up so that deposits of each type appear together.

In addition to the data presented here, case histories in the literature have also been used in support of the different idealized models. Where possible details as to length and strength of dispersion have also been tabulated in the accompanying table (Table XXVIII, after the last case history). In order to make reference to the individual case histories as convenient as possible and also to conserve space, they are all set out according to a standard format shown below.

Name of deposit or property
Author (Affiliation)

(1) Location
(2) Geology
(3) Mineralization
(4) Physiography; topography, climate, soils, vegetation, permafrost
(5) Sediment data and conclusions
(6) Soil data and conclusion
(7) Other data and conclusions

Reference(s)

No discussion of the data is given for each case history. Instead, only the conclusions are given. Discussion of all the data together is confined to the section describing the idealized models.

LAC ALBANEL Cu—Pb—Zn PROSPECT, QUEBEC

M. Tauchid (SOQUEM)*

(1) The property is located between the northern tip of Lac Albanel and Temiscamie River about 100 miles north-northeast of Chibougamau, Quebec (Fig. 80).

(2) The area is underlain mainly by gently to moderately dipping graphitic siltstone, greywacke, and iron formation of the Temiscamie Formation. Older dolomite of the Albanel Formation covers most of the eastern part of the surveyed area. The two formations are of Proterozoic age.

(3) Subeconomic sulphide mineralization was intersected in the only two holes drilled in 1972. It is confined to a 45-foot thick graphitic siltstone about 85 feet above the greywacke/siltstone contact. Pyrrhotite predominates over pyrite, chalcopyrite and sphalerite. These sulphide minerals occur in association with $\frac{1}{8}$- to $\frac{1}{2}$-inch quartz-carbonate veinlets that are parallel to the bedding. Some sphalerite veinlets were found along later fractures across the bedding. Except for the predominant occurrence of pyrrhotite and lower metal content this mineralization is quite similar to that of the Troilus copper deposit 65 miles to the southwest. Results of the geochemical analyses of the diamond drill cores for copper and zinc are shown in Figs. 85 and 86. Anomalous amounts of lead, nickel and silver were also noted in the mineralized section.

(4) The surveyed area is a gently sloping terrain with a slope gradient of about 100 feet per mile. Approximately 10% of the area is poorly drained. In most cases B horizon soil can be easily obtained; however, about 25% of the soil collected came from the A horizon. Data from the two diamond drill holes indicate overburden thickness of about 5—15 feet. The known glacial movement in the area is north—south to northwest—southeast directions.

(5) The area was selected as a result of a reconnaissance stream sediment survey carried out in 1968 and 1969 (Fig. 80). Background values for copper, lead and zinc were established at 5 ppm, 7 ppm, and 27 ppm, respectively, and anomalous values at 16 ppm for copper, 40 ppm for lead, 140 ppm for

zinc. The following were the maximum metal contents in the sediment samples: Cu = 97 ppm, Pb = 170 ppm and Zn = 1,750 ppm.

(6) Subsequent soil surveys outlined well-defined copper, lead, zinc (Figs. 81—83) as well as silver and mercury anomalies. Generally low background values for all elements were indicated: Cu = 1 ppm, Pb = 4 ppm, Zn = 1 ppm, Ag = 0.2 ppm, Hg (approximate) = 20 ppb for the B horizon and 50 ppb for the A horizon. Maximum values of up to 320 ppm Cu, 1,225 ppm Pb, 2,600 ppm Zn, 418 ppm Ag, and 870 ppb Hg were encountered in the survey.

Results of drilling over the multi-element anomalies (Figs.85 and 86) indicate that they are related to a well-defined graphitic siltstone horizon slightly mineralized with pyrrhotite, pyrite, chalcopyrite and sphalerite. No displacement of the soil anomalies was suggested. The area was also covered
Fig. 81. Copper content of surface soils, Lac Albanel property.

Fig. 82. Lead content of surface soils, Lac Albanel property.
Fig. 83. Zinc content of surface soils, Lac Albanel property.

Fig. 84. EM survey of Lac Albanel property.
Fig. 85. Copper content of surface soils and diamond drill hole 7201, Lac Albanel area.

by ground magnetometer and horizontal loop EM surveys. While the magnetic data was very useful in helping complete the geological interpretation of the area, the result of the EM survey (Fig.84) is inconclusive.

BEECHEY LAKE METASEDIMENTARY BELT, NORTHWEST TERRITORIES

E.H.W. Hornbrook (Geological Survey of Canada)

(1) The study area is located in the Beechey Lake metasedimentary belt near the eastern boundary of the Slave province, Northwest Territories (lat. 65°36′N, long. 107°55′W; Fig.87).

(2) Intermediate to acid volcanic rocks in the western part of the study area are in contact with granitic rocks to the southwest (Fig.87). The central portion of the area is comprised of a thick sequence of metasediments overlying the volcanic rocks. Slates at the base of the sedimentary sequence have
been eroded forming a narrow north-northwest striking valley parallel to the contact with the volcanic rocks.

(3) Detailed mineralogical information is not available. Sulphide gossans occur along the volcanic-sedimentary contact (gossan zone “A”) and below upper siliceous volcanic rocks (gossan zone “B”) (Fig. 87).

(4) The study area is marked by the north-northwesterly trending valley bounded on the southwest by a ridge of siliceous volcanic rock. Drainage is northeast over the low-relief metasedimentary terrain (Fig. 87). Soils and vegetation are typical for an area lying within the zone of continuous permafrost.

(5) The anomalous metal contents of lake sediments in this area, the authors believe, were derived from the oxidation of base-metal mineralization within
Fig. 87. Geochemical data for Beechey Lake area, N.W.T. The numeral following lake sediment (L.S.) is the number of samples from that lake that were averaged to provide the analyses given below. Soil sampling traverses identified as S.T. Rock sampling traverses not shown. Drainage directions given by small arrows. Note that no lake sediments were found in the lake at the eastern end of traverse S.T. 660.
zones "A" and "B". During the oxidation of these sulphides, lead and silver were largely fixed in the soils overlying the mineralization, while zinc and copper were not retained but were dispersed in solution throughout the drainage system. The retention of the former two metals in the soils is caused by the relative insolubility of their sulphates, compared to those of zinc and copper, plus the greater tendency of zinc and copper to form complexes and their lesser ease of hydrolysis. The arsenic has an intermediate character; much of this element is retained in the soils, but some is dispersed in the drainage system.

All lake sediments down-drainage from the mineralized volcanic terrane are notably anomalous in zinc and copper relative to the regional background of 32 ppm and 20 ppm, respectively. Note that lead and silver begin to rise above background levels only in the vicinity of the mineralized volcanic rocks.

(6) The four soil sampling traverses shown in Fig.87 were made in order to more closely locate the source of the base metals found in anomalous lake sediments. Unfortunately the field determinations for zinc and copper were of little assistance, because of the leaching of these elements from the soils. The soils were sampled at a depth of 6—8 inches. Table XXIV gives chemical data for soil traverse 641 (the intermediate numbers are missing as they were rock samples). Zinc is low, in the range 14—79 ppm over the slates; it rises to twice this range over the volcanic rocks. Copper is also low over the slates, but rises to 858 ppm further along the traverse. Lead and silver show the most

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<th>Cu (ppm)</th>
<th>Pb (ppm)</th>
<th>Ag (ppm)</th>
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* Sample 641 is easternmost sample; 658 is westernmost sample (after Cameron and Durham, 1974).
striking anomalies with peaks of 83 ppm Pb and 3.4 ppm Ag over the “A” gossan and 12,600 Pb and 41 ppm Ag over the “B” gossan.* The arsenic has highly anomalous concentrations over both slates and the volcanic rocks. In the case of this element, the arsenic lake sediment anomalies were probably derived from both slate and volcanic rocks.

The two northern traverse lines show much weaker, but distinct, peaks for lead and silver over gossans “A” and “B”. Spot samples taken at irregular intervals along the length of gossan “B” are generally anomalous for these two elements but the highest values occur only in the zone of maximum thickness near traverse 641. It is significant that by far the highest values for lead and silver obtained from lake sediments are found in a lake that overlies the southeastern extension of gossan “B” (Fig. 87).

Lead is present in soil sample 654 (Table XXIV) as plumbojarosite and anglesite. These minerals occur as a fine powder or grain coating. No galena is present. The lead and silver are fairly evenly distributed between the different size fractions, but lead reaches a peak of 2.2% in the minus 80-mesh, plus 250-mesh fraction.

Notable amounts of the sulphides of zinc, copper, or lead were not found along either the “A” or “B” gossans, although an intensive search for these minerals was not made. Pyrite and pyrrhotite are very common. The authors would suggest that if the former sulphides were present that they have been selectively oxidized, relative to iron sulphides. Minor disseminated sphalerite, that was difficult to identify in the field was seen in the altered volcanic rocks under the “B” zone gossans.

Reference: Cameron and Durham, 1974

CANAGAU Zn--Pb--Cu--Ag--Au DEPOSIT (BEN NEVIS AREA), ONTARIO

W.J. Wolfe (Ontario Ministry of Natural Resources)

(1) The Canagau base-metal deposit is located in east-central Ben Nevis Township, Ontario (lat. 48°19’N, long. 79°40’W), approximately 34 km northeast of Kirkland Lake and 48 km west of Noranda.

(2) The Ben Nevis area is situated in the central part of the Abitibi greenstone belt, an extensive belt of Early Precambrian (Archean) volcanic and sedimentary rocks with associated intrusions. This belt covers an area of 21,200 km² in northeastern Ontario and northwestern Quebec and includes important base-metal and gold mining districts at Timmins, Kirkland Lake and Noranda. Geological mapping in Ben Nevis Township (Jensen, 1971) has outlined a layered sequence of intermediate to felsic volcanic flow and pyro-

*The soil anomaly was drilled in July, 1974, by the Yava Syndicate. Results for the first hole give a 134.4-foot section of massive sulphide mineralization averaging 3.70% Zn, 0.71% Pb, 1.09% Cu, 2.73 oz./ton Ag and 0.036 oz./ton Au (Northern Miner, August 15, 1974).
clastic units flanking a massive to porphyritic, sub-volcanic granodiorite-quartz diorite stock located about 10 km west of the Canagau deposit. Mafic to intermediate volcanic rocks consist of massive, pillowed and flow breccia flows, and pyroclastic units of agglomerate, tuff breccia, lapilli tuff, and tuff. Felsic volcanic rocks include massive rhyolite, flow breccia, tuff breccia, lapilli tuff, and crystal tuff. The Ben Nevis volcanic rocks display a general calc-alkaline chemical affinity. In the vicinity of the Canagau deposit, volcanic strata are concentrically folded about a south-plunging anticlinal axis and it is along the hinge line of this structure that much of the base-metal mineralization has been found.

(3) The Canagau base-metal mineralization is closely associated with rhyolite tuffs, tuff breccias and lapilli tuffs that occupy the core of the anticlinal fold structure. Sphalerite, galena, chalcopyrite, pyrite, pyrrhotite, silver and gold occur as massive replacement deposits in the shear zones in altered rhyolite tuffs and as disseminated minerals in adjacent tuffs. Massive sulphide deposits vary in width from 15 to 45 cm and the largest of these has been traced to a depth of 100 m over a length of 150 m by underground exploration. This deposit is designated by a shaft symbol in Fig.88 and, along with other smaller mineralized zones nearby, is assumed to represent the mineralized bedrock source of geochemical anomalies detected in the overburden. Extensive sericite,
chlorite, talc, and carbonate alteration is developed in the mineralized rhyolite tuffs near the Canagau shaft. South of the shaft, the sheared tuffaceous metavolcanics along the axial trace of the major south-trending fold structure contain widespread disseminated sulphide minerals. Flanking metavolcanic units and central rhyolitic core rocks to the southwest are highly chloritized and contain vesicle fillings of chalcopyrite and chlorite.

(4) The Ben Nevis area forms part of an extensive, east-west-trending upland region of thinly till-covered bedrock that identifies the Hudson Bay—St. Lawrence watershed divide. This separates areas of flat lowland topography covered by lacustrine sediments of glacial Lake Barlow to the south and glacial Lake Ojibway to the north. The watershed divide between the north-flowing Hudson Bay drainage and the south-flowing St. Lawrence basin drainage crosses the study area shown in Fig.88. Maximum topographic relief is approximately 75 m. The area is generally well drained although stream and river systems are locally impeded by small swamps. Eskers, streamlined topographic features, bedrock striations and fluting indicate that the last sheet of continental ice advanced across the Ben Nevis area in a S20°E direction. The Canagau deposit is located at the up-ice end of a linear southeast-trending ridge that is semi-parallel to the glacial flow direction over a distance of about 1,500 m. The till sheet covering the crest of this ridge seldom exceeds a thickness of 3 m. Commonly it is much less. A general thickening of till deposits to the east and west of this ridge suggests that the present topography is a subdued reflection of the pre-Quaternary bedrock surface. Well-differentiated podzolic soils are developed on the freely drained till sheet that covers most of the upland area.

(5) No data.

(6) In an area measuring 2,500 m (east-west) by 1,500 m (north-south) and extending south from the Canagau shaft, soils and glacial till were sampled at 50 locations to outline patterns of metal dispersal in glacial deposits situated “down-ice” from the known base-metal sulphide deposits. At each site samples were collected from the upper “B” soil horizon and from the parent glacial till scraped from the walls of 75–100-cm deep pits located along traverse lines trending normal to the local ice-flow direction (S20°E). Till samples weighing approximately 3.5 kg were oven-dried at 80°C and passed through 80- and 250-mesh screens. The minus 80-mesh fraction of “B” horizon soils and the minus 250-mesh fraction of glacial tills were leached with hot HNO₃/HCl and analyzed for copper, zinc, lead, nickel, cobalt, and manganese by atomic absorption spectroscopy methods. Heavy minerals were separated in tetrabromethane (specific gravity 2.96) from till sample material in the minus 80-mesh, plus 25-mesh particle-size range. The heavy-mineral concentrates were examined microscopically and were analyzed for hot HNO₃/HCl-leachable copper, zinc, lead, nickel, cobalt, and manganese.

Figs.88—90 summarize the zinc contents of soil and till fractions in the Ben Nevis study area. All three diagrams show a pattern of zinc dispersal presumably caused by glacial erosion of zinc-rich bedrock near the Canagau
Fig. 89. Zinc content in minus 250-mesh till, Canagau area.

Fig. 90. Zinc content in tetrabromomethane separates of minus 80-mesh, plus 250-mesh till, Canagau area.
deposit and transport of glacial debris in a southeast direction along the crest and flanks of a southeast-trending topographic ridge. Average background zinc values are 23 ppm in minus 250-mesh till; 25 ppm in minus 80-mesh, plus 250-mesh heavy-mineral separates; and 23 ppm in "B" horizon soils. Background populations are approximately normally distributed in the 10–40 ppm Zn range.

Microscope examination of the tetrabromomethane heavy-mineral concentrates revealed a complete absence of sulphide minerals. It is concluded that sulphide minerals are generally not present in otherwise "fresh" looking near-surface samples of permeable, well-drained glacial till, implying that sulphide cations have been redistributed in the till by secondary weathering processes involving chemical and physical leaching by downward-moving groundwater. Trace element analyses of heavy-mineral concentrates therefore reflect nothing more than the metal concentrations of stable oxide minerals, primary silicate minerals and secondary iron and manganese oxides. This conclusion is supported by the observation that zinc concentrations in the minus 250-mesh fractions of anomalous tills in the Ben Nevis study area, are systematically significantly higher than those for related heavy minerals. Secondary oxides and clays in the minus 250-mesh fraction have evidently scavenged zinc cations released by oxidation of sulphide minerals which, in unweathered samples, would have been present in the heavy-mineral concentrates. Redistribution of zinc by processes of near-surface weathering and soil formation has, in terms of anomaly contrast, anomaly extent, and pattern homogeneity, produced better geochemical exploration results from "B" horizon soil analyses than from heavy-mineral analyses.

The Ben Nevis study leads to the conclusions that:

(a) The nature of the pre-glacial bedrock topography immediately up-ice and for some distance down-ice from a mineralized bedrock source has an important bearing on the nature and extent of erosion and transport by the ice.

(b) Secondary weathering processes play an extremely important role in the redistribution of mobile elements within the upper 1–2 m of permeable, well-drained silty to sandy boulder tills. Analysis of heavy-mineral concentrates from "near-surface" samples of apparently unoxidized till may not always produce the best geochemical exploration results.

COBALT Ag AREA, ONTARIO

R.W. Boyle and E.H.W. Hornbrook (Geological Survey of Canada)

(1) Cobalt, Ontario.
(2) Steeply dipping Archean (Keewatin) mafic to intermediate lavas with interflow bands of chert, tuff and agglomerate make up most of the basement rocks of the area. These are overlain in places by steeply dipping greywacke, quartzite and conglomerate of the Archean Timiskaming Group. Granitic
plutons and basic dykes and sills intrude both Keewatin and Timiskaming rocks. The Proterozoic Cobalt Group of sediments, mostly conglomerate, greywacke and quartzite, lies unconformably on Archean basement rocks. Gently dipping quartz diabase sheets have intruded both Archean and Proterozoic rocks. Ordovician and Silurian limestones, shales and dolomites in places overlie all earlier rocks.

(3) Three separate areas are described, the Nipissing—O'Brien mine of Agnico Mines Limited; the Hiho Silver mine; and the No. 6 Shaft area of the Langis Silver and Cobalt Mining Company Limited.

The Agnico O'Brien No. 6 vein occurs in diabase near the surface and passes into Cobalt sediments and Keewatin greenstones along its strike and dip. At the Hiho Silver mine, Keewatin greenstones, containing a number of interflow sedimentary bands mineralized with pyrite, pyrrhotite, sphalerite, galena and chalcopyrite, are overlain unconformably by 150 feet or more of Cobalt sediments that consist of beds of conglomerate, greywacke and quartzite. These beds are also mineralized in places. The important geological aspects of the Langis mine are a Keewatin sequence of greenstones and interflow sedimentary bands overlain by Cobalt sediments (Gowganda Formation) later intruded by Nipissing diabase. Most of the productive veins occur in the sediments of the Gowganda formation, but a few in the Keewatin greenstone and Nipissing diabase. The economic deposits in all the areas are veins containing native silver and Ni–Co arsenides with a dolomite-calcite gangue. An extensive description of the deposits and their hypogene and supergene chemistry is given in Berry (1971).

(4) The rugged broken topography of the area is typical of the Canadian Shield. In the vicinity of Cobalt a peneplain has been eroded into steeply rolling till-covered or rocky hills separated by narrow linear valleys. The trends of the valleys were determined mainly by bedrock faults and/or pre-glacial and glacial erosion. Only a few of the highest hills exceed 1,150 feet in elevation.

Drainage follows either the gentle northeasterly dipping peneplain to Lake Timiskaming or southwest-trending valleys to the Montreal River. Soil drainage is good except in low-lying valleys where peaty soils are water-saturated. The glacial deposits in the Cobalt area consist of sand and gravels, varved clays, and boulder till. Typically, sand and gravel are present west and southwest of Cobalt at Gillies Lake, whereas varved clays are present in the “Little Clay Belt” north of New Liskeard and in some valleys near Cobalt. Boulder till is typically present on bedrock or underlies the other glacial deposits.

The climate of the area is temperate, with mean summer and winter temperatures of 65°F and 10°F, respectively. Annual precipitation is approximately 32 inches. Brown forest, grey wooded, podzol, and dark grey gleysolic soils which are dominant in the New Liskeard—Engleheart area described by Hoffman et al. (1952) are also dominant in the Cobalt area.

The development of a specific soil within this group is determined by the
parent soil material, relief, forest cover, and drainage conditions. Boulder till and its derived soils, mainly podzol, generally occurred on the property studied. Dark grey gleysolic soils are developed on poorly drained till in valleys.

Details of the topography and overburden for each area are given with the geochemical results.

(5) No data.

(6) All the data discussed below has been published by Boyle and Dass (1967), Boyle et al. (1969) and Hornbrook (1972). Only certain details which are particularly pertinent to this study are given here. Further information, and particularly the diagrams, may be obtained from these published sources.

_Nipissing—O’Brien mine, Agnico Mines Limited._ The area is covered with glacial till which is 2–8 feet thick along traverse CD and 5–20 feet thick along traverse EF. Along both traverses the ground slopes to the south (Boyle et al., 1969, fig.11; Hornbrook, 1972, fig.AH). The principal features are as follows:

(a) The tills in both the A and B horizons are enriched in a number of elements particularly silver, nickel, cobalt, arsenic, copper, lead and zinc. The peaks on the two traverses are mainly correlative with the position of the vein, although they are displaced to the south up to 100 feet or more. This is probably due to downhill migration of the soluble metals in the till.

(b) The A horizons give the best response, but the B horizons also give good results.

(c) The results obtained from these traverses indicate that the veins can be fairly accurately located by till analyses where the till is relatively thin (2–8 feet) as on traverse CD. Where the till is deeper as on traverse EF the dispersion is more erratic and the peaks are less definitive.

_Hiho Silver mine._ The veins of this deposit also are covered with glacial till, but to a greater depth than those at the Agnico mine. The till is generally 20–70 feet thick (Hornbrook, 1972). The samples were analysed for silver, zinc, lead and copper in the soil and till (Boyle et al., 1969, fig.10). From these and other published data the most interesting points are:

(a) Most of the elements of interest are enriched in the A and B horizons compared with background values (see Boyle et al., 1969, table 3).

(b) The A horizons are much more highly enriched in most of the elements than are the B horizons.

(c) A series of peaks occur along the two traverses in both the A and B horizons. These may mark individual veins in some cases, but more generally they outline the vein cluster that lies some 100 feet below the surface. The deeper till in this area, compared with that at the Agnico deposit may have diminished in the anomaly definition at surface.

(d) The possibility exists that the anomalous contents of metals on these traverses result from the down-ice transport of slightly anomalous till derived from the area of the Silverfields veins that lie to the northwest. There is no way to check this because the till between the two properties is probably contaminated by the roads that run through this area.
Langis mine. The vein over which the traverse was run is covered by 90 feet or more of varved glacial clay. The results for traverse AB are shown in Boyle et al. (1969, fig.80): (a) none of the elements in the A or C horizons reflect the presence of the veins beneath; (b) the results correlate well with those obtained in the same district over the Harrison–Hibbert vein, indicating that analyses of glacial clay are not effective for locating the native silver veins in the Cobalt area; and (c) results for the CD and EF traverses parallel those for the AB (Boyle et al., 1969).

Fig. 91. Cu-Pb-Zn-Ag in till, Consolidated Mogador deposit, Quebec.
CONSOLIDATED MOGADOR Cu—Pb—Zn—Ag—Au DEPOSIT, QUEBEC

C.F. Gleeson (C.F. Gleeson and Associates)

(1) This property is located about 300 feet southeast of the Barvallee property, 30 miles north of Val d’Or, Quebec.

(2) A zinc deposit containing 1,121,000 tons grading 7.3% Zn, 0.47% Cu, 0.34% Pb, 1.63 oz./ton Ag and 0.034 oz./ton Au is reported to occur here in Precambrian tuffs.

(4) The subsurface trace of the base-metal zone is under a bog and the thickness of the overburden in the area varies from 65 to 105 feet. An 8–14-foot layer of organic material overlies 50–62 feet of glacial lake clays and silts. This is underlain by a layer of fine sand 0–15 feet thick and below the sand a layer of gravel and boulders 0–16 feet thick is present. Basal till is not always found atop bedrock and where it is found, it seldom exceeds 0.5 foot in thickness.

(5) No results.

(6) A profile across the ore zone on L2W is shown in Fig.91. The results of this work were kindly contributed by F. Dubuc of Nord Resources Corporation. The base-metal deposit is indicated by values of 1,600 ppm Cu, 612 ppm Zn and 3.7 ppm Ag in the heavy-mineral concentrates from station 400S. It is obvious that down-ice dispersion in the till taken atop bedrock is restricted to less than 100 feet. No anomalous values were found in the minus 80-mesh fraction.

DORSET AREA, ONTARIO

J.A.C. Fortescue (Brock University)

(1) The town of Dorset is situated some 160 miles to the north of the city of Toronto, Ontario. The location of the area studied is latitude 45°14’N, longitude 78°53’W (Fig.92).

(2) The Dorset area lies within the Canadian Shield in a part of the Haliburton Highland which is between Georgian Bay and the Ottawa River. The bedrock is glacially paved siliceous gneiss.

(3) There is no known mineralization in the study area.

(4) The area is rolling to hilly terrain and bedrock is covered by a shallow to deep mantle of granitic sands and sandy loams (Burger, 1967). The surface of the Precambrian bedrock is usually glacially paved, forming a sharp contact with the bottom of a layer of overlying transported material within which soil profiles have developed during the past 10,000 years. These are podsol soils at various stages of development. The depth of the layer of transported material lying on the bedrock is about 1 m in the area now covered by mineral soil. The depth of the layer of mineral material lying on the bedrock surface under the bog is not known, although it is at least 9 m (N. Woerns, personal communication, 1973).
(5) No data.

(6) The soil profile data for copper, lead and zinc are shown in Figs.93—95. From these data the following conclusions are drawn: (a) the metal levels in the bog are consistently higher than in the mineral soil; (b) the A2 (or Ae) horizon is generally depleted in copper, lead and zinc; and (c) in the bogs the values generally decrease with depth.


FLIN FLON Cu AREA, MANITOBA

D.R. Clews and J.L. Walker (Barringer Research Limited)

(1) The four deposits described all lie in the Flin Flon area, Manitoba, within 70 miles of the town of Flin Flon.

(2) The region, as a whole, is underlain by the Archean Amisk Group of volcanic and sedimentary strata. These strata are intruded by granitic rocks,
Fig. 93. Distribution of copper in soil profiles, Dorset area.

Fig. 94. Distribution of lead in soil profiles, Dorset area.
mainly contemporaneous with Hudsonian folding and metamorphism.

(3) The orebodies are principally in volcanic rocks of intermediate and basic composition or their metamorphic equivalents. Most orebodies consist of massive and disseminated sulphide zones, with the massive zones predominating. Details of the individual deposits investigated are as follows:

Keg Lake — mainly a pyrrhotite body low in copper and zinc, in sedimentary gneiss.

Pitching Lake — chalcopyrite within a pyrrhotite zone in altered volcanic rocks containing 100,000 tons of 2.41% Cu.

Schist Lake — about 300,000 tons of approximately 3% Cu in a zone of chalcopyrite and pyrrhotite in volcanics.

Shupe Lake — a Cu–Ni sulphide occurrence in gabbro with unknown economic potential.

(4) The topography is generally low and rolling with substantial areas of impeded drainage. Much of this area was covered by Pleistocene Lake Agassiz, and here the overburden is commonly stratified drift of various types. Except for one sample location at Shupe Lake, all samples were collected in soils developed on stratified drift.

(5) No data.

(6) The soil profile data for all four properties are shown in Fig.96a–d and Table XXV. The data may be summarized as follows: (a) the stratified drift
effectively blocks all surface soil response of copper and zinc; (b) the only positive copper and zinc surface soil anomaly is at profile 4, Shupe Lake, where the mineralization outcrops; and (c) at Keg Lake and Schist Lake mercury shows an anomaly directly above the mineralization, but this only reported in the organic A horizons and not in the B.
TABLE XXV

Distribution (ppm) of copper, zinc and mercury in soil profiles, Flin Flon area

<table>
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<tr>
<th>Soil horizon</th>
<th>Station number</th>
<th>1</th>
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</table>
KIDD CREEK Cu–Zn–Ag DEPOSIT, ONTARIO

E.H.W. Hornbrook (Geological Survey of Canada)

(1) The mine is located in Kidd Township approximately 12 miles north-east of Timmins, Ontario.

(2) The deposit is in volcanic rocks of the Tisdale Group of Archean age. Tisdale rocks are a typical interbedded sequence of volcanic and sedimentary rocks including rhyolitic pyroclastics which are found to the east of the deposit and andesitic pillow lavas to the west.

(3) The deposit consists of massive sulphides concordant with enclosing steeply dipping rhyolite breccia that is overlain by andesite. The orebody is at least 400 feet wide and 2,000 feet long with reserves to date totalling 60 million tons of ore averaging 4.85 oz./ton Ag, 1.33% Cu and 7.08% Zn. The mineralized zone is still open at depth. The sulphide minerals are mainly pyrite, chalcopyrite and sphalerite with small amounts of bornite, covellite, digenite, stromeyerite, pyrrhotite, marcasite, galena and arsenopyrite. The silver occurs mainly as native silver in small inclusions in the pyrite.

(4) Kidd Township is in the Great Clay Belt of northern Ontario. Typically, the relief is low and the forest cover consists of endless stretches of stands of black spruce that give way to extensive peat bogs in the lowland area. Mineral and organic soils are generally found in the high and low areas, respectively. The area is at least 200 miles south of the zone of discontinuous permafrost, but winters are severe and frost may penetrate several feet into the ground depending on snow cover.

(5) No data.

(6) Fig.97 shows the sample locations of organic and mineral soil. High zinc values in organic soil (Fig.98) are related to the soil-vegetation environment of the trembling aspen stand. These are no significant zinc, copper, nickel or lead values (not illustrated here) to show evidence of the massive sulphide ore zone. Element content in vegetation sampled on this grid did not have any significant variations that could be related to the ore zone. Thus, a few tens of feet of varved clay, overlying in most places fresh unweathered glacially paved sulphide ore, was sufficient to completely insulate the surface soils from any high element concentrations present in the mineralized bedrock or till beneath the clay.

Therefore, element variations in surface soils or vegetation, where varved clay is present, are not derived from, or related to, mineralization effectively blanketed by these varved clay sequences.

Lower-till samples in a down-ice direction from the massive sulphide deposit were also collected (Fig.97). Analysis of the minus 80-mesh (177 micron) lower till found significant copper and zinc values, greatest adjacent to, and decreasing farther down-ice from the deposit. Approximate extent of the copper and zinc dispersion halos is shown in Fig.97. The zinc anomaly is largest and extends over a mile in a down-ice direction in lower till. Vertical
Fig. 97. Location of soil and plant samples, boreholes from which surficial material was collected and the sub-outcrop area of the mineral deposit (after Fortescue and Hornbrook, 1969).
Deciduous forest cover (trembling aspen)

Cut over area (alder cover)

Organic soil

Mineral soil

Surficial material

Greenstone

STATION A B C D E F G H I J K L M N

Fig. 98. Landscape section showing bedrock geology, surficial geology, soil cover types, plant-cover types and zinc content in soil in Line 24S (after Fortescue and Hornbrook, 1969).

Fig. 99. The distribution of zinc in surficial material over the Kidd Creek deposit (borehole No.1) and to one side (borehole No.23) (after Fortescue and Hornbrook, 1969).

Borehole No. 1

Borehole No. 23

Zinc (ppm)

Cross sections showing the nature of the surficial material and zinc distribution in boreholes 1 and 23 are given in Fig.99. Borehole 23 is outside of the zinc dispersion halo. There was less than 1 foot of lower till present at borehole 1 and its zinc content shows a significant contrast to the content in clay, till or varved clay.

Therefore, where surface-soil or vegetation sampling is not effective due to the presence and insulating effect of glacial lake clay sequences, lower-till
sampling may be effectively sampled to detect and define base-metal dispersion halos from an appropriate source that was exposed to glacial erosion.


LIMERICK Ni–Cu PROSPECT, ONTARIO

I. Thomson (Barringer Research Limited)

(1) The Limerick Ni–Cu prospect is located approximately 13 miles south-southeast of the town of Bancroft in the north end of Lots 28 and 29, Concession VI, Limerick Township, southeastern Ontario.

(2) A comprehensive account of the regional geology and the local environment of the prospect is given by Lumbers (1969).

(3) Ni–Cu mineralization occurs along the eastern boundary of the Thanet Complex which is a composite basic to ultrabasic intrusion having an exposed area of about 9 square miles. The Limerick deposit occurs in the northeastern corner of the Thanent Complex in altered peridotite (metapyroxenite) phases of the complex where it forms a northeasterly trending projection into northward-trending Turriff metavolcanics and the Vansickle metasedimentary formation. Thin horizons of metasedimentary rocks are common within the intrusion in the vicinity of the deposit and in places they are mineralized.

The Limerick deposit consists of two and possibly three sulphide lenses forming a reverse L-shaped zone within metapyroxenite (Fig.100). The sulphide lenses dip steeply and plunge northwest.

Fig.100. Sample collection locations, Limerick Ni–Cu prospect, Ontario.
Sulphides seldom exceeding 15% by volume of the rock, consist of medium-to fine-grained (i.e., 0.15 mm) disseminated pyrrhotite, pentlandite, pyrite and chalcopyrite in order of abundance. Traces of cubanite and sphalerite are also present. The more basic peridotite masses occasionally carry up to 50% sulphides mainly in the form of pyrrhotite while gabbroic phases seldom contain over 20% sulphides. Minor amounts of cobalt (less than 0.10%) are present throughout the zone, most likely related to the nickel mineralization. Estimates of grade and tonnage, based on 68 diamond drill holes to a depth of 1,600 feet, are 2.9 million tons of 0.69% Ni and 0.20% Cu or 4.2 million tons of 0.57% Ni and 0.17% Cu with up to 0.05% Co (calculated at a cut-off grade of 0.30% Ni).

(4) The area comprises broken ground with a local relief of 20—60 feet. There are numerous areas of outcrop with swamp and ponds in the hollows. At the time of sampling the entire northern part of the prospect was under water having been flooded by a beaver dam.

The prospect lies in mixed deciduous woodland made up of maple, poplar, and ironwood, with local areas of conifers. A large area beside the road west of the mineralized zone was cleared to facilitate drilling. This is now grassed over with low-scrub woodland.

Soils are dominantly podzolic with local peat accumulation in some hollows. A distinct A₃ horizon is widely developed. Thin, immature regosols (3—9 inches deep) are found adjacent to outcrop.

Glacial activity in the area resulted in a minimal dislocation of the overburden although some erratic cobbles can be found. A thin local drift covers parts of the area. This is generally less than 10 feet thick increasing to 30—40 feet in a zone west of the northerly extension of the mineralization.

(5) No data.

(6) A soil traverse was collected across the mineralization (Figs.100 and 101) sampling the A₀, A, and B horizons. This traverse stopped in poorly drained ground to the west and crossed a seepage zone to the east of the ore deposit (station 3W). The ground over the deposit itself was well drained.

The data (Figs.102—104) show: (a) a moderate copper and nickel anomaly over the mineralization particularly in the B horizon; (b) a strong seepage anomaly at station 8W and a weaker seepage anomaly at 3W; and (c) over the SEEPAGE ZONE

Fig.101. Geology and location of mineralization, Limerick prospect.
Fig. 102. Distribution of copper and nickel (minus 80-mesh fraction), in A₀ horizon soils, Limerick prospect.

Fig. 103. Distribution of copper and nickel (minus 80-mesh fraction) in A₁ horizon soils, Limerick prospect.
mineralization on well-drained ground the percent cold-extractable metal is approximately 1%, while in the seepage zones it is 10–20%.

(7) Six near-surface groundwater samples (Fig.100) were collected, three close to mineralization (LW1 to 3) and three removed from mineralization (LW5 to 7). In addition a surface lake water sample was collected close to mineralization (LW4). The results (Table XXVI) show that the near-surface groundwater, draining from the mineralization is strongly anomalous in copper and nickel, proving hydromorphic movement.

TABLE XXVI

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<th>Sample No.</th>
<th>Ni (ppb)</th>
<th>Cu (ppb)</th>
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<td>17</td>
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<tr>
<td>LW1</td>
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<td>70</td>
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<tr>
<td>LW2</td>
<td>—</td>
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<tr>
<td>LW7</td>
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</table>
Acknowledgement

This work was undertaken with the kind permission of Mr. P. Sheridan, President of Sheridan Geophysics Limited, who also supplied the basic information on the geology and mineralization.

MAGUSI RIVER Zn–Cu DEPOSIT, QUEBEC

C.F. Gleeson (C.F. Gleeson and Associates)

(1) This massive sulphide Zn–Cu deposit is located about 20 miles northwest of Noranda, Quebec (lat. 48°27'N, long. 79°23'W).

The zone occurs some 1,800 feet south of Magusi River which empties in the southwest corner of Lac Duparquet.

(2) The sulphide zone is a tabular body enclosed predominantly by Precambrian felsic volcanics and lesser amounts of basalt. It strikes east–west, dips 50°S and has a length of at least 1,400 feet. The pyritic sulphide zone varies in thickness from 5 to 110 feet (Jones, 1973).

(3) The economic sulphides consist predominantly of fine-grained chalcopyrite and sphalerite with minor galena.

To date the deposit is estimated to contain 4.11 million tons averaging 1.2% Cu, 3.55% Zn, 0.032 oz./ton Au and 0.91 oz./ton Ag.

(4) The sulphide zone is underlain by 40–45 feet of glacial clay, silt, sand, and gravel. Normally, a layer of compact, basal till about 1 foot thick lies atop bedrock.

Following the discovery of the deposit by Copperfields Mining Corporation Limited and Iso Mines Limited in 1972 (Jones, 1973) extensive geophysical work and diamond drilling was carried out. In addition a geochemical programme of sampling the till/bedrock interface was completed.

(5) No data.

(6) Fig. 105 and Table XXVII show the results from three holes drilled over and 100 feet on either side of the deposit. Very anomalous values for copper, zinc, silver, and mercury were obtained in all fractions from the till.

Fig. 105. Location of overburden drill holes, Magusi River Deposit, Quebec.
### TABLE XXVII

Geochemical results from till on bedrock, Magusi River Zn–Cu deposit

<table>
<thead>
<tr>
<th>Drill hole</th>
<th>Cu (ppm)</th>
<th>Zn (ppm)</th>
<th>Ag (ppm)</th>
<th>Hg (ppm)</th>
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<td>55</td>
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<td>(2) 58</td>
<td>124</td>
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<td>50</td>
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<td>(3) 24</td>
<td>81</td>
<td>0.9</td>
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<td>2</td>
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<td>10,000</td>
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<tr>
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<td>(3) 1,750</td>
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<td>(2) 250</td>
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<td>75</td>
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<td>(3) 24</td>
<td>28</td>
<td>0.9</td>
<td>35</td>
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</tbody>
</table>

(1) Whole sample, (2) heavy-mineral fraction (specific gravity 2.96) plus 80-mesh, (3) minus 80-mesh fraction.

over the sulphide zone (drill hole 2). The heavy-mineral concentrate from this sample contained 90% sulphides.

Only the heavy fraction of the sample from drill hole 3, 100 feet down-ice from hole 2, is anomalous in copper (250 ppm), zinc (750 ppm) and silver (2.0 ppm). There are no anomalous values in the other fractions from this hole. This illustrates the importance of analyzing heavy-mineral separates when programmes of geochemical till sampling at depth are carried out.

### Acknowledgements

The author wishes to thank the personnel of Copperfields Mining Corporation Limited and Iso Mines Limited and in particular Mr. Matthew Blecha for making the above information available.

### MANITOYWAGDE Cu–Pb–Zn DEPOSIT, ONTARIO

E.H.W. Hornbrook \(\textit{Geological Survey of Canada}\)

(1) Manitouwadge, Ontario; north of Lake Superior.

(2) The area is underlain by a synclinal roof-pendant of metavolcanic and metasedimentary strata of Keewatin type, surrounded by biotite granodiorite gneiss and migmatite prevalent in the district. The orebodies are in foliated rocks, and conformable with them; all but one are in metasediments that are mainly iron formation and associated garnet-amphibole schist. The orebodies are high-temperature types of three kinds; disseminations, lode fissures containing cores of massive sulphides surrounded by disseminations, and a massive deposit.
(3) The most common minerals are pyrite, pyrrhotite, quartz, chalcopyrite, sphalerite, and galena.

(4) The area is characterized by a bedrock-controlled rugged topography with typical spruce forests and swamps interspersed in lowlands or in areas of restricted drainage. Soil development on the limestone till is poor and is generally a medium grey, fine-grained gleysolic soil. The area has a temperate climate.

(5) Stream sediment sampling, except where streams flow over excessive thicknesses of limestone till, provided geochemical anomalies that could be related to bedrock or a sulphide mineral occurrence. Geochemical dispersion halos were present in stream sediments because stream channels were eroded down to bedrock, locally derived till or the lower sections of limestone till.

(6) Essentially the geochemical and surficial geological problem in this area as respectively described by Garrett (1969) and Grant (1969) is one where the dominantly occurring limestone till has a source remote from the area and a composition that suppresses the mobility of desired pathfinder elements. A locally derived till which probably would not inhibit mobility is rare in occurrence and is normally found in bedrock depressions overlain by limestone till. Thus, most soil sampling is carried out in a poorly developed soil horizon in the limestone till.

Three typical situations were encountered. In less than 2 feet of limestone till, surface soil horizon sampling produced positive results. In deeper limestone till, approximately 5–10 feet, surface soils were not responsive and the anomalous expression of geochemical dispersion halos was confined to the bottom 2-foot section of the till sequence. In such cases on pronounced slopes, dispersion halos frequently were, for certain elements (Zn), weakly represented in surface soils downslope. This greater mobility for zinc was also found in detailed profile sampling over Big Name Creek where anomalous levels of copper were restricted to the bottom 2 feet and for zinc to the bottom 3 feet. In limestone till of depth greater than 5–10 feet surface soils did not indicate geochemical dispersion halos at depth. To carry out soil exploration in this case, till samples from the bedrock surface would have to be recovered through percussion drilling, augering, etc. Thus, the composition of a till and its derivation may severely restrict the development and dispersion of a geochemical anomaly originating from a bedrock or an underlying locally derived till source as effectively as thick sequences of glaciolacustrine, varved clays.

**MATTAGAMI LAKE Cu–Pb–Zn DEPOSIT, QUEBEC**

C.F. Gleeson (C. F. Gleeson and Associates)

(1) This mine is situated some 112 miles north of Val d’Or, Quebec (lat. 49°43’N, long. 77°43’W).

(2) The orebodies consist of two massive sulphide zones in Precambrian
tuffaceous and rhyolitic rocks enclosed by dacitic lavas and in contact with a peridotite intrusion on the north. The orebody occupies an anticline which strikes N60°W and plunges about 30°NW.

(3) The sulphides present are sphalerite, pyrite, pyrrhotite, and chalcopyrite with minor galena and arsenopyrite. Magnetite, carbonate, quartz, talc, and serpentine are usually associated with the ore.

Published ore reserves at the end of 1972 were 14,661,927 tons averaging 8.9% Zn, 0.67% Cu, 0.012 oz./ton Au and 1.08 oz./ton Ag.

(4) The property is located in low, flat, rather swampy terrain. Vegetation consists of black spruce, labrador tea, alders, some tamarak, balsam and birch. 6—24 inches of sphagnum moss covers the surface.

The area is blanketed by a layer of glacial lake clay and silt 20—100 feet thick. Generally under the glaciolacustrine deposits is a layer of sand, boulders and till from 0 to 40 feet thick.
Usually the clays and silts at or near surface are light brown in colour and they change to a grey colour about 5 feet below surface. Where the moss is thick (1 1/2–2 feet) the clays are often greenish in colour.

Normally the $A_0$ (humus or decomposed moss) horizon rests directly on the $B$ horizon (brown clay) and there are only a few locations where a thin leached ($A_2$) layer is present.

X-ray diffraction and differential thermal analyses have shown that the clays are composed essentially of finely ground rock-forming minerals consisting of quartz, feldspar and lesser amounts of chlorite, biotite and amphibole.

(5) No data.

(6) Samples of soils from the decomposed humus-moss layer ($A_0$ horizon) and the underlying clays ($B$ horizon) were obtained over both orebodies before any major mine development took place (Figs.106–109).

The samples were analyzed colorimetrically for copper and zinc after
extraction with a hot solution of HNO₃. These results are presented in Figs. 106–109.

No. 1 orebody was covered by 20—30 feet of glacial clay and bouldery clay till. The No. 2 orebody did not sub-outcrop, it was capped by a bed of tuff which was covered by some 80—100 feet of glacial clay, sand and till.

Background values for zinc and copper in the A₀ horizon are 70 and 20 ppm, respectively, and in the B horizon they are 110 and 30 ppm, respectively.

There is no marked anomaly for either zinc or copper in the humus and clays over the sub-outcrop of the ore zones (Figs. 106–109). However, there are indications of erratic increases in zinc values in the humus and clays on the north side and down-drainage from orebody. These increases are seldom more than one half times background and they could be due to the normal metal content of the overburden.
These data are presented here to demonstrate the ineffectiveness of conventional soil geochemistry in outlining base-metal deposits covered by as little as 20 feet of clayey glaciolacustrine sediments. It was for this reason that the technique of overburden sampling at depth was developed.

NIGHTHAWK LAKE AREA, ONTARIO

C.F. Gleeson (C.F. Gleeson and Associates)
E.H.W. Hornbrook (Geological Survey of Canada)

(1) This area is located 19 miles east of Timmins, Ontario (lat. 48°30'N, long. 80°55'W). The area of interest lies under Northeast Bay of Nighthawk Lake.
(2) In Northeast Bay of Nighthawk Lake several bodies of serpentinized peridotite intrude Precambrian volcanic rocks.

(3) Gold occurrences are known in felsite dykes and quartz veins and stringers cutting strongly schistened volcanics and ultramafic rocks. The gold zones are related to a N70°E fracture system.

(4) The bay is 1–10 feet deep and it is underlain by 9–144 feet of glacio-lacustrine clay, silt and sand. The lowest part of the section usually contains 1 foot or less of basal till resting on top of the bedrock.

(5, 6) The object of this work was to determine if semi-reconnaissance geochemical sampling of the till/bedrock interface could effectively outline areas containing geochemically distinctive rock types. In this case the bay was known to be underlain by several intrusions of Precambrian ultramafic rocks.

Systematic holes were drilled from the ice at ¼- and ½-mile centres and samples of the till on top of the bedrock were taken with help of a portable percussion drill and piston-type sampler.

For comparative purposes the lake sediments were sampled also.

There is no apparent relationship between the distribution of nickel in the lake sediments and the geology of the area (Fig.110). However, in the minus 230-mesh fraction of the till nickel anomalies are common. Nickel in this fraction varies from 12 to 370 ppm and averages 52 ppm.

A strong northeasterly trend of nickel anomalies (Fig.111) in Northeast Bay coincides with the area known to be underlain by ultramafic intrusions.

Fig.110. Nickel in minus 230-mesh fraction of lake sediments, Nighthawk Lake, Ontario.
Fig. 111. Nickel in minus 230-mesh fraction of till, Nighthawk Lake.

Fig. 112. Nickel in minus 50-mesh, plus 230-mesh fraction of heavy-mineral concentrates from till, Nighthawk Lake.
Similarly, on East Peninsula the easterly trend of the nickel anomalies coincides with easterly striking bands of ultramafic rocks.

A similar pattern is shown for nickel in the minus 50-mesh, plus 230-mesh heavy-mineral fraction (specific gravity 2.96) of the tills (Fig.112). Nickel in the heavy-mineral concentrates varies from 20 to 1150 ppm and averages 163 ppm.

The strongest nickel anomaly occurs in the northeast where it is underlain by a serpentinized peridotite body. The heavy-mineral concentrates from here contain traces of pyrrhotite, pyrite and chalcopyrite indicating that some of the nickel here is probably due to sulphide occurrences. Other significant anomalies are present on East Peninsula and north and south of it. All these anomalies are closely associated with ultramafic intrusions and/or their altered equivalents.

Therefore, it has been demonstrated that semi-reconnaissance geochemical sampling of the till/bedrock interface can be effective in outlining economically significant geological targets where these targets are covered by up to 144 feet of glaciolacustrine deposits.

In the example presented here nickel in the minus 230-mesh fraction of the till and in the heavy-mineral concentrates of the minus 50-mesh, plus 230-mesh fraction of the till effectively outlined areas underlain by ultramafic rocks.


FOX LAKE Cu–Zn DEPOSIT, MANITOBA

D.R. Clews (Barringer Research Limited)

(1) Located 25 miles southwest of Lynn Lake, Manitoba, immediately south of Dunphy Lakes.

(2) This area lies within the Superior province of Archean age. Locally the rocks consist of a series of metavolcanics surrounded by undivided granites.

(3) Massive Cu–Zn sulphide mineralization in a zone approximately 2,000 feet long.

(4) The topography in the area is moderate. Drainage is generally poor with a large number of lakes connected by generally slow-flowing streams. The majority of the area is covered by glacial till, stratified drift being generally absent.

(5) The lake sediment and lake water data are shown in Fig.113. From these data it is evident that total copper in the water does not reflect the presence of underlying mineralization. In contrast the sediment samples show a strong anomaly in Fox Lake itself, related to the mineralization.

(6) No data.
SOUTHERN LAKE Ni PROSPECT, NORTHWEST TERRITORIES

W.W. Shilts (Geological Survey of Canada)

(1) Southeast end of Southern Lake, District of Keewatin (lat. 62°10'N, long. 94°17'W; Fig. 114).

(2) The bedrock directly underlying the study area is intermediate to basic submarine volcanic rocks, flanked on the east by granodiorite and on the west by a gabbro intrusion.

(3) At point “A”, mineralization is reported to be pyrite and nickeliferous pyrrhotite disseminated in amphibolitic mafic rocks adjacent to shear zones near the southwestern contact of the volcanic rocks and mafic plutonic rocks (Davidson, 1970). In one trench at point “B”, near the contact, chalcopyrite was noted with pyrrhotite. Heavy-mineral separates from till near point “A” contained pyrite and a mineral identified by microprobe analysis as bravoite (Ni, Fe)S₂, a rare nickeliferous pyrite.

The region around point “A” was explored by drilling in the mid-1950’s by Sherritt Gordon Mines Limited. The area of outcrop or sub-outcrop of
mineralized rock is unknown, and the mineralization is of sub-economic grade.

(4) Southern Lake is in a broad, 100-foot deep trough cut into basic volcanic rocks. The Copperneedle Esker runs down the middle of the trough, forming a discontinuous, 10–50-foot high, sinuous ridge. The rest of the trough is largely covered by sandy till with areas of ribbed moraine and a moderately heavy cover of boulders. The trough was at one time at least 350 feet below the surface of the Tyrrell Sea, but marine deposits are patchy and rare. Small gossans are common within the area sampled.

Drainage is indistinct and disrupted by numerous small lakes that occupy glacial erosional/constructional or thermokarst depressions. Drainage channels are practically impossible to find except for that of the Copperneedle River which drains Southern Lake at its southeast end.

The climate is severely cold and dry, total annual precipitation averaging 7–9 inches and mean annual temperature averaging 10–13°F. Permafrost extends to depths of at least 1,000 feet and the surface thaws from 3- to 6-foot depths under bare or thinly vegetated till or gravel. In flat, wet, frost-cracked areas, organic cover is thick and the active (thawed) zone reaches a maximum thickness of only 6–30 inches. Except in these latter areas the tundra vegetation is particularly sparse and soil profiles are well developed only on well-drained gravelly sediments. Profiles on silty marine sediments
or till are poorly developed because of the physical mobility of these sediments in the active zone.

(5) No data.

(6) The copper and nickel content of the near-surface till is shown in Figs. 114 and 115. From these data the following conclusions can be made.  
(a) Copper mineralization is associated with the reported nickel mineralization. Till sampling has clearly indicated known mineralization.
(b) There are probably more zones of mineralization near the southeast end of the lake than seen in outcrop.
(c) There is no clear-cut glacial dispersal train extending southeast from known sources (this may only be a function of sampling pattern and density, however). Elsewhere within the region, however, strong glacial dispersal trains are developed.
(d) Average trace element values in the minus 250-mesh fraction of eskers are higher by a factor of 4 or 5 than similar values in adjacent till. This has been found to be true of all well-drained gravelly sediments and results from a proportionately higher amount of high-exchange capacity minerals in esker sediments. Mobile cations released by weathering in till are scavenged by well-crystallized phyllosilicates with limited exchange capacity. Secondary iron and manganese oxides and degraded or mixed-layer clays are removed from

Fig. 115. Nickel in the minus 250-mesh fraction of till samples, Southern Lake.
till as they are formed by mud-boiling processes. On eskers, where mud-boiling does not take place and the secondary scavengers are trapped within the sandy matrix, proportionately higher amounts of mobile ions are retained and adsorbed onto material that comprises much of the minus 250-mesh fraction.

(e) The esker reflects known mineralization or an extension of known mineralization at the southeastern end of the lake.

(f) The large esker segment that forms an island in the lake has very high copper values and may indicate previously unknown copper mineralization within the lake basin.

TROILUS Cu DEPOSIT, QUEBEC

M. Tauchid (SOQUEM) *

(1) The property is located in Gauvin Township about 35 miles northeast of Chibougamau, Quebec.

(2) Proterozoic dolomite and graphitic shale of the Albanel Formation

underlies most of the property. Complex gneisses of the Grenville border the eastern margin.

(3) Chalcopyrite and pyrite are found associated with quartz and carbonate veinlets in graphitic shale host rock.

(4) The overburden is sandy till of approximately 70 feet depth.

(5) No data.

(6) Forgeron (1971) reported the usefulness of the mercury soil survey on the property. Gaucher and Gagnon (1973) indicated that all anomalous mercury values reported by Forgeron correspond to the A horizon soils. Resampling only the A horizons by SOQUEM produced a slightly different picture (Fig.116). Gaucher and Gagnon suggested that the mercury anomalies may not be related to the copper mineralization but more to the soil horizons collected. The case strongly indicates the common oversimplification in geochemical interpretation. The neglected factor in the above discussion was the establishment of background values for mercury in the different horizons of the soil profile. It should be pointed out, however, that result of the resampling (only the A horizon) over 5 lines still indicates well-defined anomalous zones

![Graph showing mercury, copper, zinc, and manganese in soils across the Troilus deposit.](Fig.117)
Diamond drilling results over some of these anomalies suggest that the high mercury values are related more to the quartz-carbonate veinlets (lenses) rather than the copper mineralization itself (J.T. Flanagan, personal communication, 1973). It is therefore concluded that the relation between high mercury values in the soil and the copper mineralization is indirect. The thought that the mercury anomalies may reflect the graphitic shale horizons is contradicted by the fact that mercury contents of both nonmineralized shale and dolomite are around 200 ppb.

The A horizon soils collected were also analyzed for their copper, lead, zinc, silver, and manganese contents (Fig.118). The values obtained range in the following order: copper from less than 1 ppm to 18 ppm, lead from 3 ppm to 55 ppm, zinc from 1 ppm to 72 ppm, silver from 0.2 ppm to 3.8 ppm, and manganese from 1 ppm to 8,400 ppm. As shown in the accompanying profiles the distribution of zinc follows that of mercury rather consistently. The most striking and well-defined anomalies are produced by the manganese values. These anomalies coincide with the mercury peaks. Further correlation with available diamond drill hole data is required to determine the significance of these high manganese values.

Reference: SOQUEM, Company files.

Fig.118. Mercury soil traverses, Troilus Mines Limited (after Gaucher and Gagnon, 1973).
WINTERING LAKE Cu—Ni PROSPECT, MANITOBA

P.M.D. Bradshaw (Barringer Research Limited)

(1) 30 miles south-southwest of Thompson, Manitoba, on an island near the centre of Wintering Lake (lat. 55°24'N, long. 97°42'W).

(2) The entire island is composed of Archean-banded amphibolite, although the country rock in the surrounding area is quartz-mica gneiss.

(3) The mineralization is massive pyrite-pyrhotite with chalcopyrite and pentlandite in a vein approximately 5 feet wide. This vein dips steeply and occurs in a much wider gossan zone. The wall rock is a garnet amphibolite gneiss.

Fig. 119. Distribution of copper and nickel in lake sediments, Wintering Lake area, Ontario.

Fig. 120. Distribution of copper and nickel in soil profiles, Wintering Lake area.
(4) The entire area is covered by glaciolacustrine clay which, in places, overlies till, and in places lies directly on top of the bedrock. There is a very good podzolic soil horizon development in the top 5 inches of this clay. The soils, where sampled, were well drained.

(5) Lake sediment samples were collected along the shore of the island as shown in Fig.119. All the samples, with the exception of sample 218, are anomalous in nickel and the majority are anomalous in copper. The very high values in sample 215 undoubtably reflect mechanical movement of sulphides into the sediments as the mineralization outcrops on the edge of the lake. The other samples, however, probably represent a combination of hydro-morphic and mechanical movement, both from the mineralization and the gossan area.

(6) Two soil profiles were collected, one directly over the vein and the other some distance away in a background area (Fig.120). The profile over mineralization shows a strong response in the basal till, and also in the $A_0$ horizon. However, the anomaly in the $A_0$ cannot be taken to reflect the mineralization, as an “anomalous” response was also found in the $A_0$ background profile. These abnormally high metals in the $A_0$ were encountered in several places in this area, apparently unrelated to mineralization.


APPENDIX*

Common glacial sediments of the Shield, their properties, distribution, and possible uses as geochemical sampling media

(1) Lodgment and ablation till

**TABLE XXVIII**

Summary of length and strength of anomalies over different deposits*

<table>
<thead>
<tr>
<th>Name (reference)</th>
<th>Overburden</th>
<th>Extraction and element</th>
<th>Sediments</th>
<th>comments</th>
<th>Soils anomaly size</th>
<th>strong-est contrast</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-outcrop size of mineralization</td>
<td>Extrac-</td>
<td>Sediments</td>
<td>max. dis-</td>
<td>strength</td>
<td>Sediments</td>
<td>anomaly size</td>
<td>strong-est contrast</td>
</tr>
<tr>
<td>Economic metal</td>
<td>tion and</td>
<td>elemental</td>
<td>persion length</td>
<td>contrast</td>
<td></td>
<td>length</td>
<td>contrast</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>width)</td>
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<tr>
<td>Massive sulphide-type mineralization</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Kidd Creek</td>
<td>varved clay</td>
<td>tot Zn</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000' x 100' Cu, Zn, Ag</td>
<td>till</td>
<td>tot Zn</td>
<td>3000' x 2500'</td>
<td>40</td>
<td>strong smearing down-ice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>clay</td>
<td>tot Cu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coppermine 47-zone (Allan et al., 1972)</td>
<td>till</td>
<td>tot Cu</td>
<td>1600' x 8000'</td>
<td>4</td>
<td>B horizon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1800' x 100' Cu</td>
<td></td>
<td></td>
<td>2000' x 1600'</td>
<td>5</td>
<td>O/A horizon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coronation mine (Scott and Byers, 1965)</td>
<td>till</td>
<td>tot Cu</td>
<td>100' wide</td>
<td>100</td>
<td>A horizon; A1, A2, and B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40' wide where sampled Cu</td>
<td></td>
<td></td>
<td>50' wide</td>
<td>2</td>
<td>horizons also give anomaly but only 8-10 x background; on a second traverse with overburden 20' thick anomaly is very weak</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N. Copperniff zone, Chibougamau (Er-</td>
<td>till</td>
<td>tot Cu</td>
<td>100' wide</td>
<td>10</td>
<td>some smearing down-ice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mengen, 1957) 100' wide where sampled Cu</td>
<td></td>
<td></td>
<td>100' wide</td>
<td>10</td>
<td>seen in profile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campbell, Merrill zone, Chibougamau (Er-</td>
<td>till</td>
<td>tot Cu</td>
<td>400' wide</td>
<td>20</td>
<td>strong seepage anomaly in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mengen, 1957) 60' wide where sampled Cu</td>
<td>shallow</td>
<td>tot Zn</td>
<td>200' wide</td>
<td>15</td>
<td>a swamp 900' downslope</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Sample Type</td>
<td>Element</td>
<td>Width (ft)</td>
<td>Peak (ft)</td>
<td>Notes</td>
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<tr>
<td>Eaton Bay, Chibougamau</td>
<td>Boulder till</td>
<td>tot Cu</td>
<td>300</td>
<td>3</td>
<td></td>
<td></td>
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<tr>
<td>100' wide at traverse</td>
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<tr>
<td>Cu</td>
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<td></td>
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</tr>
<tr>
<td>Keg Lake, Flin Flon area</td>
<td>Sand and clay</td>
<td>tot Cu</td>
<td>nil</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40' wide where sampled</td>
<td>2' deep</td>
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<td></td>
<td></td>
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<tr>
<td>Low Cu, Zn</td>
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<td></td>
</tr>
<tr>
<td>Pitching Lake, Flin Flon</td>
<td>Sand and clay</td>
<td>tot Cu</td>
<td>nil</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>area</td>
<td>2' deep</td>
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<tr>
<td>15' wide where sampled</td>
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<tr>
<td>2.4% Cu</td>
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<tr>
<td>Schist Lake, Flin Flon</td>
<td>Clay-gravel</td>
<td>tot Cu</td>
<td>nil</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>area</td>
<td></td>
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<tr>
<td>50% wide where sampled</td>
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<tr>
<td>3% Cu</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shupe Lake, Flin Flon</td>
<td>Clay and minor</td>
<td>tot Cu</td>
<td>50'</td>
<td>2</td>
<td>anomaly only on outcrop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>area</td>
<td>Outcrop</td>
<td></td>
<td></td>
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<tr>
<td>90' wide where sampled</td>
<td></td>
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<tr>
<td>Low Cu, Ni</td>
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<td></td>
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<tr>
<td>Vein-type mineralization</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Agnico mines, Cobalt area</td>
<td>Glacial till</td>
<td>tot Ag</td>
<td>200</td>
<td>10</td>
<td>minor displacement of about 100' down-ice;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ag (Zn, Pb, Cu, As)</td>
<td>Average 2–8;</td>
<td></td>
<td>100</td>
<td>2</td>
<td>one single anomalous peak; length not determined</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A horizon</td>
<td></td>
<td>100</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Results</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agnico mines</td>
<td>Glacial till</td>
<td>tot Ag</td>
<td>&gt;300</td>
<td>10</td>
<td>anomaly apparently smear down-ice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average 5–20';</td>
<td></td>
<td>&gt;300</td>
<td>5</td>
<td>some distance; several anomaly peaks which are less definitive</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A horizon</td>
<td></td>
<td>&gt;300</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Results</td>
<td></td>
<td>200</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hiho Silver mine, Cobalt</td>
<td>Glacial till</td>
<td>tot Ag</td>
<td>500</td>
<td>4</td>
<td>anomaly diffuse and spread down-ice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
<td>500</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500' wide</td>
<td></td>
<td></td>
<td>500</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name (reference)</td>
<td>Overburden</td>
<td>Extraction and element</td>
<td>Sediments</td>
<td>Soils</td>
<td>Comments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>------------</td>
<td>-----------------------</td>
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<td>----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>max. dispersion length (miles)</td>
<td>strongest contrast</td>
<td>anomaly size (length x width)</td>
<td>strongest contrast</td>
<td>comment</td>
</tr>
<tr>
<td>Langis mine, Cobalt area</td>
<td>varved gla.</td>
<td>tot Ag</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ag, (Zn, Pb, Cu, As), Cu</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>cial clay</td>
<td>tot Zn</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>tot Pb</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>tot Cu</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kekko, Chibougamau area (Ermengen, 1957)</td>
<td>till</td>
<td>tot Cu</td>
<td>150' wide</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12' wide where sampled 3% Cu</td>
<td>2'--10' thick</td>
<td>tot Zn</td>
<td>400' wide</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-grade zinc zone, Chibougamau area (Ermengen, 1957)</td>
<td>till shallow</td>
<td>tot Zn</td>
<td>200' wide</td>
<td>7</td>
<td>B horizon slightly wider in Ao</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narrow Zn, (Cu)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portage Island, Chibougamau area (Ogden, 1954)</td>
<td>cross-bedded sand 4--10' deep</td>
<td>tot Cu</td>
<td>200' wide</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80' wide where sampled 0.3% Cu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lac Albanel Narrow veins</td>
<td>till</td>
<td>tot Cu 0.6</td>
<td>320</td>
<td>20</td>
<td>the outline of the mineralization is poorly</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>tot Pb 0.6</td>
<td>300</td>
<td>25</td>
<td>known making details</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>tot Zn 0.6</td>
<td>2,600</td>
<td>60</td>
<td>as to size, etc., difficult</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>tot U 0.5</td>
<td>24</td>
<td>2.5</td>
<td>to estimate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>tot Ag</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>tot Hg</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
### Disseminated mineralization

<table>
<thead>
<tr>
<th>Setting</th>
<th>Type</th>
<th>tot Mo</th>
<th>tot Cu</th>
<th>Dispersion distance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Lake</td>
<td>glacial</td>
<td>tot Mo</td>
<td>tot Cu</td>
<td>3500' x 1500'</td>
<td>80 some hydromorphic movement of metals; varved clay apparently inhibits soil anomalies but geochemistry may still be effective</td>
</tr>
<tr>
<td></td>
<td>till</td>
<td>flanked by</td>
<td></td>
<td>2000' x 1200'</td>
<td>20 scattered nature of mineralization makes size very hard to calculate; virtually no glacial smearing</td>
</tr>
<tr>
<td></td>
<td>varved clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shawinigan Ni--Cu</td>
<td>mainly thin</td>
<td>tot Ni</td>
<td>tot Cu</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>(Felder, 1974)</td>
<td>glacial till</td>
<td>1</td>
<td>1.3</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Scattered Ni, Cu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Where no reference is given, the example is contained in the text of this volume.
sediments that form massive, pebble-poor, very clay-rich till. The Cochrane till of the Timmins–Noranda area is the most important example of this type on the Shield.

**Transportational history.** Debris are transported roughly in a straight line in the direction of flow. The distance of transport is dependent on whether the material is carried in the basal or the englacial position, resistance to abrasion, glacial bed roughness, etc. For common elements, in average Shield terrain, distance of anomaly detection may be 10 to 20 times the width of the source lying across direction of glacial movement. If ice-flow directions shift significantly during the period of deposition the anomaly may be fan shaped, curved or irregular.

**Depositional environment.** Deposited by plastering on or melting out of sediment carried near the base of the glacier. Ablation till is a variant, generally consisting of coarser debris that is carried on or high in a glacier and is, therefore, not subjected to as much abrasion as the basal load. Ablation till may overlie lodgment till in thicknesses from a boulder pavement to several tens of feet of sandy, bouldery till.

If the till is deposited near the ice front in an end moraine complex, it may be complexly interfingered with stratified sediment. In this environment, till may be deposited primarily by slumping from the ice front into piles or fans as debris is melted out of the ice.

The glacial bed may be ripped up by overriding of thick ice and shear plates of till may be stacked one upon another against obstructions or at locations where conditions are such that shear stacking may occur. This mode of deposition and redeposition may be much more common than formerly thought.

**Weathering.** Depth of oxidation and leaching increase with sandier texture. Sulphides, carbonates, and some ferromagnesian minerals are destroyed in the zone of oxidation. The depth of weathering is variable, depending on surface drainage and presence or absence of permafrost. Weathering is slight or nil under boggy or poorly drained surfaces; significant at 4–20-feet depths under well-drained surfaces; 3–5 feet in areas of permafrost.

Cations by weathering can be scavenged by the fine portion of till (clay minerals, secondary oxides) so that analyses of weathered samples should be aimed at these fine constituents. Comparing samples with widely varying amounts of fine constituents should be done with caution as high element values may merely reflect abundant clay or manganese or iron oxides/hydroxides.

**Postglacial reworking.** Till may be washed where formerly submerged; washing and resulting removal of fines is more significant near major strandlines in postglacial lakes where drainage and lake-level changes were sudden events. In areas of marine submergence, isostatic rebound and resulting shore migration was slow and steady so that surface modification is more evenly spread.

Till may be modified by moving down slopes when wet (colluviated) or by landsliding. In areas of permafrost, the till in the seasonally thawed zone is significantly reworked by mud boiling and/or solifluction. Physical displacements of colluviated tills may be as far as the longest slopes in any given area.

**Sample preparation.** Sample fractionation is important in till geochemistry; the minus 80- and minus 250-mesh, the common sieve fractions used, are adequate for detailed sampling; centrifuged minus 2-mesh (clay) fraction is best for permafrost areas and good but probably unnecessarily expensive for areas south of the permafrost boundary. Bromoform, tetrabromomethane, methylene iodide separates are good for unweathered till but very poor for near-surface sampling (see comments under weathering). Light mineral analyses and magnetic mineral analyses are good in some cases, particularly in exploring for ultrabasic or serpentinitized ultrabasic rocks.

Sand sizes in the 250–60-mesh range should generally be used for heavy, light, or magnetic mineral analyses, but coarser grains, such as 10–60-mesh rock fragments, may be useful in many cases.
Value as geochemical sampling medium. Advantages:
(a) Wide distribution.
(b) Straight-line transport.
(c) Direct derivative of bedrock.
(d) Ease of identification.
(e) Where unweathered, contains primary minerals from orebodies, some of which are readily destroyed in postglacial derivatives of till, such as stream sediments, soils, lake sediments, and marine deposits.
(f) Easily related to known ice-movement directions.
Disadvantages:
(a) Relatively deep weathering (makes meaningful sample processing more expensive and difficult).
(b) Burial beneath late-glacial fluvial, lacustrine, or marine sediments — in some areas.
(c) Readvance till only reflects composition of underlying lake sediments.
(d) Several till units lead to stratigraphic complications, i.e. may be difficult to know which till is being sampled, or to find criteria that allow differentiation among tills.
(e) Earlier tills or other glacial sediments may have covered orebodies so that they were inaccessible to later glaciers.
(f) Difficult to sample at depth because of general stoniness and friability of Shield tills.
(g) Depositional environments of some high arctic Shield tills may have been different because polar glaciers were frozen to their base.

(2) Esker gravel/sand

Distribution, form. Eskers can be found in virtually all parts of the Canadian Shield, which holds the greatest number of eskers known anywhere. In terms of surface area underlain by esker sediments, however, eskers are a minor component (<1%) of the glacial landscape. Eskers may form straight to sinuous ridges from tens of feet to hundreds of miles long or may consist of individual lumps or “beads” of gravel spaced at intervals of several hundred feet.

Provenance. Eskers derive sediment primarily from underlying till or englacial or supra-glacial sediment. To some extent they also derive sediment directly from bedrock but this source is secondary.

Transportational history. Sediment transported along an esker from source becomes abraded and comminuted with distance; a particular component may become apparent in an esker right at its source or may appear only at some distance downstream; most eskers are probably built in short segments so that, by overlapping one upon the other, they give the impression of a continuous ridge; thus the distance of transport can only be as far as the average length of the segments, which may be only a few hundred to a few thousand feet in a typical shield esker.

Depositional environment. Eskers are fluvial sediments deposited by meltwater streams in tunnels or open channels in a glacier. Where a glacier fronted in water, deltas formed at tunnel mouths. Eskers deposited in ice that fronted in lakes or the ocean are interrupted by deltaic bulges. Actively flowing ice formed apparently continuous eskers by maintaining a relatively short tunnel or channel close to the ice front; as the front melted back, the tunnel or channel extended itself “up-ice” by headward erosion or melting of the glacier, much as modern streams chew into their divides by headward erosion. Eskers may have tributaries and distributaries and all the features that modern stream systems have in plan, but they are not analogous to modern streams; they rarely have tributaries higher than third order and derive fresh sediment from the floor and sides of their ice tunnels or channels, not weathered sediment from all over the drainage basin as in a normal stream system.
Weathering. Eskers are usually weathered to significant depths because of the high porosity/permeability of the sediment, except in areas of permafrost where weathering takes place only down to the permafrost table (about 4–6 feet). As with tills, ferromagnesian silicates, sulphides, carbonates, and other unstable minerals are destroyed leaving a residue of Fe–Mn oxides/hydroxides and poorly crystallized clay (phylllosilicate) minerals of fine grain size; this secondary debris filters down through and is trapped in the sandy-gravelly sediment.

Postglacial reworking. If the esker is not submerged, some slumping may take place on the sides until they rest at the angle of repose for sand and/or gravel. Many Shield eskers have been submerged in marine or lake water. The degree of alteration by wave action is dependent on time exposed to nearshore washing and topographic position of esker, i.e. whether it is located in a swale where it is protected, or on a flat or high area where it is exposed. Wave washing removes fines leaving boulder cover. These boulders often act as "armor" which, once formed, protects the esker from further erosion. Winnowing of an esker's upper surface may cause concentrations of minerals of high specific gravity, such as magnetite. Sand washed by waves into hollows adjacent to the esker may be blown back onto the esker (minus a significant proportion of heavy minerals) after the area emerged from lake or sea and before vegetation took hold, resulting in a thick aeolian cover not representative of the esker composition.

Sample preparation. Because minus 250-mesh fraction is mostly secondary material, it is best for analysis, but large samples must be taken to secure adequate "fines". It is not unusual for a 5-pound sample to yield only 500–1,000 mg of minus 250-mesh material. Magnetic mineral analysis is good in some cases, heavy minerals are only good if they are from unweathered sample.

Value as geochemical sampling medium. Advantages:
(a) Distinctive landform; ridge; allows positive identification of sediment type.
(b) Effective sample processing by simple sieving is easy.
(c) Analyzing minus 250-mesh sample that consists largely of weathered debris with high cation-exchange capacity causes anomalous to background contrasts to be large.

Disadvantages:
(a) The distribution of eskers is not dense enough for general reconnaissance.
(b) The source of esker sediment is difficult to pin down. It may be far-travelled sediment from surrounding glacier or bedrock or till eroded from subglacial floor, or complex combinations of these.
(c) Esker samples usually reflect only bedrock or transported debris in immediate proximity to their channels, not an average from their drainage basins.
(d) Eskers that were formerly submerged may be mantled by lake or marine sediment, windblown sediment, or may be severely reworked and flushed of fines by waves, making it difficult or impossible to obtain a sample that accurately reflects the original esker composition.

(3) Ice-contact stratified drift — other than eskers

Distribution. Usually associated with end or lateral moraines or with large areas of disintegration moraine. Areally, distribution of this sediment is spotty and relatively unimportant on the Shield. A pitted or hummocky form is typical.

Provenance. Usually consists of sand and gravel washed from local till or from ice that deposited the local till. Thus, composition is similar to coarser fractions of nearby till, but in interlobate moraines and "kame terraces", fluvial transportation from till or ice source may be long and complex.

Transportational history. Generally the same as for till. Fluvial complications after debris was melted out of glacier noted under "Provenance".

Depositional environment. Generally can be summarized as sand and gravel deposited in the fluvial environment. Where water is largely derived from melting, ice and fluvial
channels are closely associated with or constrained by ice. Sediments are largely derived from the glacier and are deposited in, on, or around ice. When the glacier retreated and the buried ice melted, collapse caused numerous undrained depressions or kettles to be formed, giving these deposits the pitted or hummocky appearance.

Where the glacier was in contact with a lake or ocean, meltwater flowing off the ice or debouching from esker tunnels built deltas. These are also classified as ice-contact stratified drift and are particularly well-developed where esker swarms are prominent below the marine limit on the west side of Hudson Bay, south of Chesterfield Inlet.

Weathering. Same general characteristics as eskers.

Postglacial reworking. Same general characteristics as eskers.

Sample preparation. Same general characteristics as for eskers.

Value as a geochemical sampling medium. Advantages:
(a) Easy sample processing.
(b) Background to anomalous values should have large contrast for minus 250-mesh separates from weathered samples.

Disadvantages:
(a) Irregular and relatively rare occurrence.
(b) Complex depositional environment makes interpretations difficult.
(c) Formerly submerged deposits may be severely reworked, making it difficult to collect adequate samples of the original sediment.
(d) Till and ice-contact stratified drift grade into each other, are complexly inter-stratified, and underlie similar geomorphic forms in former ice-marginal area. Therefore, it is difficult to distinguish samples types on the basis landforms alone.

(4) Outwash gravel and sand

Distribution, form. Rare in the Shield. Cordilleran-type, valley-filling outwash is common in mountainous northeastern portions of the Shield (Baffin Island, northern Labrador). May form broad, flat, sandy-gravelly plains bounded, on the upstream side by ice-marginal features, or may fill valleys that drained a former ice front. Characterized by braided channel patterns resulting from overloading of sediment.

Provenance. Sediment probably largely derived from ice within 1 mile or less of ice front. With distance from the associated ice front, the sediment gains more and more the character of the valley sides and tributaries, i.e. it becomes the deposit of a normal, sub-areal stream system deriving components from all parts of its drainage basin.

Transportational history. Similar to modern streams, except that meltwater discharge and amount of suspended sediment fluctuated diurnally and seasonally, giving rise to minor differences in channel morphology and sedimentary structures. Generally the sediment melted from the glacier at any one time is diluted quickly and regularly in the downstream direction by older glacial deposits, frost-riven debris, or other unconsolidated sediment.

Depositional environment. Fluvial environment differs from modern streams in respect to (1) greater sediment load; (2) sediment close to glaciers is freshly ground rock and not predominantly debris subjected to surface weathering as in modern streams; and (3) diurnal and seasonal fluctuations in meltwater flow and suspended sediment occur. Colder climate probably caused less chemical weathering in the drainage basin, also.

Weathering. Same as for eskers if not site of postglacial drainage. Modern drainage may have been covered with organic-rich flood plain silts and peats, causing reducing conditions in the outwash.

Postglacial reworking. Reworking by "normal" streams that continued to occupy outwash valleys may remove or partially remove outwash or erode and redeposit outwash until sediments from the two environments are indistinguishable.

Sample preparation. Same as for eskers for weathered outwash. Heavy minerals for unweathered outwash.
Value as a geochemical sampling medium. Advantages:
(a) Ease of sampling.
(b) Ease of sample preparation.
(c) Interpretations of data may be similar to stream sediment surveys.
(d) Occurrence in areas of sparse glacial sediments, i.e. northern Labrador, parts of Baffin Island.

Disadvantages:
(a) Mixture of glacial and non-glacial sediments.
(b) Sparse distribution.
(c) Difficulty in differentiating from modern stream sediments.
(d) Quick downstream dilution of glacial sediments.

(5) Marine and lake nearshore sediments; beaches, bars, spits, etc.

Distribution form. In the vicinity of ancient shore lines. Marine beaches may occur at virtually all altitudes below the marine limit. Lake beaches tend to be concentrated within certain altitude ranges related to lake outlets. Nearshore sediments form low ridges parallel or at right angles to the former shorelines. They are often associated with small modern lakes, originally dammed by ancient bay-mouth bars or formed in the back-beach environment.

Provenance. Generally formed of material washed from underlying glacial sediment. Best developed where glacial sediment was sandy or gravelly but may be found on any type of sediment.

Transportational history. Transportation is variable depending on strength of longshore or offshore currents and size of sediment. Longshore drift of more than 1 mile can be demonstrated for sand-granule component of some raised marine beaches near Hudson Bay.

Depositional environment. Deposited by erosion and redeposition of sediment in the high-energy nearshore zone. Agents redistributing sediment in glacial and postglacial lake and marine shores are (1) longshore/offshore currents, (2) normal and storm waves, (3) pack-ice shove, and (4) wind. Ice shove during break-up is particularly effective in redistributing nearshore sediment.

Weathering. Same in general as for eskers. Abrasion in the nearshore zone probably selectively removes many of the easily weatherable minerals during formation of the nearshore feature, however.

Postglacial reworking. Generally minimal except in areas of permafrost where thin nearshore gravels may founder in mud where they overlie silty till, marine, or lacustrine sediments. Postglacial, downslope transport of foundered nearshore gravels can be several hundred feet or more.

Sample preparation. Same as for esker.

Value as a geochemical sampling medium. Beaches have not been systematically sampled to any extent in the Shield and their value is largely unknown, but a few generalizations can be made.

Advantages:
(a) Easy to recognize by landform.
(b) Easy to sample.
(c) Easy sample preparation.
(d) Representative of underlying glacial sediment.
(e) High contrast between background and anomalous values.

Disadvantages:
(a) Limited distribution; only in areas formerly submerged and often rare in those areas.
(b) Selective removal of economically interesting minerals by severe abrasion during formation.
(c) Uncertain transport history.
(d) Selective concentration of minerals of high specific gravity (i.e. magnetite) by wave action.
(e) Difficulty of differentiating among origins of complex, similar-appearing, near-shore facies assemblages, such as wind-blown, back-bench, storm beach, ice-shoved ridge, offshore features such as bars, shelves, etc., and relict subaqueous permafrost features.

(6) Marine and lake silty/clay bottom sediments

Distribution, form. Distribution spotty and unpredictable in areas of former submergence; may form thick blankets over considerable areas of the Shield, however, as in the Timmins—Noranda area. Where the sediments are thick, they form a plain, as in the “clay belt” of western Quebec and Ontario.

Provenance. Derived from suspended sediment in meltwater entering the lake or marine basin from glacier, non-glacial streams, or from shore erosion around sides. Icebergs and pack ice also carry debris of all sizes around the basin and on melting drop the debris more or less at random into the generally fine-grained bottom sediments.

Transportational history. Fine sediment may be transported hundreds of miles from its source, as may ice-rafted sediment. In varved sequences, individual varves are generally thickest near the former ice front, thinning radially outward.

Depositional environment. Deposited in relatively quiet water at depths greater than wave base. Fine sediment in marine water tends to flocculate and form a massive silty clay. Silty clay in fresh-water lakes tends to be laminated or “varved”, particularly where much sediment comes from glacial meltwater. Sediment deposition is rapid and sediment is silty in summer when meltwater flows rapidly, but meltwater stops flowing in winter and sediment supply is cut off leaving finest suspended sediment to settle out forming a thin, clayey “winter” layer or varve.

Weathering. Well-crystallized, fine-grained phyllosilicates and ferromagnesian minerals are altered to poorly crystallized clays. If sulphides are present they are oxidized. Oxidation-leaching is generally slower because of low permeability and poorly drained surfaces.

Postglacial reworking. During and after deposition, sediments are subject to density foundering and turbidity flows. Where the waterbody shrinks by slow offlap, as in isostatic rebound of marine areas, beaches may be formed on offshore sediment or sediment may be partially or wholly washed away.

Sample preparation. Sieving to minus 250-mesh or separation of clay by centrifuging.

Value as a geochemical sampling medium. Advantages:
(a) Where thin, clays may scavenge cations from groundwater to form a hydro-morphic anomaly.
Disadvantages:
(a) Long distances of transport from source.
(b) Unrelated to local materials.
(c) Covers other glacial deposits, masking them and bedrock with impermeable sediment.
CONCEPTUAL MODELS IN EXPLORATION GEOCHEMISTRY
The Canadian Cordillera and Canadian Shield

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(Received and accepted July 2, 1974)

ABSTRACT


This volume summarizes the exploration geochemical conditions in the secondary environment, in the Canadian Cordillera and the Canadian Shield. This is achieved by a number of conceptual models which describe the principles and mechanisms of formation of anomalies, which govern the use of exploration geochemistry. These models have been constructed by drawing together information already existing in the literature plus 38 individual case histories contained in this volume.

The formation of anomalies is described for: (1) residual overburden, (2) overburden of local origin (e.g. till), and (3) transported overburden of remote origin (e.g. stratified glacial drift and alluvium). Within each of these categories the effect of element mobility, seepage zones, bogs, variation in overburden thickness, rock type change and soil type change are also described.

An attempt has been made, not only to summarize both these conditions where geochemistry can be used as a reliable exploration tool, but also to identify areas where the use of geochemistry is unreliable.

A summary is also given of the length of anomalous dispersion and contrast in both soil and sediments for all the case histories quoted, both in this volume and in the literature. This summary is divided according to the type of deposit, i.e. porphyry copper, massive sulphide, etc., and provides a guide for planning the optimum sampling interval.