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CONCEPTUAL MODELS IN EXPLORATION GEOCHEMISTRY
The Canadian Cordillera and Canadian Shield

P.M.D. BRADSHAW (Compiler and Editor)

FOREWORD

This volume originated from a desire to see a number of excellent case histories appear in print as these are important in guiding exploration. At the same time, it was recognized that there already exists a large and often bewildering volume of exploration geochemical data, and it was necessary to present any new data, and if possible also combine old data, into a form readily useable by exploration geologists.

The contents of this volume represent the culmination of an effort to combine these two apparently opposed objectives. Firstly, the initial approach to this volume was generated by discussions between D.R. Clews, J.L. Walker, I. Thomson and myself. These discussions, together with suggestions by John Fortescue, particularly as regards the adoption of the landscape format, helped consolidate the final outline as seen. Finally, as indicated by the authorship of the different sections, a considerable number of individuals gave their data, time and ideas, allowing me to compile this volume.

The Shield and Cordillera sections together contain 38 case histories in different stages of completeness. The objective of this volume is to present these data in a concise form and to assimilate them together with the already published data into a relatively low number of idealized models or landscapes, which it is hoped, are easier to understand and assimilate into exploration programmes than the raw data on their own.

It is hoped that the style of presentation and format used here will find acceptance within the industry, and that compilation from other areas will follow.

P.M.D. BRADSHAW

March 1973

ACKNOWLEDGEMENTS

The amount of work involved in compiling a volume such as this is quite considerable and the authors are very much indebted to a number of individuals who helped considerably in this respect.

Rod Marcroft of Barringer Research designed the layout for all the idealized models and drafted them. His invaluable help and suggestions in this regard are very much appreciated. The majority of the case history diagrams were drafted by Emma Carrillo of Newmont Mining, Barbara Procher of Amax Exploration and Ray Agnew of Brock University. Their help, particularly in undertaking this work in the limited time available, is gratefully acknowledged.

The final typing of the manuscript was undertaken by the Ontario Department of Mines and British Columbia Department of Mines. Much of the typing of the first draft, and also the final corrections were done by Barringer Research, in particular Pat Marshall of that company. To all these people we are very much indebted.

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CONCEPTUAL MODELS IN EXPLORATION GEOCHEMISTRY
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ABSTRACT

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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.

Prologue

THE USE OF LANDSCAPE GEOCHEMISTRY TO PROCESS EXPLORATION GEOCHEMICAL DATA

JOHN A.C. FORTESCUE

> "The wise learn from the experience of others, the fool only from his own."
>
> An Old Adage

INTRODUCTION

The landscape geochemistry approach was chosen as a basis for the organization of this paper largely because it provides a rigorous, logical foundation for the systematic comparison of information obtained from exploration geochemistry. Although landscape geochemistry has been offered as a subject in Russian universities for over twenty years, it is only very recently that it has been considered seriously in North America. Some idea of relationships between landscape studies involving specific disciplines, important aspects of applied geochemistry, and general landscape geochemistry may be obtained from Fig.1 where it is seen that landscape geochemistry is that subject which includes exploration geochemistry as a special case.

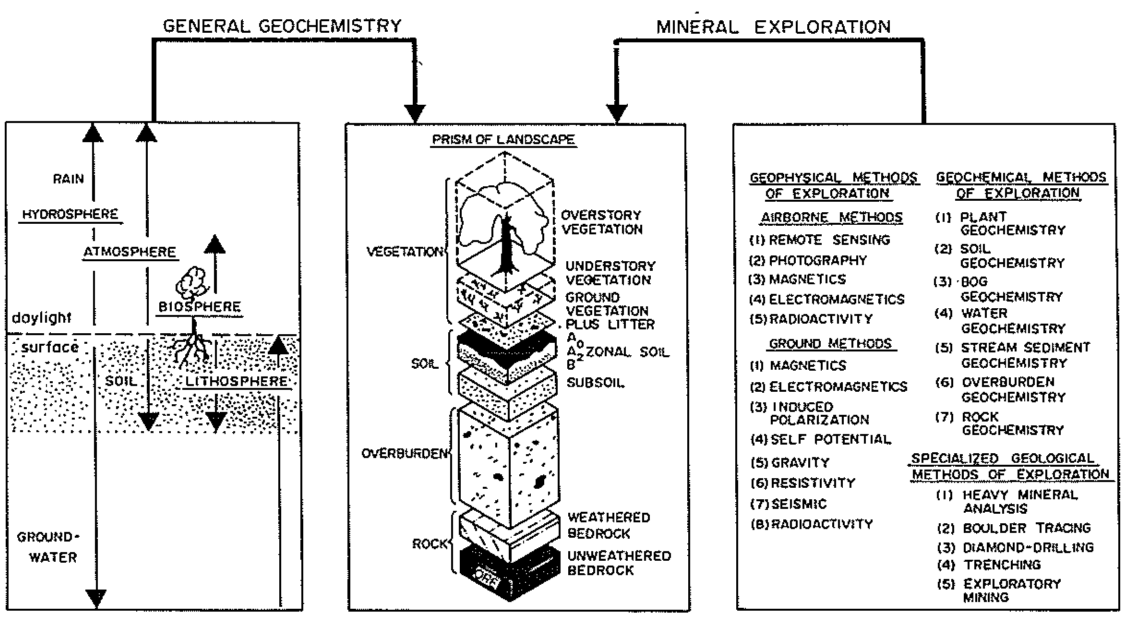


Fig.1. Relationships between general geochemistry, landscape and mineral exploration.

Exploration geochemists in North America and elsewhere currently face a difficult problem; on the one hand there is a large amount of case history data (both published and unpublished) which cannot be readily synthesized and analyzed and on the other hand, exploration geochemists and students need to obtain comparative information from case history data in order to plan research activities. Some attempts to solve this problem on the basis of descriptive statistics have not so far met with much success, largely because the mathematical manipulations which are used as a basis of syntheses are not readily understood by geologists and geochemists who do not have special training. The purpose of this volume is to draw the attention of exploration geochemists to ways in which the fundamental principles of landscape geochemistry can be applied to the solution of this problem, and the purpose of this prologue is to outline very briefly how this will be attempted.

LANDSCAPE GEOCHEMISTRY

The periodic table may be regarded as a conceptual model which is used to focus attention on relationships between the chemical elements. As exploration geochemists have discovered, it is not such a simple matter to describe complex relationships between chemical elements and the environment by such a simple model as that of the periodic table. When one considers the complexity of environmental descriptive systems devised to describe landscapes by foresters, ecologists, and others (e.g. Hills, 1960; Sukachev and Dylis, 1964; Krajina, 1972; and in the case of plant-cover types, Shimwell, 1971), it becomes clear

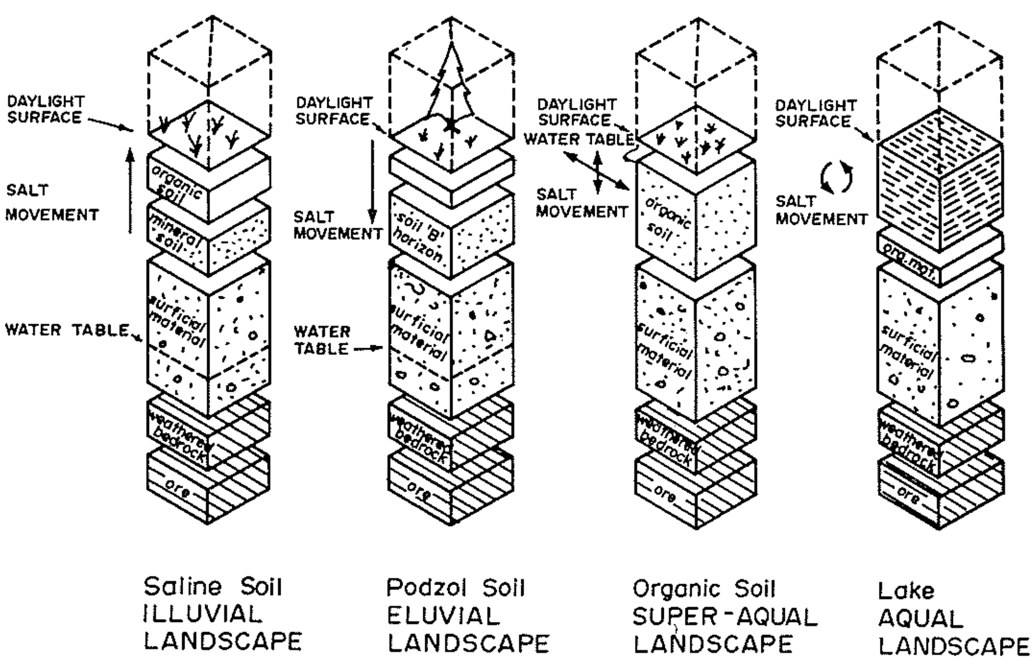


Fig. 2. Prisms of landscape drawn to represent four elementary landscape types (after Polynov, 1937).

that none of these are suitable for the needs of the exploration geochemist. It is here that the relative simplicity of the landscape geochemistry approach, as pioneered by B.B. Polynov (1937), becomes evident. Polynov grasped the idea that during geological time under a given set of climatic constraints, the chemical interactions between the lithosphere, hydrosphere, atmosphere, and biosphere are largely controlled by relationships between the daylight surface and the water table (or hydrosphere). Accordingly, he described four elementary landscape types which represent each of the four ideal types of landscape from which more common types may be derived. These four types are illustrated in Fig.2 by means of idealized conceptual models of "landscape prisms". Briefly, an illuvial landscape is found where the water table is below the daylight surface and evaporation exceeds precipitation; an eluvial landscape is found where the water table is below the daylight surface and the precipitation exceeds the evaporation; a super-aqual landscape occurs in a marsh (or bog) where the daylight surface and the water table coincide; and the aqual landscape is found in areas of river or lake where there is a layer of water permanently above the surface of solid matter. Further information on landscape types can be obtained from Glazovskaya (1963) and information on the flow patterns through landscapes may be obtained from Kozlovskiy (1972).

RELATIONSHIPS BETWEEN LANDSCAPE GEOCHEMISTRY AND EXPLORATION GEOCHEMISTRY

Some general relationships between landscape and exploration geochemistry are indicated in Fig.3 where it is seen that the concepts of landscape and geochemistry on the one hand and the exploration methods on the other hand

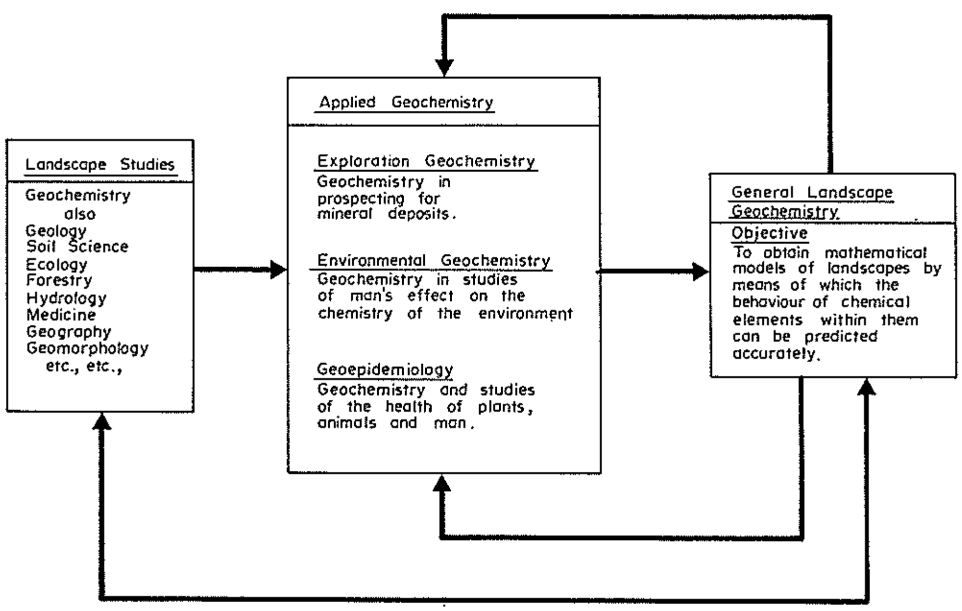
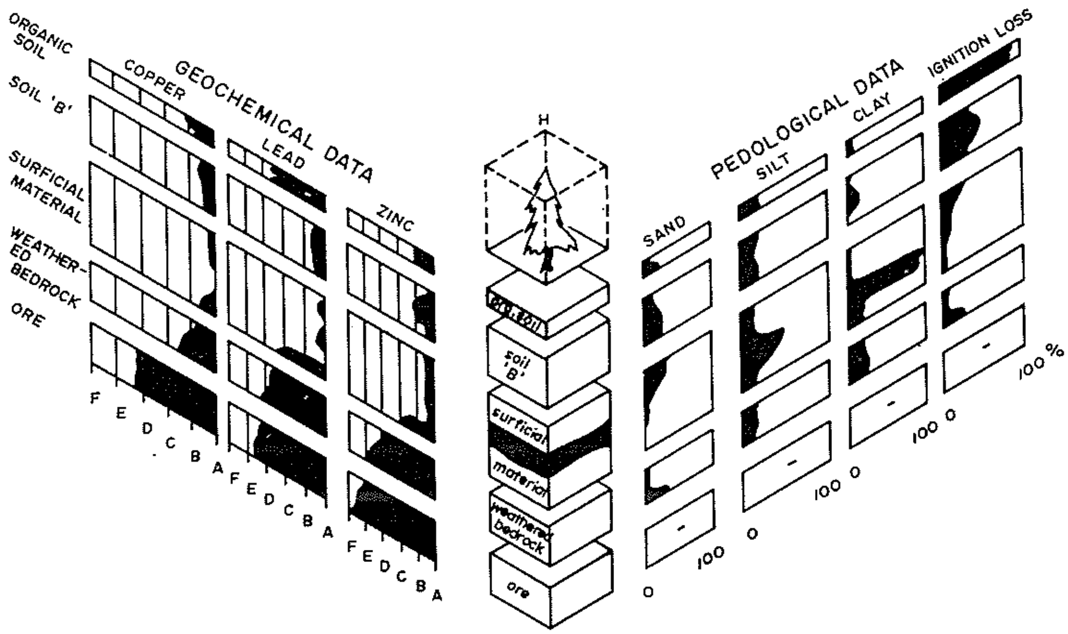


Fig.3. Flow diagram showing relationships between fundamental and applied aspects of landscape geochemistry.



A = 1 PPM
B = 10 PPM
C = 100 PPM
D = 1000 PPM
E = 10000 PPM
F = 100000 PPM
TOTAL METAL IN THE -80. MESH
FRACTION OF THE MATERIAL

Fig.4. Block diagram of a prism of landscape showing a display of data on the geochemical and other properties of the surficial materials.

are combined with reference to the conceptual model of the prism of landscape. The great advantage of using the landscape geochemistry approach as described by means of three-dimensional diagrams, such as those shown in Fig.2, is that they may be used to combine information of several kinds which otherwise would be displayed independently. For example, in Fig.4 the distribution of copper, lead, and zinc, and both physical and chemical properties of the same landscape prism are displayed on a diagram of a generalized conceptual model which can be readily compared with similar diagrams. The information in Fig.4 indicates that the failure of the soil geochemical prospecting technique at that point was due to a layer of clay in the surficial material.

When one considers the application of the landscape geochemistry approach to case history data obtained from exploration geochemistry, it is both useful and convenient to distinguish between three kinds of diagrams (Fortescue and Bradshaw, 1973). A diagram of a landscape prism, landscape section, or block diagram drawn to scale on the basis of field observations is referred to as field level information. A similar diagram showing the same information which has been generalized somewhat in order to clarify the display of information which may not be drawn exactly to scale is called a tactical level set of information. No tactical level diagrams were needed in this paper where case history information is always presented as raw data. A diagram on which information from a number of sets of field data is generalized is called a strategic level diagram. The purpose of diagrams of this kind is to emphasize the mechanisms of migration and factors controlling the use of geochemistry which are common to a particular kind of landscape. In making generalizations of this kind, it is understood that much of the detail included in field case history data is omitted because it is of local rather than general significance. From the viewpoint of the exploration geochemist looking at data systematized according to these principles, strategic level diagrams provide an invaluable introduction to more detailed information included at the tactical or even the field levels of intensity.

Section A

INTRODUCTION

GENERAL

The object of this volume is to develop idealized models for the systematic description of exploration geochemical data obtained from the Canadian Cordillera and Canadian Shield, which adequately describe in easily understood form the principles and mechanisms of formation of anomalies which govern the use of exploration geochemistry.

Exploration geologists find considerable difficulty in absorbing the large volume of data on exploration geochemistry which exists for the Canadian Cordillera and Canadian Shield. It is difficult to draw together the large number of complete and partial case histories which exist in the literature and to obtain valid conclusions and generalizations from these data. Although individual case histories are vital to understanding the mechanisms controlling geochemical dispersion, they are in fact, "a laborious approach to understanding. For situations are so varied that even a number of case histories might be a misleading example, whilst each is so complex that even a detailed description may be too summary: and none is comprehensible outside the historical sequence in which it grew" (Vickers, 1965, p.173). However, sufficient data are now available to allow general conclusions to be drawn concerning the mechanisms of geochemical migration and also generalizations as to the size and shape of the anomaly which can be anticipated. In this paper, from a synthesis of existing data, a series of conclusions are postulated from which it is hoped the observable behaviour of elements during geochemical exploration may be predicted accurately. These conclusions provide an overall understanding of the mechanisms of geochemical migration and a framework into which further data can be fitted. It must be emphasized however, that the conclusions presented here are valid only up to the time of writing; as new data become available modified conclusions may well be required. This is the normal process of scientific deduction.

An important aspect of this summary is that conclusions are given as to the areas where geochemistry can be successfully applied as well as about those where it is known that present techniques are not applicable. Discussion in this volume is confined to the use of soils and sediments in exploration geochemistry. Bedrock data is excluded because the principles of primary dispersion apply universally and are not restricted to a particular physiographic boundary. Consequently, they should be discussed on a world-wide basis. Biogeochemistry and geobotany could logically be included. However, it was considered more desirable to restrict this already large volume to those media most commonly used by exploration geologists.

LANDSCAPE GEOCHEMISTRY

The conclusions as stated here are presented within the framework of landscape geochemistry. That is, it involves consideration of an entire volume unit located to include the earth daylight surface and extending downward to fresh bedrock. No single medium is considered in isolation. In this volume, consideration is given to the interaction of the lithosphere with the hydrosphere, biosphere, and atmosphere during geological time, under a given set of microclimatic constraints. In this manner, the *total* environment together with consideration of *all* elements within this environment are treated together. In practice, the present volume deals only with trace elements, but within this more general framework, other parameters such as major elements and physical perimeters, etc., can be fitted in.

The framework of landscape geochemistry is also being adopted by other disciplines such as forestry, and consequently will allow a better and more direct comparison of data and principles between disciplines than is the case at the present time.

Landscape geochemistry originated in Russia, largely as the result of pioneer researches carried out by B.B. Polynov prior to the Second World War (Polynov, 1937). Work in this area has been continued in a number of disciplines including geochemistry (Perel'man, 1961; Fortescue, 1967a). As a result of working within this framework, it is possible to establish basic principles for the circulation of geochemical elements in landscapes which may be directly applied to a synthesis and analysis of the vast amount of empirical exploration data which has accumulated in recent years.

IDEALIZED MODELS

Those general conclusions concerning exploration geochemistry (both positive and negative) which can be made are expressed in the form of idealized models. These models are presented in three dimensions in order to show the whole volume unit.

One important aspect of these models is that they have no scale. That is, they indicate the mechanisms of formation of geochemical anomalies only, and not the magnitude and size. This is because the mechanism is fundamental to a variety of conditions and areas (e.g. the mechanism of hydromorphic dispersion operates virtually universally). On the other hand, the magnitude and size of geochemical anomalies is affected by many local variations and cannot be summarized in the same way. A table summarizing field data on the size and magnitude of the observed anomalies over different properties is included at the end of each section as a guide to the strength of anomalies which can be anticipated. Each idealized model is shown only with reference to, and if supported by, a number of actual field examples, or case histories. These case histories form an integral part of this volume. It is considered fundamental that no idealized model, or no aspect of any idealized model, should be drawn without support of field examples. As a consequence of this there are still a number of gaps and omissions in the idealized models presented because case history proof is lacking.

It is not possible to express both the broad and detailed conditions on one idealized diagram in a satisfactory manner. Consequently, throughout this volume three types of three-dimensional idealized diagrams are used:

(1) *Idealized models* which show the total surface area affected by the geochemical anomaly.

(2) *Idealized cross sections* which display the geochemical characteristics along a continuous section.

(3) *Idealized prisms* which show details of geochemical changes up and down a particular profile.

In certain cases the cross section and prism diagrams are "exploded" to show more detail.

STANDARDIZATION OF FIELD DATA

Before field data can be truly compared the same data must be collected (i.e. same elements, mesh analytical size, extraction, etc.) and presented in a common format as to scale, etc. In the present instance none of the data used was originally plotted to any standard format. An attempt has been made here to redraft some of the data to a more common format to facilitate intercomparison as far as possible. However, there are still many shortcomings in this regard. At the back of this volume, in Section D, a summary is given of a suggested standard format for the collection and presentation of future data.

APPLICATION

The primary intention of this volume is to provide a synthesis of the large and complex volume of exploration geochemical data by means of a series of idealized models from which the principles and applications of geochemistry can be better understood, and hence applied by exploration geologists. In addition to this primary aim, there are a number of others:

(1) To help formulate the thoughts of those expert in the field by pointing out areas where knowledge is still lacking. In this way, research efforts can be focused on areas where more information is required and hopefully expand the use of exploration geochemistry into these fields.

(2) To assist communication with different disciplines so that geochemistry can benefit from the vast amount of information that exists in such fields as pedology, glaciology, and forestry, and vice versa.

(3) The empirical approach of establishing models has been used. This is largely because historically this is the way geochemistry has developed. However, it is hoped that more fundamental research will be conducted into the exact mechanisms of formation of geochemical anomalies, and that this will lead to a more fundamental understanding.

(4) The groundwork has been laid and the parameters established for other workshops. It is hoped that workshops synthesizing the data in other geographic areas will follow.

GENERAL PRINCIPLES OF GEOCHEMICAL MIGRATION

Before studying individual situations, it is important to have an overall appreciation of the mechanisms of migration of elements from bedrock into soils and stream sediments. This has been outlined in a number of publications of which the textbooks by Hawkes and Webb (1962) and Levinson (1974) are the most comprehensive. Therefore, only a brief review of the mechanisms is given here.

In a residual soil, geochemical anomalies are characteristically formed directly over mineralization (although later modification by downslope creep may occur) during normal processes of soil formation. That is, as the bedrock weathers and the soil forms from the weathering bedrock, the metal from mineralization, like the other components, is incorporated in the soil horizons. This anomaly is consequently derived "in situ" by normal weathering processes involving both mechanical and chemical modification. Such anomalies are characterized by relatively strong metal-bonding as contrasted with hydromorphic anomalies. In a residual environment, the anomaly may be further modified by downslope creep. This is a purely mechanical function and does not chemically alter the metal bonding. Originally the size of the anomaly may be roughly the dimensions of the mineralization with lateral spreading due to natural causes such as slumping and spreading during the normal process of rock weathering and soil compaction, acting on the anomaly until it may be several-fold larger than the bedrock expression. In addition to metal movement during this soil-forming process, some metal is taken into solution by the groundwater. The rate at which metal is taken into solution is dependent on many factors such as the chemical species present and their activities, stability of solid phases, etc., but probably most dependent on the Eh and pH of the groundwater. The pH of groundwater is markedly influenced by the rocks through which it passes. Carbonate rocks have the greatest effect, neutralizing acidic waters and giving them an alkaline pH. Igneous rocks have only a limited effect on pH. In the latter case, the groundwater frequently has a neutral to mildly acid pH, encouraging hydromorphic movement of most metals. In the former case, many elements are considerably less mobile. Close to sulphide deposits, no matter what the wall rock, metal is generally contributed to the groundwater at a relatively high rate, due to the production of acidic constituents as a consequence of the weathering sulphides. Metal incorporated in the groundwater remains in solution until a change in the chemical environment occurs. Such a change is encountered when the groundwater enters the relatively oxidizing and generally less acid conditions of the surface environment, either as seepage areas at the break of a slope or in streams or lakes. Here, the metal is adsorbed and/or absorbed by clay minerals, organic matter, hydrous oxides, or precipitated as the salts of the metals give rise to hydromorphic anomalies. When moved in solution and fixed in this manner, the metals are commonly loosely bonded. Metals which can readily move hydromorphically are termed mobile. These generally include copper, zinc, nickel, cobalt, fluorine, and molybdenum; while rather less mobile elements are lead, silver, tungsten, and others. Certain elements such as gold and tin are virtually insoluble in near-surface groundwaters and surface waters and are termed immobile. That is, while they are moved by the normal mechanical processes, they are not moved to any appreciable degree hydromorphically under the conditions generally encountered. Complications due to glacial action, soil development, bogs, permafrost, etc., are additive to the processes described. Their effect is described in the appropriate sections.

Section B

THE CANADIAN CORDILLERA

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INTRODUCTION

The Canadian Cordillera is presented first for three reasons. Firstly, from a geochemical point of view it is simpler than the Shield environment. Many of the principles which apply in the Cordillera also apply in the Shield, but with added complications. The reverse is not true. Secondly, because the Cordillera is the simpler environment to work with, it can be described more easily and in greater detail. Thirdly, there is more exploration geochemical data available in the public domain for the Cordillera.

Within the Canadian Cordillera, there are a number of different environmental areas of significantly different geochemical characteristics. These result from different glacial histories and different physiography which have in turn profoundly affected the climate. These combined have greatly influenced geochemical behaviour of the elements. This section outlines the broad differences which can be expected under widely different conditions within the Cordillera. However, prior to a discussion of the geochemistry, the broad characteristics of mineral zoning, Pleistocene geology, physiography, and soils are outlined. These provide the groundwork for the geochemical data.

Mineral zoning and distribution of mineralization

The zonal distribution of mineral deposits in the Canadian Cordillera is now well documented (Sutherland-Brown, 1969; Sutherland-Brown et al., 1971). The zoning is related to the tectonic belts, i.e. belts of similar geology that can generally be related to the physiographic systems as shown in Table I. A sequential change occurs west to east in metals, in mineral deposits, and in the genetic and morphological types of deposits. Metals of first importance in one belt are commonly of lesser importance in adjacent belts, so there is a pattern rising through the orders of importance to a peak, possibly of first importance,

TABLE I

Distribution of metals in mineral deposits

Physiographic systems:	Western		Interior		Eastern
Tectonic belts	Insular	Coast	Intermontane	Omineca	Eastern Marginal
1st	Fe	Fe, Cu	Cu, Mo	Pb, Zn, Ag	Pb, Zn
2nd	Cu	Zn, Mo	Ag	W, Cu	Ag
3rd	Mo	Ni	Hg	Mo, Sn, U	Th, Cu

TABLE II

Background in silts (ppm) by tectonic belt

	Insular	Coast	Intermontane	Omineca	Rocky Mtn.
Cu	62.5	45	38.2	26.3	25
Zn	80	70.3	80.2	59	59
Mo	2.5	2.1	2.6	1	1
Pb	6.5	4	2.5	22	18

and then descending. This also has an effect on the geochemistry and in a recent paper, Sutherland-Brown (1974) has shown a virtually identical zoning occurs in regard to background levels of metals in silts and soils. For example, Table II illustrates this zoning for silts in the various tectonic belts.

Pleistocene geology

The present surficial cover of Canadian Cordillera is very largely formed of transported materials as a result of widespread Pleistocene glaciation. This transported cover has had a profound effect on geochemical patterns and hence knowledge of Pleistocene geology is vital to geochemists.

A world-wide cooling of climates occurred in the Late Cenozoic which culminated in the Pleistocene period with multiple glaciations that occurred over broad areas of the continents down to middle latitudes. Most of British Columbia and more than half of the Yukon were repeatedly covered with glacial ice. Evidence of the earlier glaciations are largely destroyed by the latest, except in some fringe areas of the Yukon. There is, however, a large area in the Yukon which escaped glaciation due to the aridity of the arctic climate in the lee of St. Elias Mountains. In addition, isolated peaks projected through the ice sheets through the mountain belts. The last glaciation, called the Fraser in the Cordillera, terminated only about 10,000 years ago. Soil development since then has been rudimentary in much of the terrain.

The Fraser glaciation can be summarized as follows: With the onset of renewed cooling, ice caps were generated on the mountains, particularly the Coast Mountains, and spread outward to fill the interior plateau. The ice mass impinged upon the Rocky Mountains, thickened, and flowed to the south into the United States, and northward into the Yukon. It also extruded through passes in the Rockies to meet the Keewatin ice sheet just east of the foothills and through the Coast Mountains to dissipate at ice shelves on the Pacific Ocean. In so doing, the glaciers carved the valleys to form fiords and finger lakes, sculptured the mountains, and deposited a sea of debris in the lowlands as till, glaciofluvial deposits, and silts deposited in short-lived proglacial lakes.

The gross features of the Fraser glaciation are shown in Fig.5, including

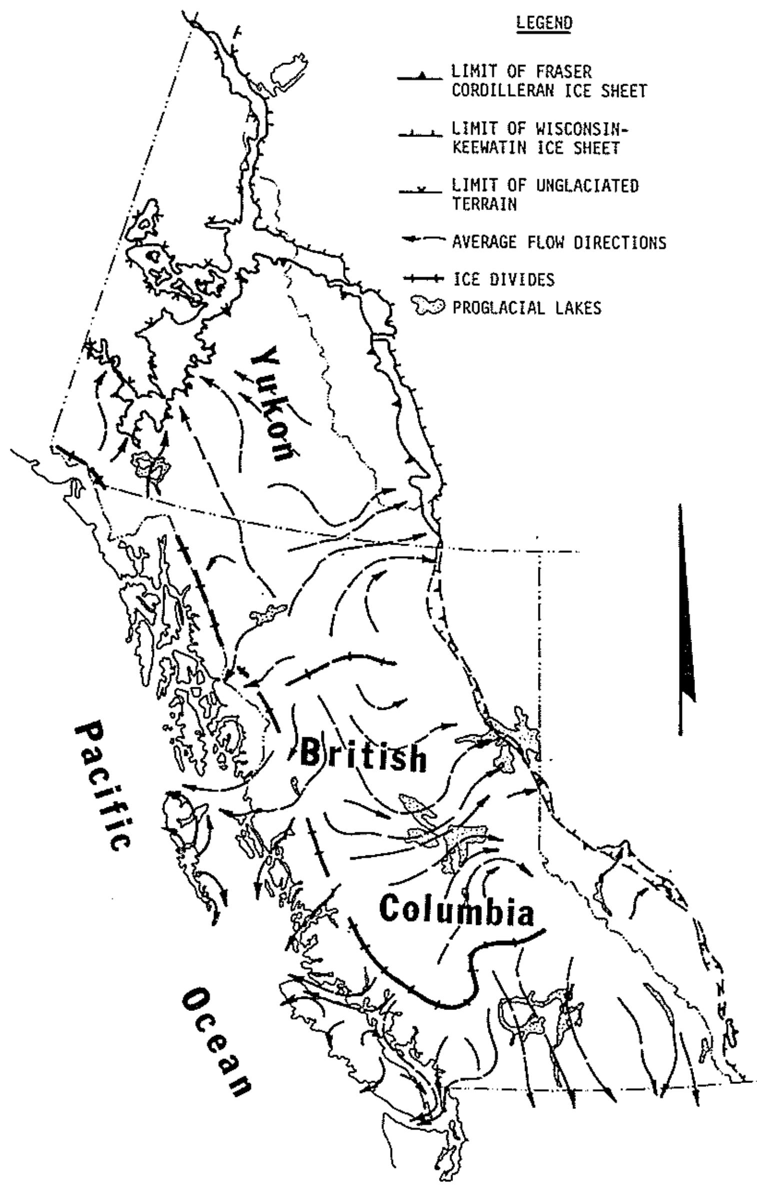

Fig.5. Limits of glaciation and average glacier flow directions in the Canadian Cordillera.

major ice divides, flow directions, proglacial lakes, areas not glaciated in Fraser or earlier glaciations, and the zone of contact of Keewatin and Cordillera in ice. A good summary of the glacial geology of the Cordillera by V.K. Prest may be found in *Geology and Economic Minerals of Canada* (Douglas, 1970).

Study of rock trains of distinctive petrology and geochemistry in till down-ice from ore deposits has led to the realization that, in general, the average length of transport of clasts from their source is not large. This is particularly true for the finer till fragments, even in areas where larger boulders have been ice-rafted up to several miles. From an exploration point of view, this till, particularly on the higher slopes, can frequently be regarded as essentially residual, with displacements a maximum of several hundred feet, but frequently only tens of feet. However, in other cases, particularly in lower slopes, the degree of glacial movement of till is much higher and this is further modified by post-glacial downhill creep. Further downslope still, the broad U-shaped valleys are filled with glaciofluvial and glaciolacustrine deposits of foreign provenance. From a geochemical point of view, these areas are not suitable for conventional soil sampling. When conducting geochemical exploration, it is most important to recognize the type of overburden which prevails in any particular area.

Physiography and climate

The dominant elements of geochemical environment at the present time are physiography and climate. These determine the type and rate of weathering, soil types, and drainage conditions, factors which profoundly affect the geochemical behaviour of metals.

The Canadian Cordillera is a northwesterly trending linear belt of mountains and plateaux extending from the 49th Parallel for over 1,500 miles to the Arctic Coastal Plain. Throughout its length, the Cordillera is characterized by flanking alpine mountain systems to both east and west that enclose a complex interior system composed of plateaux and intercalated mountains and highlands. In their gross aspects, the systems are parallel and linear in British Columbia, but to the north the eastern system forms a great arcuate salient convex eastward that encloses an equivalent enlargement of interior plateaux and mountains (Bostock, 1948, 1970; Chapman, 1952; Holland, 1964).

There is a high degree of correspondence between bedrock geology and structure, and physiographic expression and nomenclature throughout the Cordillera (Fig.6). The western system is dominated by the alpine Coast Mountains and also includes the St. Elias, Insular, and Cascade Mountains, and the Coastal Trough.

The interior system is the most heterogeneous system for, although it is characterized by intermontane plateaux, it also has extensive mountains, highlands, and great lineal trenches. In general, mountains tend to fringe the eastern side of the interior system, but the Columbia Mountains and Highlands extend completely across the system to limit the interior plateau to the south.

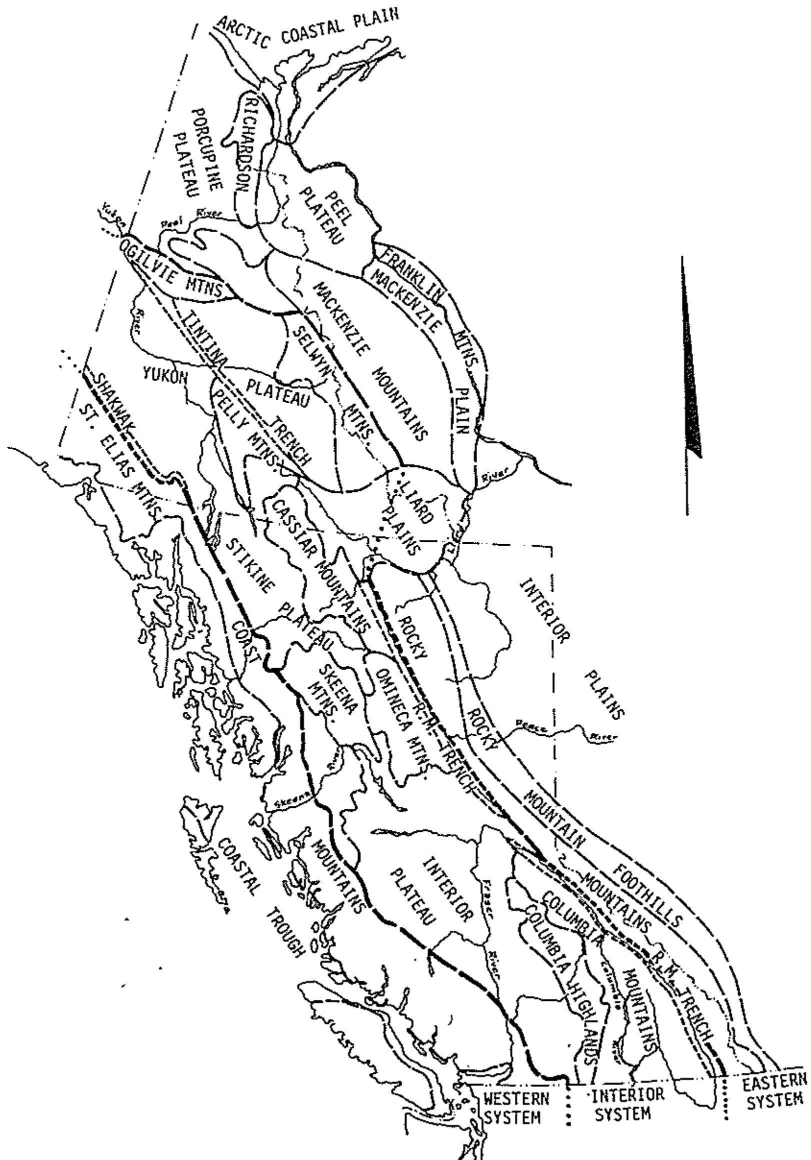

Fig.6. Physiographic elements in the Canadian Cordillera (after Bostock, 1948; and Holland, 1964).

The Omineca and Skeena Mountains terminate this plateau in north-central British Columbia. Beyond this barrier to the north, the Stikine and Yukon Plateaux extend into Alaska and are bordered or interrupted by the Cassiar, Pelly, Selwyn, and Ogilvie Mountains. The great linear valleys called trenches border the system in the northwest (Shakwak Trench), and on the east in British Columbia (Rocky Mountain Trench), but the latter's projection in the Yukon (Tintina Trench) transects the eastern salient of Yukon Plateau, etc.

The eastern system is homogeneous in British Columbia and Alberta consisting solely of the Rocky Mountains and Foothills. However, in the Yukon and Mackenzie Territory, it is more diverse, consisting principally of the Mackenzie Mountains that are analogous to the Rockies, but including several lesser mountain areas as well as plateaux and plains. A full discourse on the physiography can be found in *Landforms of British Columbia* (Holland, 1964) and by H.A. Bostock in *Geology and Economic Minerals of Canada* (Douglas, 1970).

The climate of the Cordillera is greatly influenced by the physiography as well as latitude and proximity to oceans. Rainfall varies widely and is greatly influenced by topography; it attains a maximum (100—200 inches per annum) over the coastal mountains and a minimum (below 20 inches per annum) over the semi-arid southern interior plateau. Much of the interior plateau experiences moderate rainfall (25—35 inches per annum) whilst this is slightly higher (40—50 inches per annum) over the interior mountains. Average temperatures are more sensitive to elevation change than latitude. Hence, in the Cordillera, tundra extends from the Arctic Coastal Plain at sea level to the 49th Parallel at elevations above approximately 6,000 feet. Continuous permafrost occurs only in the extreme north of the Yukon. Much of the Yukon Territory is covered by the zone of discontinuous permafrost whilst a few patches of sporadic permafrost occur in northern British Columbia.

Soils

Many geologists are unfamiliar with the soil classifications now employed by Canadian soil scientists and, as a result, may be unable to fully utilize information contained in soil survey maps. Consequently, before describing

TABLE III

Some common lowercase suffixes from *The System of Soil Classification for Canada*

Suffix*	Meaning and example
c	A cemented horizon; e.g. horizons cemented by iron oxides in Podzols (Bfc)
ca	A horizon of secondary carbonate enrichment (Cca)
e	An eluvial horizon characterized by removal of clay, iron, alumina, etc.; e.g. the leached horizon of Podzols (Ae)
f	A horizon enriched with secondary iron oxides as in Podzolic soils (Bf)
g	A horizon characterized by grey colours and/or mottling brought about by reduction below the water table (Bg), either throughout the year or periodically
h	A horizon characterized by accumulation of organic matter (Ah)
t	A horizon enriched in clay minerals, e.g. in the illuviated (accumulation) zone of Luvisols (Bt)
z	Permafrost (Cz)

*Suffixes are combined as required, e.g. Bth, Aeg, etc.

soils of the Cordillera, the prevalent scheme is briefly outlined. A full description is given in *The System of Soil Classification for Canada* (Canada Department of Agriculture, 1970).

Soils are the product of many factors — parent material, climate, topography, vegetation, time, etc. – which result in the development of layers (horizons) parallel to the land surface. Presence or absence of horizons and their physical and chemical characteristics enable soils to be classified. In the older classification schemes, subdivisions of the principal horizons (A, B, and C) were indicated with numeric subscripts: A_1, B_1, B_2, etc. These subscripts have now been replaced by lower-case letters indicating distinctive features of the horizon, e.g. "Ae" indicates an eluviated (leached) A horizon whereas Cca denotes a carbonate-rich C horizon. Some of the commoner suffixes are summarized in Table III and the old and new schemes are compared in Fig.7. On the basis of this classification, eight orders of soils are recognized (Table IV) and can be subdivided further with increasing detail into groups, families and soil series.

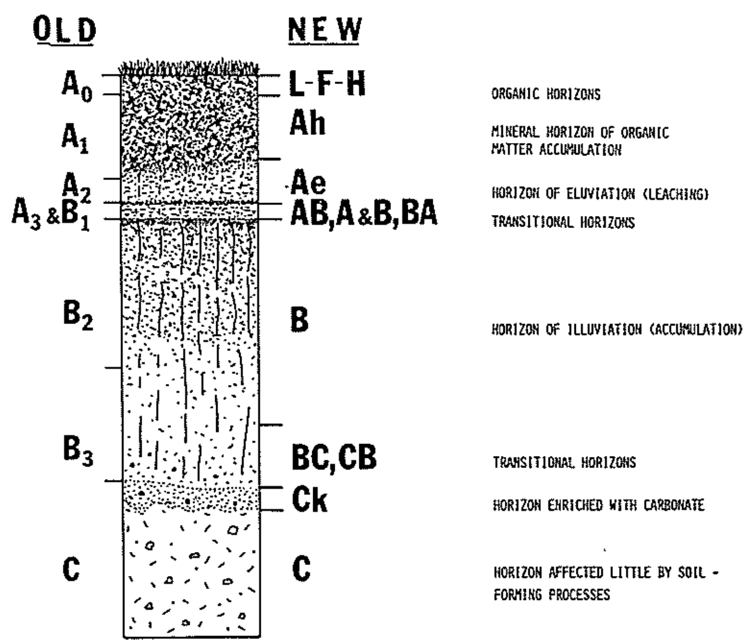

Fig.7. Comparison of the new classification of soil horizons used by the Canadian Department of Agriculture (right) with the old system (left).

In British Columbia, distribution of soil orders is closely related to climate and physiography (Fig.8). Thus the high rainfall of Vancouver Island, the western slopes of the Coast Mountains, and the Columbia Mountains, favours strong leaching and development of podzolic soils. In contrast, throughout much of the interior (with rainfall less than 20 inches per annum) luvisols predominate but give way to brunisols in the cooler, wetter northern interior. Brunisols also occupy a transitional zone between podzols and luvisols on the

TABLE IV

Soil orders in the Canadian system of soil classification

Order	Summary description and occurrence
Chernozemic	Well to imperfectly drained mineral soils with dark surface Ah, Ahe, or Ap horizons and with B or C horizons of high base saturation with divalent cations, calcium usually being dominant. These soils are found in areas with cool, semi-arid to sub-humid continental climates. Typical of grasslands.
Solonetzic	Soils characterized by the accumulation of salts. Usually developed on saline parent materials.
Luvisols	Well to imperfectly drained soils formed under forest cover in moderate and cool climates. Soils have an eluvial Ae and illuvial Bt horizons. Slight accumulations of $CaCO_3$ may occur under the B horizon. Parent materials are usually either neutral or alkaline.
Podzolic	Well and imperfectly drained soils developed under forest or heath vegetation in cold to temperate climates, generally with a distinct Ae horizon. B horizons are characterized by accumulation of organic matter, iron and alumina (Bh, Bfh). Usually formed on acid parent materials.
Brunisolic	Well to imperfectly drained soils with a brownish solum. The podzolic B horizon is absent.
Regosolic	Well to imperfectly drained mineral soils in which horizon development is too weak to enable classification in any of the other orders.
Gleysolic	Soils saturated with water and under reducing conditions for at least part of the year. Characteristic grey or mottled horizons reflect reducing conditions.
Organic	Soils with thick organic accumulations as in peat bogs

eastern side of the Coast Mountains. Chernozemic soils are only important in the driest, most arid zones of the central and southern interior.

Fig.8 shows the predominant soil order within a district. Depending on local conditions (slope, parent material, drainage, etc.), other soil orders will almost invariably occur.

Format

Within the soil-sediment environment the single factor, which is of greatest influence in geochemical dispersion patterns, is the nature of the overburden. In this respect landscape geochemistry differs markedly from petrochemistry in which geology is the primary controlling factor in the origin and interpretation of geochemical patterns. In the soil-sediment environment discussed here, separate models are drawn for each of the three important parameters in regard to the overburden, i.e. whether it is (1) residual, (2) transported material of

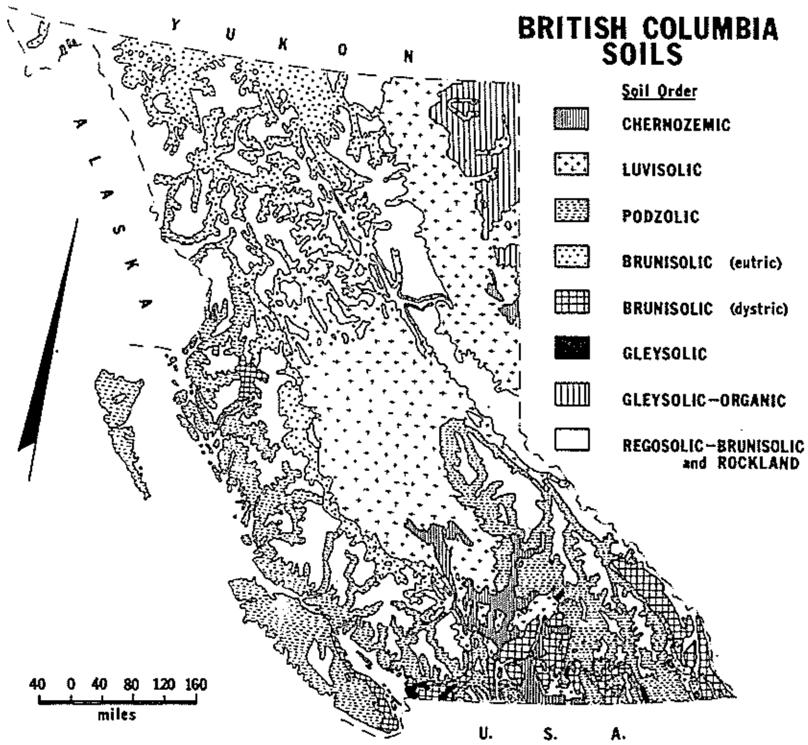

Fig.8. Distribution of soil orders in British Columbia.

local derivation (i.e. till), or (3) transported material of remote derivation (this includes glaciofluvial and glaciolacustrine deposits, alluvium, volcanic ash, and any other material of remote origin). In addition, there are a number of features of secondary importance. These include geology, seepage zones, bog developments, behaviour of elements of different mobility, etc. These various factors have been summarized in Table V. This table is also an index of all the pertinent data related to each individual Cordillera model. It shows the figure number of each model (or models), the number of all supporting field data quoted in this paper, and also the references of any supporting data in the literature.

IDEALIZED MODELS

The idealized models are discussed in turn, generally going from the simplest to the most complex. Referring to Table V, "Index of examples", interpretation of geochemical anomalies in the different categories generally increases in complexity from left to right and from top to bottom. The formation of anomalies is discussed firstly for residual overburden, then till, and finally for overburden of remote origin, such as glaciofluvial outwash. The same criteria which apply in the simplest case (residual soil) also apply in the more complex cases but with added complications. In this way it is a natural progression to discuss residual soils, followed by till, followed by overburden of remote origin.

TABLE V

Index of examples, Section B*

1. Residual overburden	2. Transported overburden of local origin (e.g. till)	3. Transported overburden of remote origin (e.g. stratified glacial drift, alluvium)
A. General (Mobile elements in well-drained soil)		
(A1)**Casino	(A2) Anvil	(A3) Anvil
(Archer and Main, 1971)	Afton	Bell Copper
Keno Hill	Cariboo Bell	Ingerbelle
Ketza River	Chutanli	Island Copper
(Archer, 1967)	Central Coast Mountains	MacMillan Pass
Maloney Creek	(Woodsworth, 1971)	Yukon Copper mines
Mount Nansen	Boss Mountain	(Smith, 1971)
Sheslay	Boundary District	
Williams Creek	(White and Allen, 1954)	
	Galore Creek	
	(Barr, 1966)	
	Gibraltar	
	Huckleberry	
	Island Copper	
	Highmont	
	Luckey Ship	
	(Hornbrook, 1969)	
	Sam Goosly	
	Dansey-Rayfield River	
	(Hoffman and Fletcher, 1972)	
B. Mobile elements in seepage zones		
(B1) Casino	(B2) Boundary District	
(Archer and Main, 1971)	(White and Allen, 1954)	
Sheslay	Chutanli	
	Huckleberry	
	Luckey Ship	
	(Hornbrook, 1969)	
	Valley Copper	
	Several areas	
	(Horsnail and Elliott, 1971)	
	Highmont	
	Tom (Fletcher and Doyle, 1974)	
C. Mobile elements in bogs		

	Tom (Fletcher and Doyle, 1974)	
C. Mobile elements in bogs	(C2) Cariboo Bell Valley Copper Whipsaw Creek (Gunton and Nichol, 1974) Several areas (Horsnail and Elliott, 1971) Highmont	
D. Effect of variation in overburden thickness		(D3) Bell Copper Ingerbelle Island Copper MacMillan Pass Maloney Creek
E. Chemical mobility Casino (Archer and Main, 1971) Keno Hill Mount Nansen Shesley	(E2) Gibraltar Tom (Fletcher and Doyle. 1974)	
F. Effect of rock type change Keno Hill (Boyle, 1965)	(F2) Central Coast Mountains (Woodsworth, 1971) Hess Mountains (Fletcher and Doyle, 1971) Boss Mountain Papoose Lake Tom (Fletcher and Doyle, 1974)	
G. Different soil types Mount Nansen	(G2) Afton Dansey-Rayfield River (Hoffman and Fletcher, 1972) Cariboo Bell Keno Hill Island Copper	MacMillan Pass

*References with author and date refer to literature references given at the back of this volume. The remainder are case histories given here.
**The numbers refer to the idealized models as given.

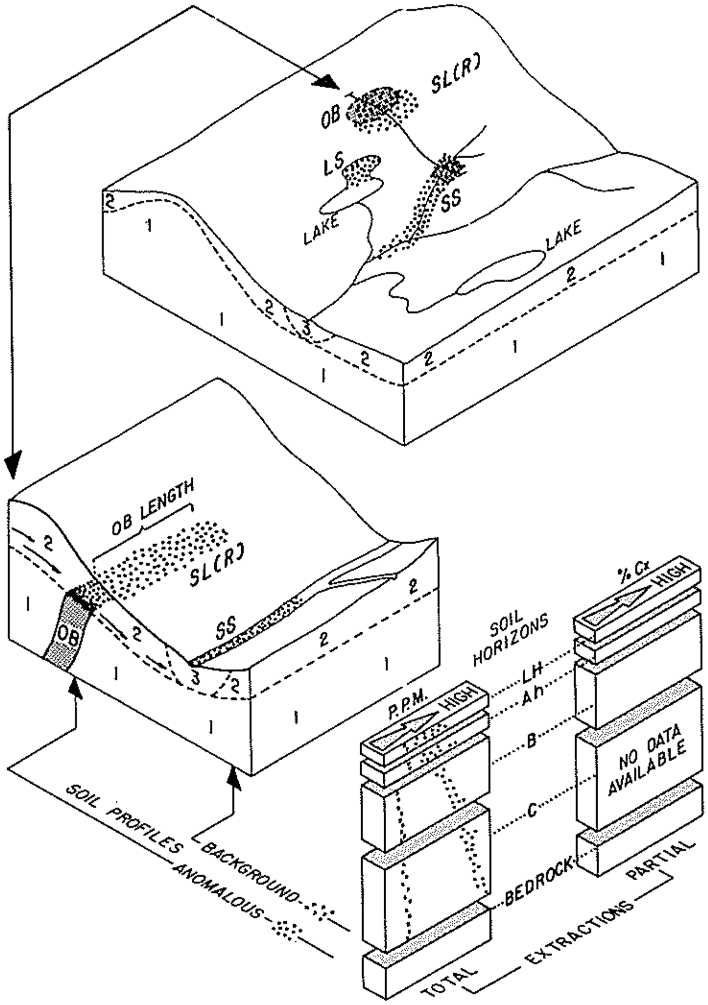

Fig.9. Model A1 (Cordillera). Idealized models for geochemical dispersion of mobile elements in well-drained residual soil.

Anomaly types: SL(R) = residual soil anomaly, SL(M) = mechanically smeared soil anomaly (by glacial action), SS = stream sediment anomaly, LS = lake sediment anomaly, SP = seepage anomaly, BG = bog anomaly.

Overburden types: 1 = bedrock, 2 = residual soil, 3 = recent alluvium, 4 = till, 5 = overburden of remote origin.

Others: OB = orebody, : : : : = the density of dots indicates anomaly strength.

In certain cases, sufficient case history information is not available to reliably construct an idealized model. In this case no model is given.

In order to keep the idealized models as simple as possible, the same legend is used for all models. Space does not allow the inclusion of this legend in each diagram; hence it is only given in full in the caption of Fig.9. This should be referred to when examining any of the idealized diagrams.

A. Mobile elements in well-drained soil

Cordillera models A1, A2 and A3 (Figs.9—11) show the general characteristics which may be expected from mobile elements in well-drained soil in residual overburden, transported overburden of local origin, and transported overburden of remote origin, respectively. The valid generalizations which can be made are as follows:

Surface soils. In residual soil conditions, the anomaly is normally developed virtually directly over the mineralization but may show downslope spread due to the effect of gravity and soil compaction, although the magnitude of this is variable. For example, Archer and Main (1971) found that the copper and molybdenum anomalies in soil over the Casino porphyry copper deposit were only slightly larger than the mineralization itself, downslope creep normally being 200—500 feet. Similar dispersion distances were found at Mount Nansen

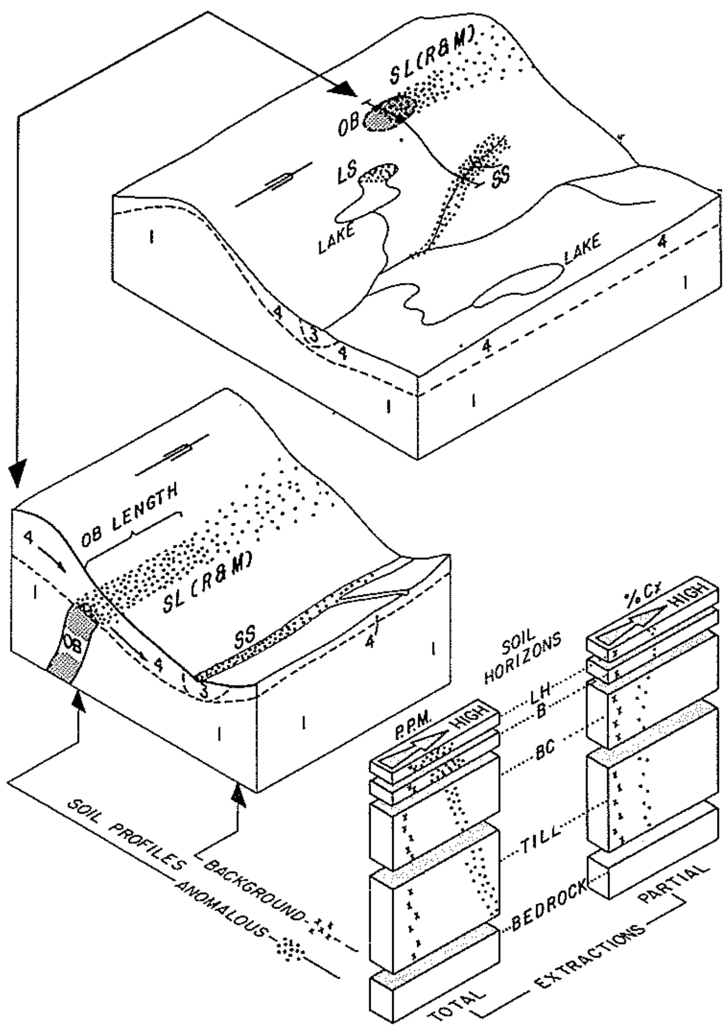

Fig.10. Model A2 (Cordillera). Idealized models for geochemical dispersion of mobile elements in well-drained till (see Fig.9 for legend).

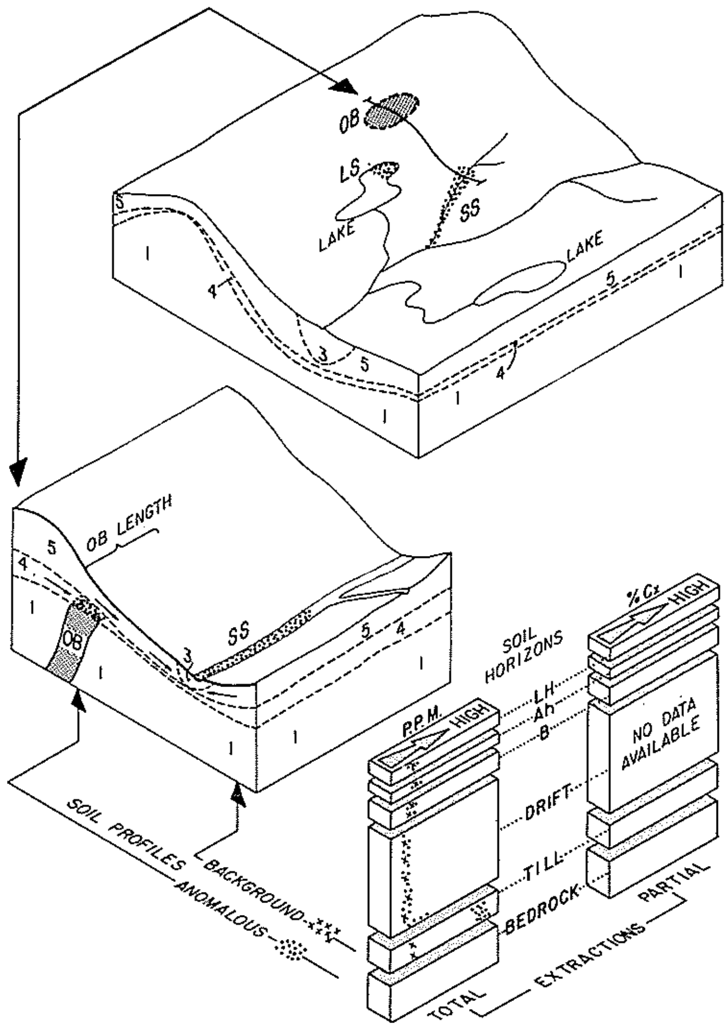

Fig.11. Model A3 (Cordillera). Idealized models for geochemical dispersion of mobile elements in well-drained overburden of remote origin (see Fig.9 for legend).

and Ketsa River (Archer, 1967), while at Sheslay dispersion was in the order of 2,000—3,000 feet downslope. However, wherever it can be determined, the length of the anomaly along the line of the topographic contour is normally about the length of the mineralization (e.g. as at Casino and Ketsa River).

In areas of till cover, a surface soil anomaly is observed but is distorted by mechanical movement due to glaciation. This movement is generally in the direction of the most recent glacial event and causes the anomaly to spread out and become more erratic down-ice. For example, at Highmont (Bergey et al., 1971), the geochemical anomaly has been displaced upslope resulting in the highest geochemical response lying some 2,000 feet away from the centre of the nearest mineralization. At Sam Goosly (Ney et al., 1972), the effect of glacial smearing is again most marked. Silver and copper are spread up to 2 miles down-ice, while the anomaly shows quite a sharp cutoff in the up-ice direction, directly over the mineralization. At Chutanli, the extent of glacial smearing is approximately 6,500 feet. In other cases however, such as at Luckey Ship (Hornbrook, 1969) and Huckleberry, this effect seems to be quite minor and glacial transport can be measured only in terms of tens of feet to a maximum of hundreds of feet.

In transported overburden of remote derivation which is of any appreciable thickness (normally greater than 5—10 feet), the surface soil response is normally completely masked as depicted in model A3. For example, at the Silver King vein, Keno Hill, glaciofluvial material has completely masked all geochemical response in the surface soils, in spite of the fact that many other veins in the area which are not covered with this transported material show strong soil anomalies. At the Island Copper porphyry deposit, the effect of glaciofluvial material is quite marked. The only soil response is seen in a window in glaciofluvial cover. Where this transported overburden exceeds a depth of approximately 10 feet, a geochemical response at the surface is blanketed out. This same effect is found at Ingerbelle and is also reported by Smith (1971) over the Yukon Copper deposit.

Soil profiles. Details of the effect of different soil types are summarized in model G2 (Fig.20). For the present, however, general characteristics are given. In residual soils directly over mineralization, the soil values normally remain more or less constant or increase consistently with depth as seen for example over the No.6 vein fault at Keno Hill. The same feature is also seen at Maloney Creek, although in this case the increase in metal content with depth may be accentuated by dilution due to volcanic ash near surface. At Mount Nansen, profile samples show up to a ten-fold increase from surface down to bedrock. In each case, due to the fan-shaped nature of the anomaly, which is normally accentuated downslope (see Mount Nansen for example), if profile samples are taken to one side of mineralization, the values will normally decrease with depth.

In till-covered areas, a very similar distribution to that found in residual soils is observed, as for example at Cariboo Bell and Island Copper. Data from Cariboo Bell also shows that the percent of cold-extractable metal is up to 40% in the A horizon over the mineralization, but in the mineral soils it is normally around 20—25%. In background soils, it is about 5% for all horizons.

In areas of exotic or remote origin overburden, there is normally no response in the soil profile until either residual soil or till is encountered at depth, as seen for example at Island Copper and also at New Imperial mines (Smith, 1971). In some cases, due to hydromorphic movement, the anomaly may move from several inches to several feet into the overlying overburden (for example, at the Bell Copper deposit). However, normally the anomaly ends quite abruptly within a few inches of the contact with drift of remote origin, as shown in the examples just quoted. At the Anvil deposit, the same effect was observed.

Sediments. In areas of residual soil, for mobile elements, stream sediment anomalies are normally quite well developed and show a generally good dispersion train downstream. The length of the dispersion train is normally determined to a large extent by the rate of erosion of barren material, either by bank collapse or by the anomalous stream joining non-anomalous streams. For example, at Casino the maximum dispersion is observed for copper and is 8 miles in length. At Keno Hill, dispersion distances are generally hard to calculate due to the multiplicity of veins in a number of areas, but are commonly in the order of several miles in the areas of residual soil. This, however, is not universal since at Maloney Creek, dispersion is generally very short. The restricted drainage anomaly found here may be in part due to permafrost, although in other permafrozen areas dispersion distances are significant. Also at Williams Creek, there is no recognizable sediment anomaly, possibly due to the absence of pyrite in the orebody; hence the pH is not reduced sufficiently to promote hydromorphic movement.

In till-covered areas, very similar types and strengths of sediment anomalies are normally observed, with the possible exception that streams may more rapidly erode till, causing faster dilution than is the case for residual soils. Typical examples are found at Granite Mountain where the sediment copper anomaly is visible 2 miles downstream from the mineralized belt and at Huckleberry where it is visible up to $1\frac{3}{4}$ miles downstream and limited only at that point by the influx of the anomalous stream into a major river. At Sam Goosly, the anomalies are also very long, but detailed interpretation is complicated by two types of mineralization in the same drainage basin. At Boss Mountain, the anomalous molybdenum dispersion train is 6 miles, with exceptionally strong values immediately below the deposit.

In areas of remote origin overburden, a stream sediment anomaly is frequently built up by the process of hydromorphic movement, in spite of the fact that no surface soil anomaly is visible. Although precise comparison of anomalous dispersion length under these conditions as opposed to others cannot be made due to a large number of other variables, it would appear that such anomalies are generally shorter due to the high dilution of barren material. The presence of a sediment anomaly in the absence of surface soil response is seen for example at the Bell porphyry copper deposit. There may also be evidence for this process at Keno Hill although transport of anomalous material from residual soil areas is also possible.

Other conditions. The characteristics referred to above describe the formation and dimensions of geochemical anomalies under what are normally the simplest and most straightforward conditions. Although these basic characteristics normally apply nearly universally, there are in nature a number of complicating and additional factors which serve to distort the simplest case. These include seepage anomalies, bogs, different overburden thicknesses, the effect of different mobilities of individual elements, effect of geology, and the effect of different soil types. These are dealt with in turn in the following models.

B. Mobile elements in seepage zones

Due to the hydromorphic process already described, metals frequently move in solution in groundwater, in which their solubility is frequently higher than in the surface environment. Where these groundwaters encounter the surface environment, some metal is immediately precipitated or absorbed onto mineral or organic material at that point. This normally occurs on stream or lake sediments. Where there is a break in slope resulting in a spring line or seepage zone, even of a very weak and intermittent type, then anomalies can be built up in the soil. These are normally referred to as seepage anomalies. The extent and distribution of these seepage anomalies is closely controlled by topography and drainage patterns.

In idealized models for residual overburden, transported overburden of local derivation and of remote derivation are shown in idealized models B1, B2, and B3 (Figs.12—14), respectively. The generalizations which may be made from these are as follows:

Surface soils. For residual soil conditions the anomaly developed directly

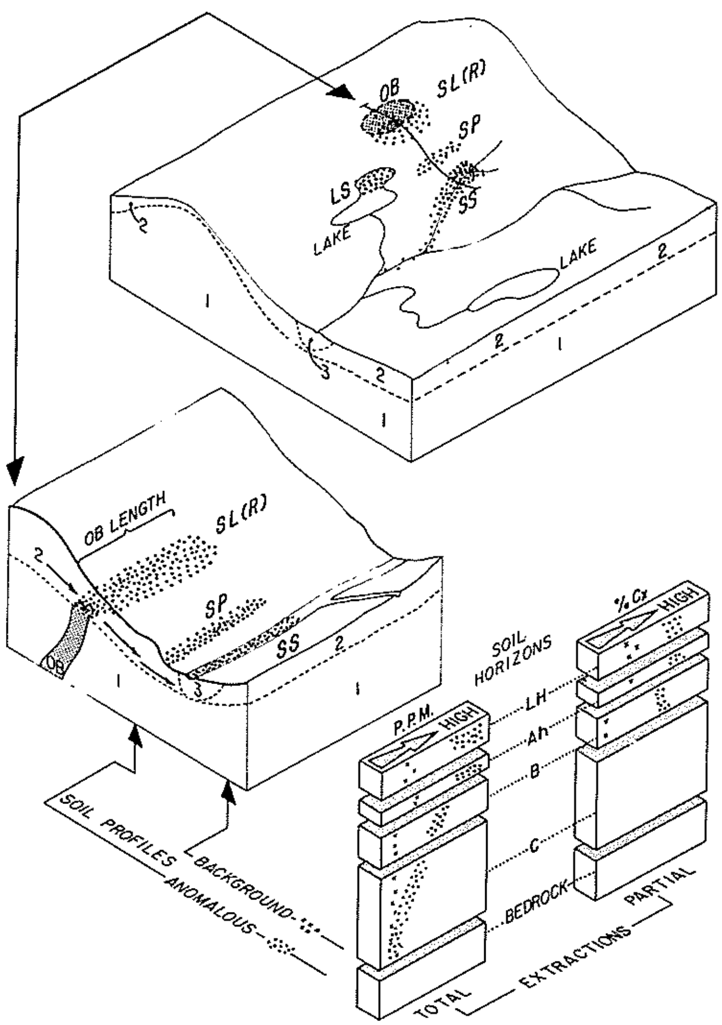

Fig.12. Model B1 (Cordillera). Idealized models for geochemical dispersion of mobile elements in well-drained and poorly drained ground — residual soils (see Fig.9 for legend).

over the mineralization is exactly the same as for model A1. However, in addition to this anomaly there is a seepage anomaly developed at the break in slope downhill. Depending on the topography, this seepage anomaly may be more or less continuous with the residual soil anomaly, or may be separated from it by a gap in which the soils report background content of metals. For example, at Sheslay there is a total copper soil anomaly over the mineralization, then for approximately 1,000 feet downslope the soils are close to or below threshold, and then approximately 3,000 feet downslope, a very strong anomaly at a break in the slope. On the other hand, at Casino (Archer and Main, 1971) there is apparently a seepage copper anomaly in the soil more or less directly adjacent to the residual soil anomaly. The positioning of the seepage zone appears to be influenced, however, by a window in the permafrost as much as by topography.

In transported material of local derivation, seepage anomalies are also devel-

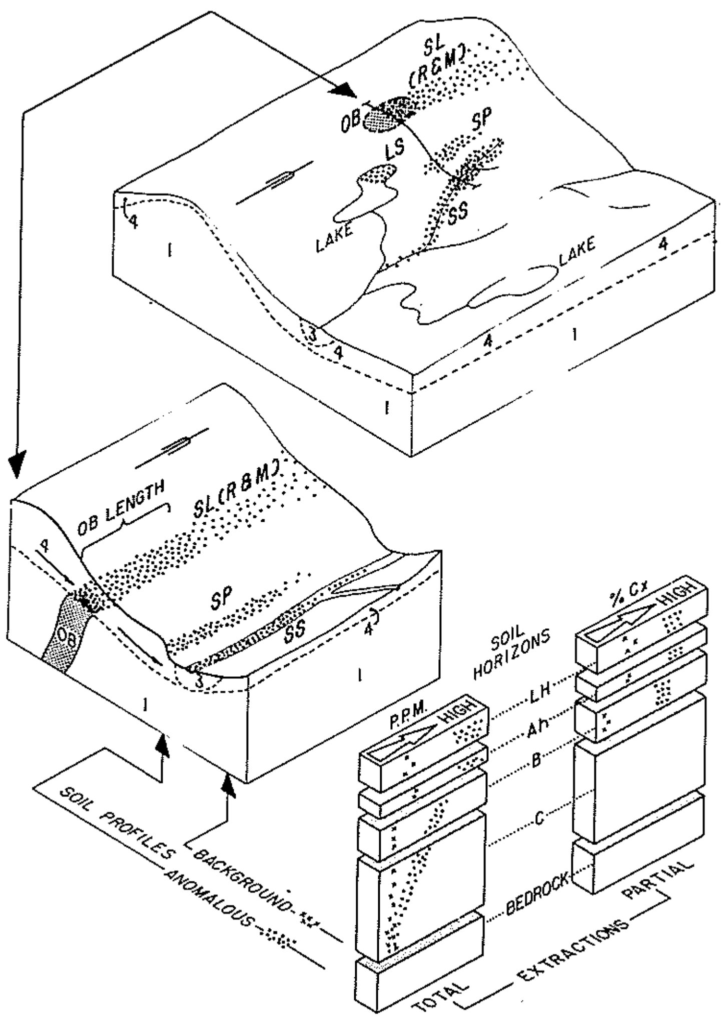

Fig.13. Model B2 (Cordillera). Idealized models for geochemical dispersion of mobile elements in well-drained and poorly drained ground — till overburden (see Fig.9 for legend).

oped directly downslope from the bedrock source and also to some extent from the glacial transported anomaly. Moreover, the magnitude of these seepage anomalies is frequently very much higher than the residual and mechanical anomalies on well-drained ground upslope. For example, at Valley Copper there is an exceptionally strong copper seepage anomaly at the break in slope approximately 2,000 feet downslope from the porphyry copper mineralization. Indications of a similar trend are seen at Highmont (Bergey et al., 1971) where moderate to strong soil copper anomalies are developed downslope from the best mineralization. In other examples, seepage samples collected downslope and some distance from the mineralization at Huckleberry show a very strong copper and molybdenum response; at Cariboo Bell, strong seepage copper anomalies are seen downslope and at Chutanli, the surface soil molybdenum values are considerably stronger at the break in slope below the deposit than

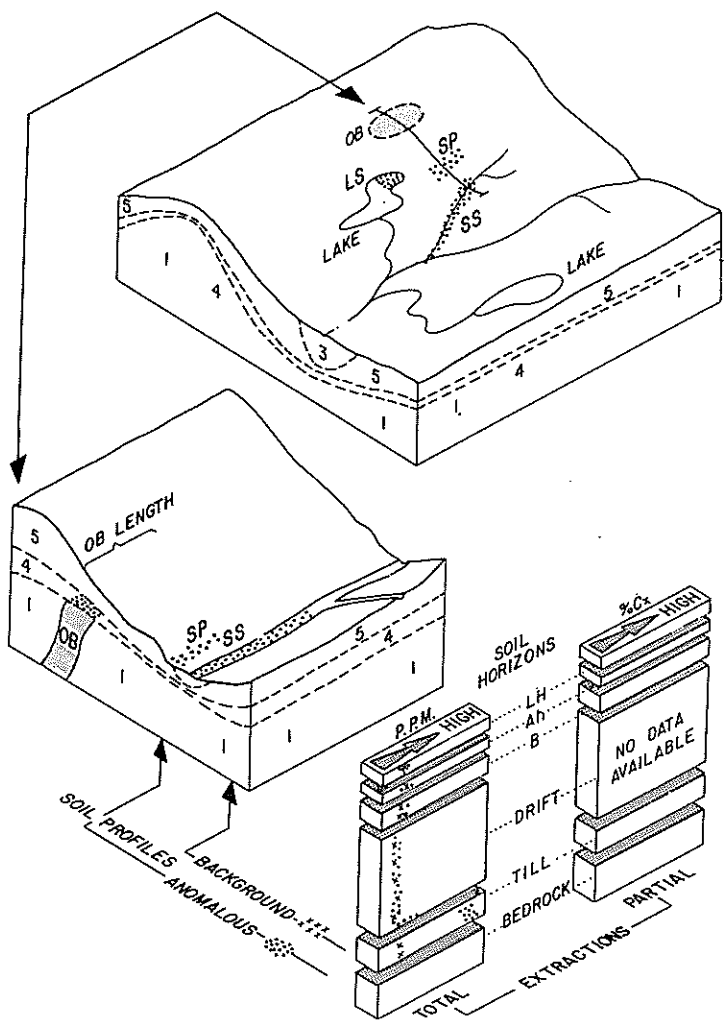

Fig.14. Model B3 (Cordillera). Idealized models for geochemical dispersion of mobile elements in well-drained and poorly drained ground — overburden of remote origin (see Fig.9 for legend).

anywhere else on the property. In overburden of remote origin, particularly if it is not too thick, the seepage anomaly may be found downslope even when no anomaly is developed directly over the mineralization as for example at Bell Copper. This is established by the process of hydromorphic movement through this transported cover.

Soil profiles. The anomalous dispersion of metals down profile is similar for both residual and transported overburden of local origin. Directly over the mineralization, it is exactly the same as shown in models A1 and A2. However, over the seepage anomaly there is normally a significant difference. Firstly, the concentration of metals normally decreases with depth; and secondly, the percentage of cold-extractable metal tends to be significantly higher as a result of hydromorphic transport of the metal. Demonstration of both these points is seen in the profile data for Cariboo Bell. At the break in slope downslope from mineralization, the metal decreases rapidly from strongly anomalous in the A horizons to below threshold in the B at a depth of only 10—15 inches. Concomitantly, the percentage of cold-extractable metal in the anomalous portion of the profiles is approximately 40%, as opposed to 20—25% in the residual profile directly over the mineralization for the same horizons. This very high percentage of cold-extractable metal in the near-surface samples is typical of seepage zones. A high percentage of cold-extractable metal in near-surface samples in the seepage zone can also be seen from the single traverse across Valley Copper.

Sediments. As far as can be determined by comparing the different case histories already mentioned, the sediment anomalies in all cases (models B1 to B3) correspond to similar situations without seepage anomalies (models A1 to A3). In other words, the occurrence of seepage anomalies does not seem to modify to any great extent the sediment anomaly distribution.

C. Mobile elements in bogs

Swamps and bogs are quite commonly encountered in the Cordillera, although they are generally of fairly limited areal extent. However, these bogs frequently are greatly enriched in metals due to their accumulation in the organic (humic) material. There are two principal situations, one where an orebody or mineralization lies to one side of the bog as shown in model C2(1); and the second case where the mineralization lies directly under the bog as shown in model C2(2), (Figs.15 and 16). These are dealt with in parallel.

Surface soils. When the orebody lies to one side of the bog and is overlain by transported overburden of local derivation, there is an anomaly built up in the soil in the same manner as is described in model A2. In the bog itself, when the source is to one side of the anomaly, the magnitude of the response in the bog tends to be much higher than in either the residual soil anomaly or the seepage anomaly. This is seen for example, at Valley Copper and also at Cariboo Bell. Values not infrequently reach 1,000 ppm or even percent range for mobile elements such as copper. Similar results are also shown by Horsnail and Elliott

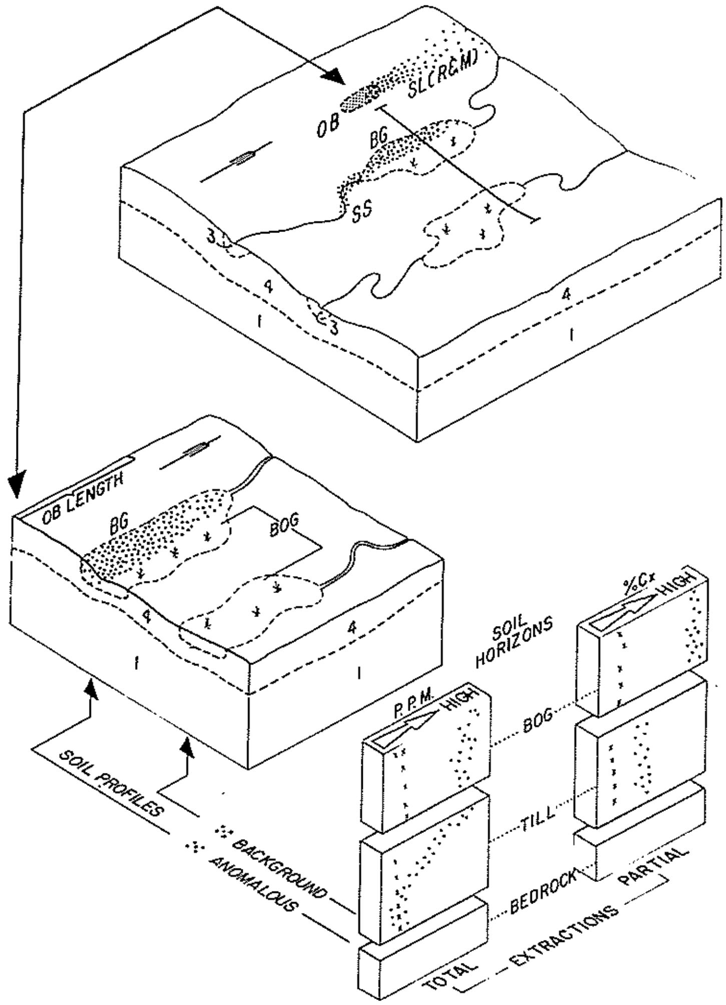

Fig.15. Model C2(1) (Cordillera). Idealized models for geochemical dispersion of mobile elements in bogs overlying till, with mineralization to one side of bog (see Fig.9 for legend).

(1971). When the source lies directly under the bog the values still tend to be exceptionally high in the overlying bog, again in the thousands of ppm or up to the percent range for mobile elements such as copper (Gunton and Nichol, 1974). The strength of these anomalies is generally such that it is mandatory to treat the bog and the well-drained soil separately when calculating threshold, otherwise genuine anomalies in well-drained ground may be regarded as background fluctuations, the magnitude being so small with respect to the bogs. This is depicted already in Valley Copper where an anomaly in well-drained ground over mineralization is only 75 ppm against a background of 20, whereas anomalies in the bog downslope from mineralization are as high as 4,000 ppm Cu.

Soil profiles. When the source of the anomaly lies to one side of the bog, the values normally decrease down profile, in some cases quite sharply. For example, Horsnail and Elliott (1971) show this to be the case for copper and/or molybdenum in three separate examples. It was also found to be the case at

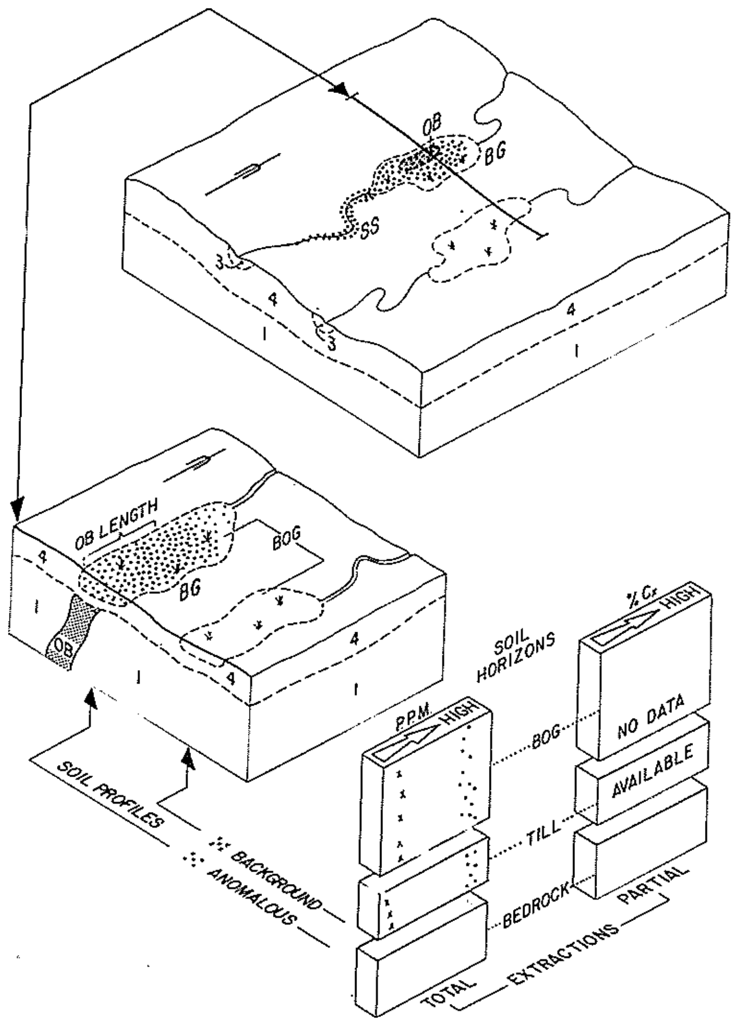

Fig.16. Model C2(2) (Cordillera). Idealized models for geochemical dispersion of mobile elements in bogs overlying till, with mineralization underneath the bog (see Fig.9 for legend).

Cariboo Bell. When the underlying till is penetrated, it normally contains only background concentrations, except possibly for the top few inches as shown by Horsnail and Elliott. In addition, when the source lies to one side of the bog, the metal content normally has a very high percent cold extraction. Horsnail and Elliott found typical cold-extractable levels between 70 and 90% EDTA extractable. Virtually identical results were found at Cariboo Bell, while at Highland Copper, the percent cold extractable was nearer to 60%. Again in the till, the values tend to be those normally found for background areas. In contrast, however, when the source lies directly under the mineralization, the values tend to remain much the same or possibly even increase slightly with depth both in the bog and in the underlying till (for example see Gunton and Nichol, 1974).

One very important feature to note from models C2 is that whether the source of the metal is to one side or underneath the bog, the bog is still anomalous with respect to normal background bogs with no source within its watershed. In other words, if a bog is found to be anomalous, there is a source of the metal somewhere within the groundwater catchment area. It is of course equally important to realize that the values in the bog may be highly accentuated by the "scavenging" effect of bogs, so that a very strong anomaly may reflect very weak widely disseminated mineralization of no economic value.

The field data shown here also demonstrate the value of till sampling at depth under the bog to determine if the source lies underneath or to one side. However, as is the case with geochemistry in all the secondary environment media, the magnitude of the anomaly cannot be taken as any reliable indication of the magnitude of the underlying mineralization.

D. Effect of variation in overburden thickness

In strictly residual overburden, the effect of variations in the thickness of the overburden is anticipated to be quite small. Although there are no case histories in the public domain within the Cordillera which demonstrate this point, there is substantial information from elsewhere in the world. For example, in the residual soil environments of South America and Africa, where the overburden can average 150 feet thick over mineralization, residual soil anomalies are found at surface which have the same characteristics as normally found in much shallower residual overburden. It is possible that through thicker overburden, the magnitude of the anomalies is weaker than it would be in thin overburden, but it is difficult to compare case histories of natural phenomena in that detail.

In areas of transported overburden of local derivation, the effect of overburden thickness is again possibly not too important, although again there is little public information for the Cordilleran region which demonstrates that this is so. The only possible suggestive proof of this is the fact that, for all the case histories quoted here, where the overburden is till, of no matter what thickness, there is a soil anomaly developed. It is quite possible, however, that as the till gets thicker, the anomaly is spread further down-ice and over a larger area. Proof of this can be found for the continentally glaciated areas in Section C, but cannot be demonstrated with a case history for the Cordillera at this time.

For areas of transported overburden of remote origin, there are quite clear differences in the geochemical patterns developed, dependent on the depth of the transported material. Model D3 (Fig.17) shows the case for transported overburden overlying residual soil which in turn overlies the bedrock. However, in some cases the transported material may directly overlie bedrock, or in other cases, may overlie till. In every case, the surface soil response and the sediment response will be the same, the only difference being the type of response found in the till directly overlying the bedrock. Idealized model D3 shows three cross sections for thin, moderate, and thick transported overburden of remote origin. The sections for these profiles are the same as that shown in model A2. In all three sections a thin veneer of A and B soil horizon

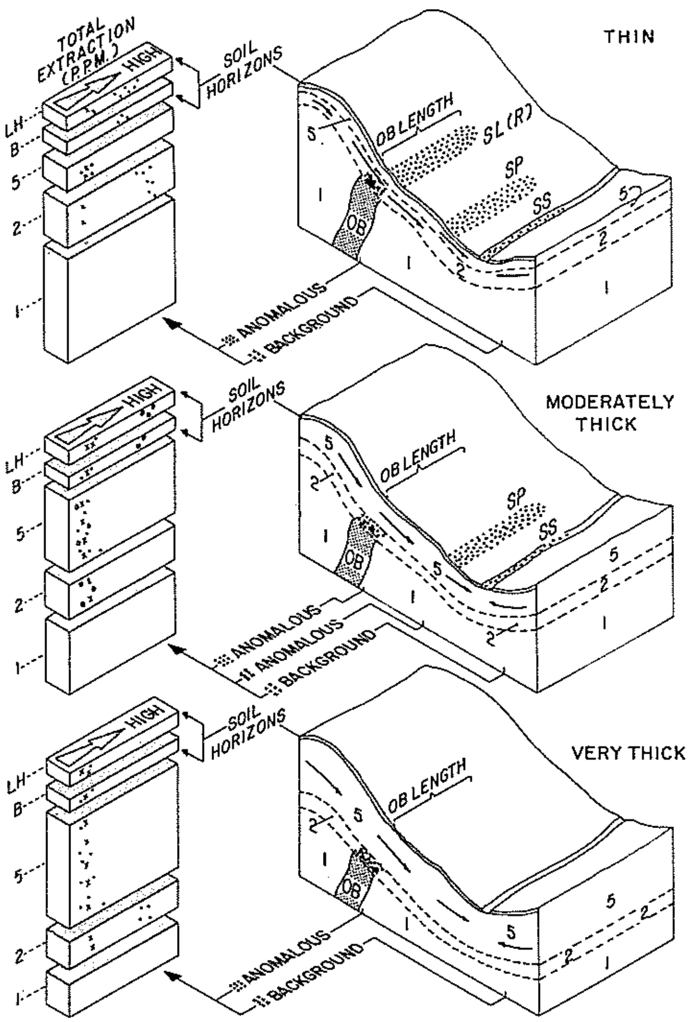

Fig.17. Model D3 (Cordillera). Idealized models for the effect of variation in the thickness of transported overburden of remote origin in the geochemical dispersion of mobile elements (see Fig.9 for legend).

is also depicted; in nature these horizons generally total between 2 and 8 inches in thickness.

Surface soils. In conditions of thin transported overburden of exotic or remote origin (less than 1 foot) the surface soil anomaly is normally seen in the overlying A and B horizon, in exactly the same manner as if the transported material was absent. This was found to be the case, for example, at MacMillan Pass. Although in this case, the bedrock is not mineralized, the values in the underlying till and overlying soil horizons are virtually identical, in spite of the fact that the intermediate volcanic ash layer is low in all metals. A similar situation was found at Maloney Creek, where inclusion of volcanic ash material material in the near-surface sample caused a lower result but did not blanket out the anomalous response in the overlying soil. In these cases, the reflection on underlying material in the overlying A and B horizon would appear to be due to the transport of metals by the root system of plants through the volcanic ash into the plant leaves, etc., following which by the normal process of plants dropping their leaves, there is a build-up of metals in the soils on the top of the volcanic ash. In this way metal is introduced in anomalous concentrations into the overlying soil. A parallel type of response can be expected where a thin veneer of glaciofluvial, glaciolacustrine, or other transported material of remote origin appears, as long as the root systems of the plants are capable of penetrating this in sufficient numbers.

Where the transported overburden of remote origin is of moderate to great thickness, there will be no overlying soil anomaly, as has already been shown to be the case for Ingerbelle, Island Copper, Keno Hill, Yukon Copper mines, and Bell Copper. However, if the overburden is only of moderate thickness, as is the case at Bell Copper, a seepage soil anomaly downslope may be encountered. This is the situation as depicted in the central profile in model D3, and as found at Bell Copper. Here, at a seepage zone downslope from the mineralization, the surface soil samples were anomalous, although the equivalent samples directly over the mineralization were non-anomalous due to a transported layer of boulder till. In cases where the transported overburden is sufficiently thin and porous for groundwater to reach surface through it, a soil anomaly will be developed in seepage zones by normal hydromorphic transport.

Where the overburden is exceptionally thick and/or non-porous, and groundwater cannot move from the mineralization up into the seepage zones, then no surface soil anomaly, or even sediment anomaly in extreme cases, can be expected, as is depicted in the bottom profile of model D3. However, in this situation collection of overburden samples at depth, or collecting material below transported overburden in either till or residual soil, can be effective. This technique has been used successfully by Smith et al. (1965) and Van Tassell (1969) in the Keno Hill area, and is discussed more fully in Section C on the Canadian Shield.

In every case, the anomalous metals may migrate a few inches into the bottom of the transported material either during the time the transported material was laid down, or by later hydromorphic movement. This was found to be the case at Bell Copper.

Soil profiles. The distribution of anomalous metal down the soil profile over the mineralization in the case of thin transported cover is shown on the top profile of model D3. In this case, distribution down the profile is almost identical to a residual soil situation as shown in model A1, with the exception that the transported material itself is normally very low, as for example at MacMillan Pass.

Where the transported material of remote origin is moderately or very thick, there is no anomaly seen directly over the mineralization except possibly in the lowermost 2—6 inches of the transported material as already noted above.

Sediments. Under conditions of thin and moderately thick transported overburden of remote origin a sediment anomaly will be built up in the same way as seepage anomalies. Again this was found to be the case at Bell Copper where a sediment anomaly and a seepage soil anomaly reflected the mineralization, but no overlying surface soil anomaly was present. However, where material is very thick and no seepage anomaly is built up, no sediment anomaly can be anticipated.

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, the other hydromorphic. The former is purely a physical process, and the solubility of metals or compounds are not affected. However, the degree of hydromorphic movement is directly dependent on the extent to which the metals are soluble in water. This solubility is a direct function of Eh—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 hydromorphically relatively mobile (i.e. soluble) while others are relatively immobile (i.e. insoluble). Making generalizations and accurate predictions is complicated by the fact that the mobility of an element can change with a change in one or more of the parameters already listed. Consequently, an element may be regarded as mobile in one area, but found to be only partially mobile in an adjacent environment. Although the effects of Eh and pH are fairly well documented under laboratory conditions, and in isolation their effects can be predicted by the use of phase diagrams, the other factors are not nearly so 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 situations.

Only the idealized model for transported overburden of local derivation is presented (model E2, Fig.18). The models for residual soil conditions are virtually identical to this model, and case histories for residual soil are discussed in support of this model. The conditions for areas of transported overburden of remote derivation can also be anticipated to be the same. However, case history data are lacking and this condition is not considered further.

Two idealized models are shown in diagram E2, one for partially mobile elements and one for immobile elements. These should be compared with model B2 which depicts the anomalies for mobile elements under otherwise identical conditions. These three idealized models must be considered together.

Surface soils. For anomalies, which are purely residual and smeared by mechanical glacial action, the effect of element mobility is negligible. Consequently, the surface soil anomalies for mobile, partially mobile, and immobile elements is virtually identical in all three cases.

On the other hand, for seepage anomalies, which are caused by hydromorphic movement, the effect of element mobility is quite significant. Model B2 and supporting field data have already shown that extremely strong seepage anomalies can develop from mobile elements, which may be severalfold higher in metal level than the residual anomalies. Rather than try and find two com-

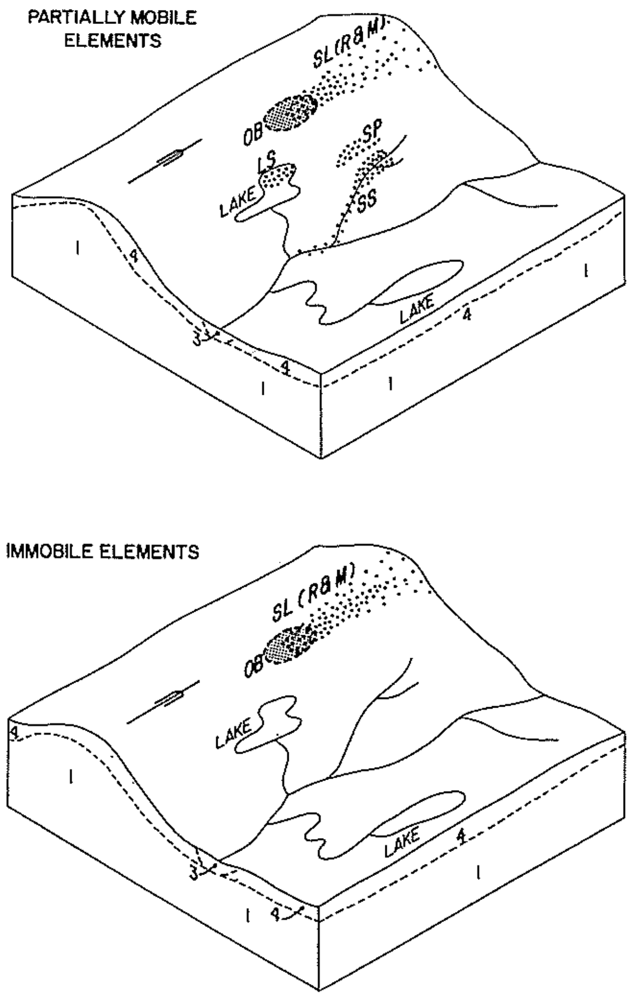

Fig.18. Model E2 (Cordillera). Idealized models of the effect of chemical mobility of elements on their dispersion pattern in till-covered areas (see Fig.9 for legend).

parable deposits as to topographic condition, slope, amount of water runoff, etc., it is preferable to compare the mobilities of different elements within the same deposit. For example, the presence or absence of the seepage anomaly over one particular deposit could be the result of several possible causes. However, if for the same deposit one element shows a seepage anomaly whereas the other does not, provided the bedrock tenors are within reasonable limits of each other, then certain conclusions can be drawn as to the respective mobility of the two elements. For example, at Mount Nansen there is very strong evidence of hydromorphic movement of zinc downslope, a limited movement of lead, and no movement of antimony, indicating the relative mobility of these elements in that order. At Sheslay, there is a strong hydromorphic copper anomaly developed downslope from mineralization and a weak molybdenum anomaly; exactly the same relationship for these two metals is seen at Highmont (Bergey et al., 1971), again indicating the relative mobility of these two elements. At Casino (Archer and Main, 1971), there are good indications of the hydromorphic accumulation of copper and molybdenum in a window in the permafrost. However, no such indication is seen for gold. This is only to be expected as gold is normally immobile, except by mechanical movement. Consequently, for partially mobile elements (such as to some extent molybdenum, and to a great extent, lead and silver), a seepage anomaly can be expected, but to a weaker degree than is normally encountered for the other elements, such as copper and zinc. However, for immobile elements, such as gold, no seepage anomaly can be anticipated.

Stream sediments. Since the formation of stream sediment anomalies by hydromorphic movement is identical to that of seepage anomalies, similar results can be anticipated. For example, at Gibraltar, copper shows a greater mobility than molybdenum. At the Tom property, zinc shows a greater mobility than lead, whereas at Keno Hill, the decreasing order of mobility as indicated by length of dispersion train is zinc, copper, lead, and silver. Consequently when the orebody is in an interfluvial area and no clastic sediment anomaly can be anticipated, the formation and strength of stream sediment anomalies are dependent to a considerable degree on which of the elements are mobile. For the partially mobile elements, such as molybdenum, and to a greater extent, lead and silver, moderate to weak stream sediment anomalies can be expected in comparison to those developed for the mobile elements, such as copper and zinc, under the same conditions. For the immobile elements, such as gold, no stream sediment anomaly can be expected under the same conditions.

F. Effect of rock type change

Wherever a rock unit with a high metal content occurs, this may cause a sediment or soil anomaly in exactly the same way as mineralization. This is due to the normal weathering of the bedrock which results in trace as well as major elements being incorporated in the overlying soil. The degree of hydromorphic movement away from rock units with a high metal content is generally lower than for mineralization, because there are no sulphides to lower the pH.

Model F2 (Fig.19) shows the distribution of anomalies which may be expected over a rock type with high levels of trace metals. This model is drawn particularly for areas covered with transported soil of local derivation. However, virtually the same type of criteria can be anticipated for residual soil and transported overburden of exotic origin subject to the controls already discussed.

Surface soils. Within the present study, there is only one case history which shows contrasting response for trace metals in soils over different lithologies within the same area, and that is at Boss Mountain. Here, the molybdenum-bearing hydrothermal biotite from the Boss Mountain stock gives rise to a strong molybdenum anomaly in soil, unrelated to mineralization. However, an appreciation of the fact that threshold does change from place to place

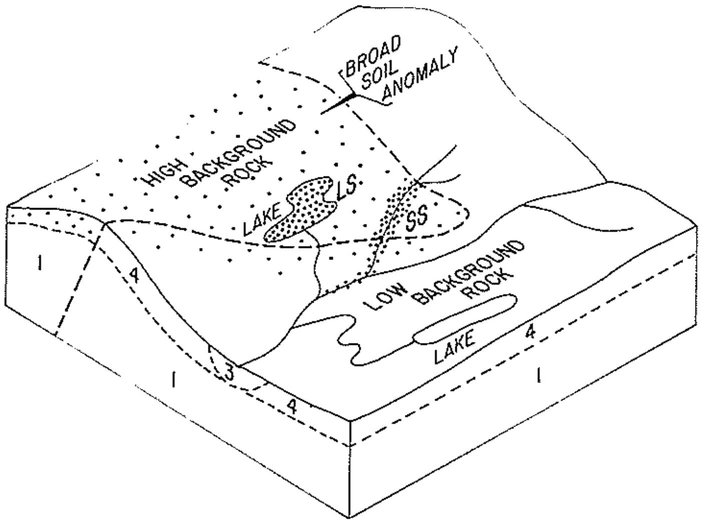

Fig.19. Model F2 (Cordillera). Idealized model for the effect of rock type change on the geochemistry of the overlying soils and sediments (see Fig.9 for legend).

can also be seen by comparing thresholds for the same elements for different areas. For example, at Sam Goosly over dacitic pyroclastic beds, copper threshold was chosen at 500 ppm; at Island Copper over quartz-feldspar porphyry 50 ppm; at Sheslay in volcanic sediments 200 ppm; at Keno Hill over limestone 50 ppm. Although there are other factors besides change in rock type which can cause differences in threshold levels in different regions, rock type can also be anticipated to have a marked effect. The regional levels of background have been shown to change systematically across the Cordillera, related to the exposed lithology and thus to the tectonic environment (Sutherland-Brown, 1974).

Sediments. The effect of rock types with different trace element contents on the metal content of sediments is well documented. In the literature (for example Woodsworth, 1971; Doyle et al., 1973; Fletcher and Doyle, 1974) and in the studies contained in this volume, Papoose Lake and the Tom property all show this effect. For example, at Papoose Lake, the threshold varies from 30 ppm over quartz-diorite to 60 ppm over porphyritic andesite which contains disseminated but barren pyrite. In this case, as in all the others quoted, the background trace metal content of stream sediments varies depending on which rock type (or types) lies within the drainage system of the streams.

G. Different soil types

A summary of the soil conditions found in British Columbia and the Yukon has already been outlined. Of the eight soil orders which occur within the Canadian system of soil classification, five occur reasonably frequently in the Cordillera. These are regosols, brunisols, luvisols, podzols, and organic (bog). The characteristics for each of these soil orders has been given in the earlier section on soils.

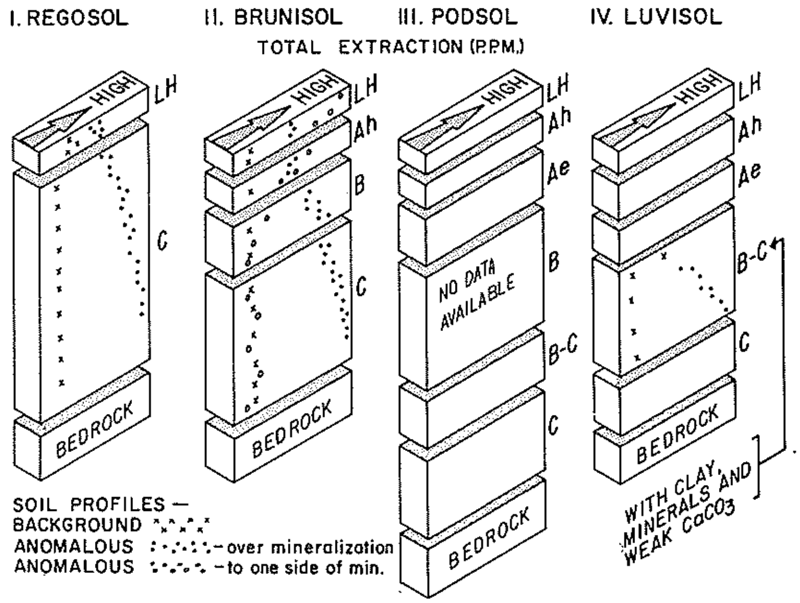

Fig.20. Model G2 (Cordillera). Idealized models for the dispersion of mobile elements in different soil profiles (see Fig.9 for legend).

An average soil profile for mobile elements for each one of these classifications is shown in model G2 (Fig.20). Because of the normal variations found in nature, any individual profile may deviate from this quite significantly. However, the pattern of trace element distributions should approximate to those shown here. Well-documented profiles are not common in exploration case histories; however from the data available, the following generalizations may be made:

Regosols. Background regosols normally show a more or less uniform copper distribution with depth. They may, however, show a slight increase in the metal content of the LH horizon, as for example in the zinc content in the MacMillan Pass.

In anomalous profiles over mineralization it is normal to find a relatively consistent increase in metal content with depth, as is found for lead, zinc, and antimony at Mount Nansen and also for copper at Rayfield River (Hoffman and Fletcher, 1972).

Brunisols. In this soil in background areas, the metal content normally remains fairly uniform throughout all horizons, as was observed for example at Island Copper and Cariboo Bell.

Directly over mineralization, there is normally a consistent increase of metal content with depth such as that observed at Island Copper, Keno Hill, and Cariboo Bell, although in fact at Cariboo Bell, the Ah horizon was no higher than the LH horizon.

When the source of the metal lies to one side of the profile being sampled, as at one of the profiles sampled at Cariboo Bell, the metal content may be strongly anomalous in the LH and Ah horizons, but will drop drastically in the B horizons.

Luvisols. In luvisols field data are lacking. In the only case history given here where this type of soil was encountered, at Afton, the metal patterns down profile were similar to those observed for regosols and brunisols. That is, over background areas the metal content stays fairly constant with depth while over mineralization the metal content increases.

Organic. The variation of metal content down organic or bog profiles has been covered in Section C.

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.

In some instances part of a case history which has previously appeared in print has been reproduced here. There are several reasons for this. In some instances data has been redrafted so that it can be more easily compared with the other data presented here and hence its pertinence to the present study becomes obvious. In certain cases the original data were published some time ago in journals without a wide circulation, and hence they are not 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 have not been previously released.

An attempt has been made to present all the data in this section in 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 much of the information presented here was collected with no view to standardization. It is hoped that future data will be collected with this format in mind, as set out in Section D on suggestions for an orientation survey.

The individual case histories are given in alphabetical order according to property name and their location is shown in Fig.21. The details of the size and strength of the anomaly for each area are summarized on the accompanying table (Table XXI). This table is organized such that the deposits for each type appear together.

Besides 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 XXI).

In order to refer to the individual case histories conveniently, and also to conserve space, all are set out according to a standard format which is as follows:

Name of deposit or property
Author (Affiliation)

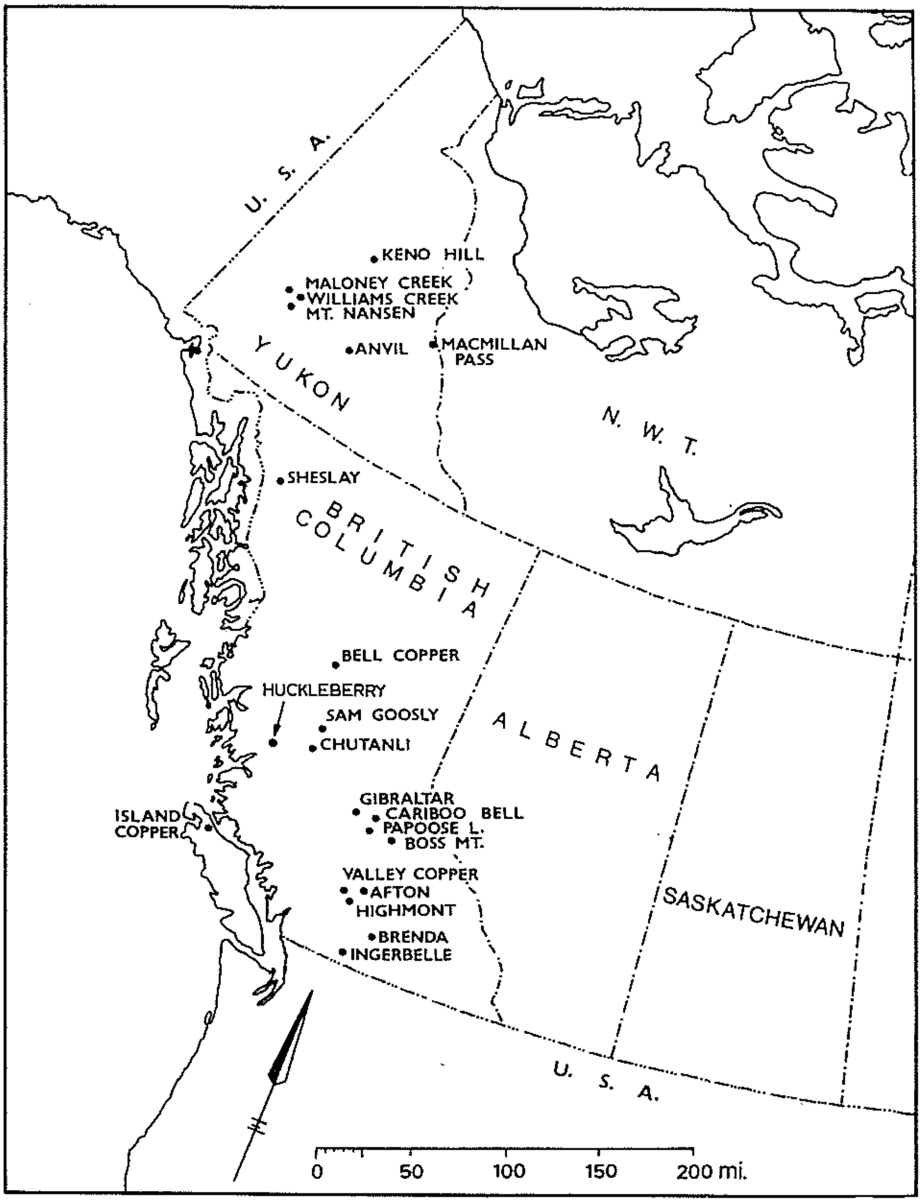

Fig.21. Map showing location of case history areas included in Section B.

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

Reference(s)

AFTON Cu DEPOSIT, BRITISH COLUMBIA

J.M. Carr (*Highmont Mining Corporation Limited*)
P.M.D. Bradshaw and B.W. Smee (*Barringer Research Limited*)

(1) This deposit is located 15 miles west of Kamloops in south-central British Columbia (lat. 50°39′N, long. 120°30′W).

(2) The mineralization is elongated in an east—west direction and dips to the south (Fig.22). The mineralization is the porphyry type in diorite, syenite porphyries, and intrusive breccias of the Iron Mask batholith. This intrudes Upper Triassic volcanic and sedimentary strata, and to the north unmineralized Tertiary volcanic and sedimentary rocks.

(3) The mineralization is native copper, chalcocite, bornite, chalcopyrite, and pyrite, both disseminated and as fracture fillings. The ore deposit contains 34 million tons averaging 1.0% Cu.

(4) This area has a generally very arid climate, and the vegetation consists mainly of open sagebrush and grass with open stands of yellow pine. Because of the arid climate, there is a weak luvisolic soil development with a high salt soil horizon, frequently occurring near surface.

The entire area is underlain by glacial till, generally only 3—10 feet in thickness. This in turn overlies highly weathered and altered bedrock where oxidation can be seen to a depth of 200 feet.

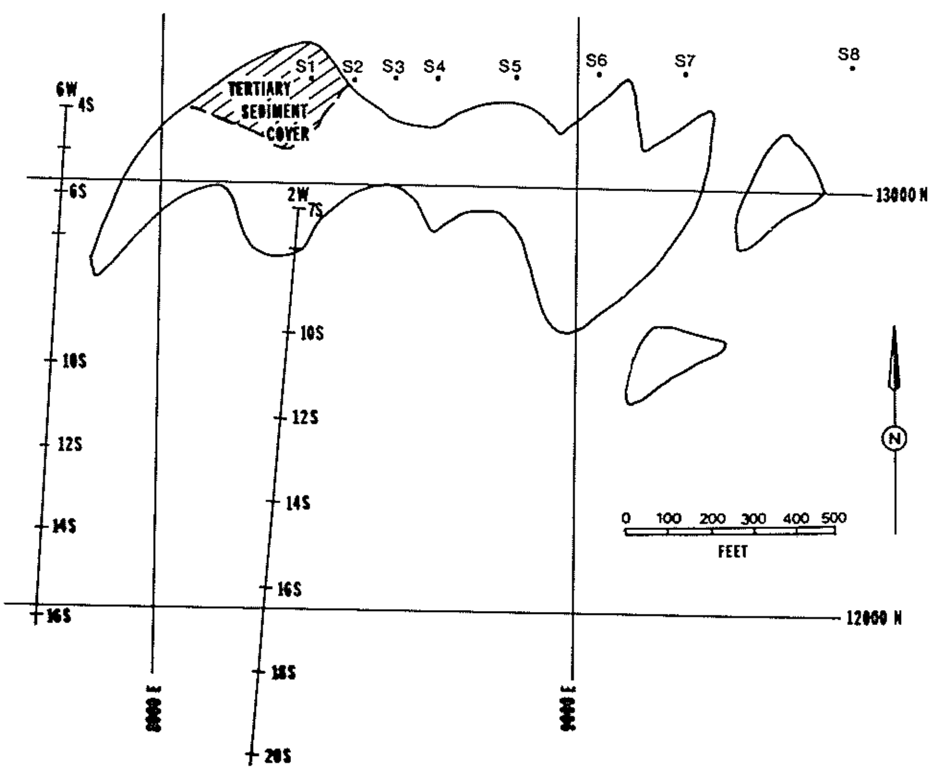

Fig.22. Soil sample locations, Afton, British Columbia.

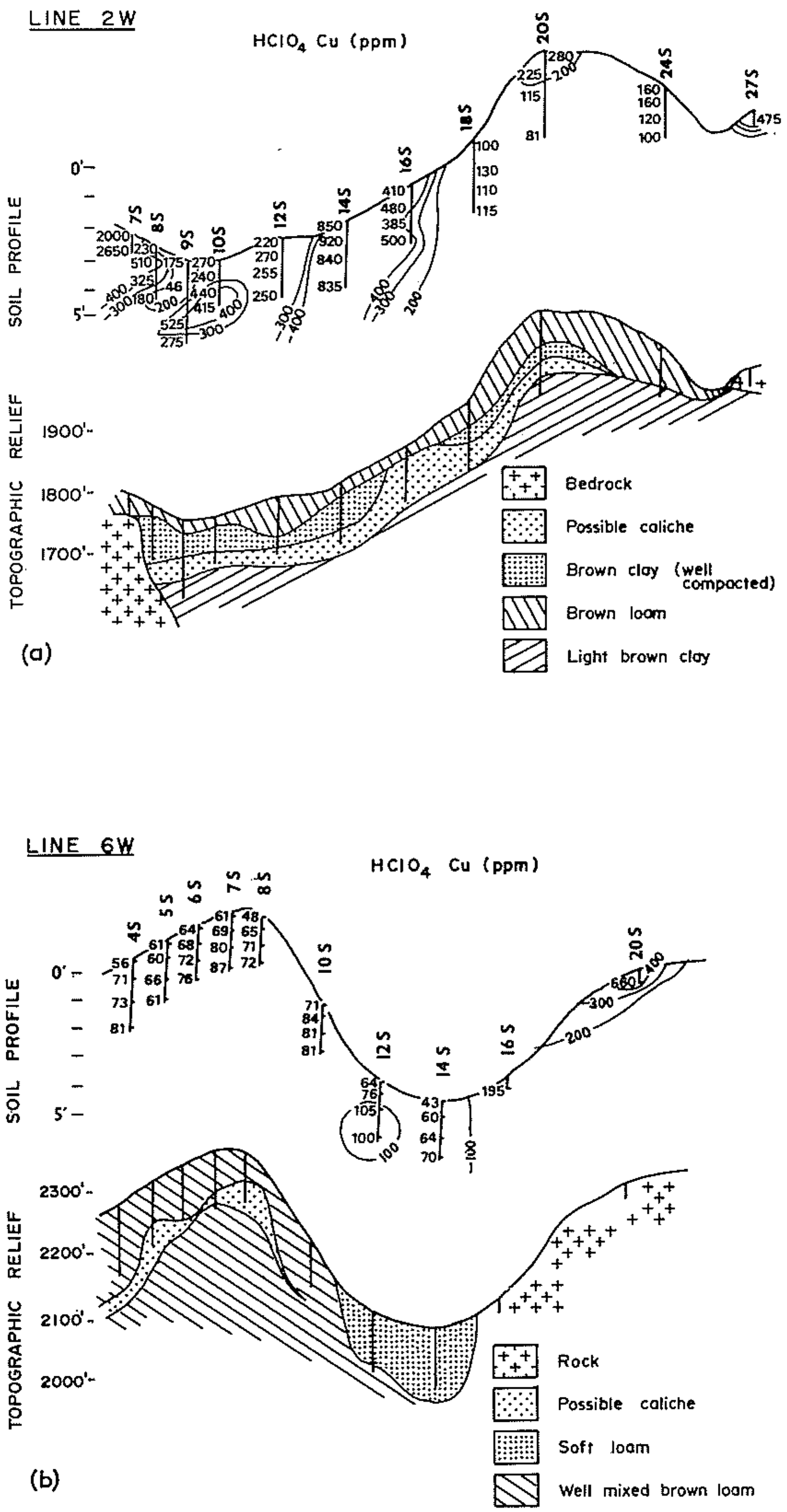

Fig.23 (legend see p.49).

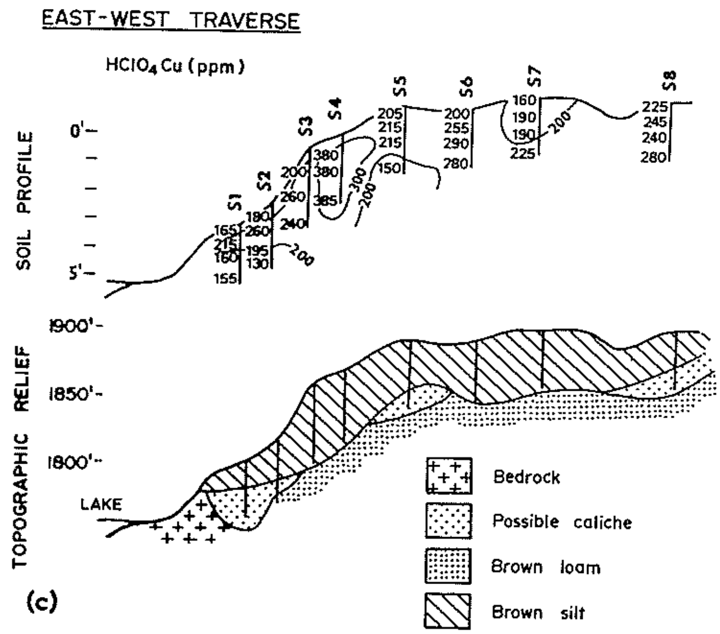

Fig.23. Distribution of total copper in soil profiles, minus 80-mesh, Afton: (a) Line 2W, (b) Line 6W, (c) east—west traverse.

(5) No data.

(6) Soil profiles were collected as indicated in Fig.22. The results for total copper are given in Fig.23. In summary, the near-surface and sub-surface soils reflect the presence of mineralization although the anomalies are generally very weak. The occurrence of a weak caliche layer does not appear to have a direct effect on the anomaly.

ANVIL Pb—Zn DEPOSIT, YUKON TERRITORY

P. Morton and K. Fletcher (*University of British Columbia*)

(1) Anvil mine, 125 miles northeast of Whitehorse, Yukon Territory.

(2) Proterozoic and Paleozoic quartzites, schists, phyllites, slates, limestones, cherts, and volcanics are intruded by a Late Cretaceous batholith. During the Pleistocene, glaciation from the east-northeast deposited a variable thickness of till along valley slopes and glaciofluvial deposits in the melt-water channel corresponding to the valley south of the mine.

(3) Sulphide orebodies are associated with a grey quartz-rich phyllitic unit. Sulphides, in order of abundance, are pyrite, pyrrhotite, sphalerite, galena, and minor chalcopyrite.

(4) The climate is continental with a mean daily temperature of 15—60°F, and annual precipitation of 10—15 inches. The soils are predominantly regosols with patchy developments of permafrost. The vegetation is largely white and black spruce, lodgepole pine, and alpine fir to the timberline at about 4,500 feet.

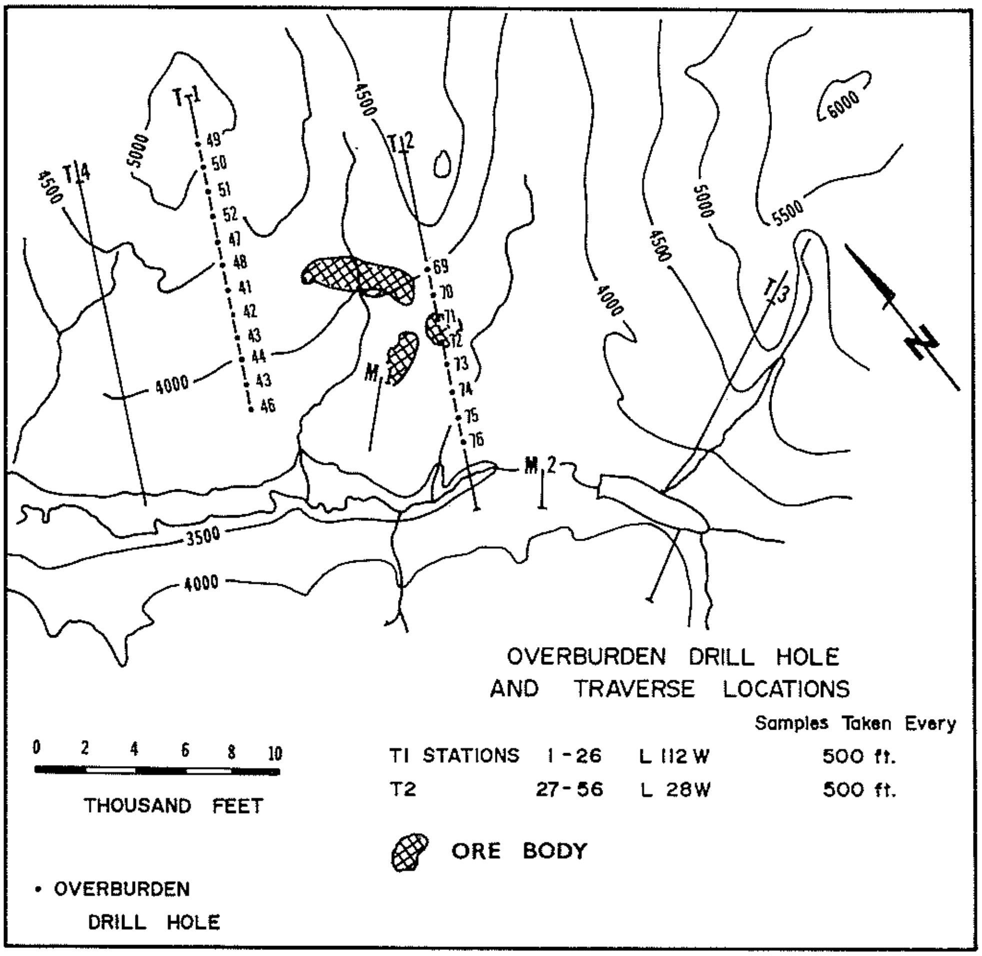

Fig.24. Location of traverses and overburden drill holes, Anvil, Yukon Territory.

(5) No data.

(6) The minus 10-mesh, plus 270-mesh fraction of overburden drill samples and minus 80-mesh soils were analysed by atomic absorption after digestion with 4/1 nitric-perchloric acid. Profiles are given for lead and zinc in overburden over the Faro No.2 zone (Line 28W) and Line 112 west of the orebody. The data (Figs.24—28) illustrate: (a) differences in metal content of the tills and glaciofluvial deposits (Table VI); (b) development of both lead and zinc anomalies over the orebody but with limited extent downslope (i.e. normal to ice movement) and in the direction of ice movement.

Reference: Morton, 1973.

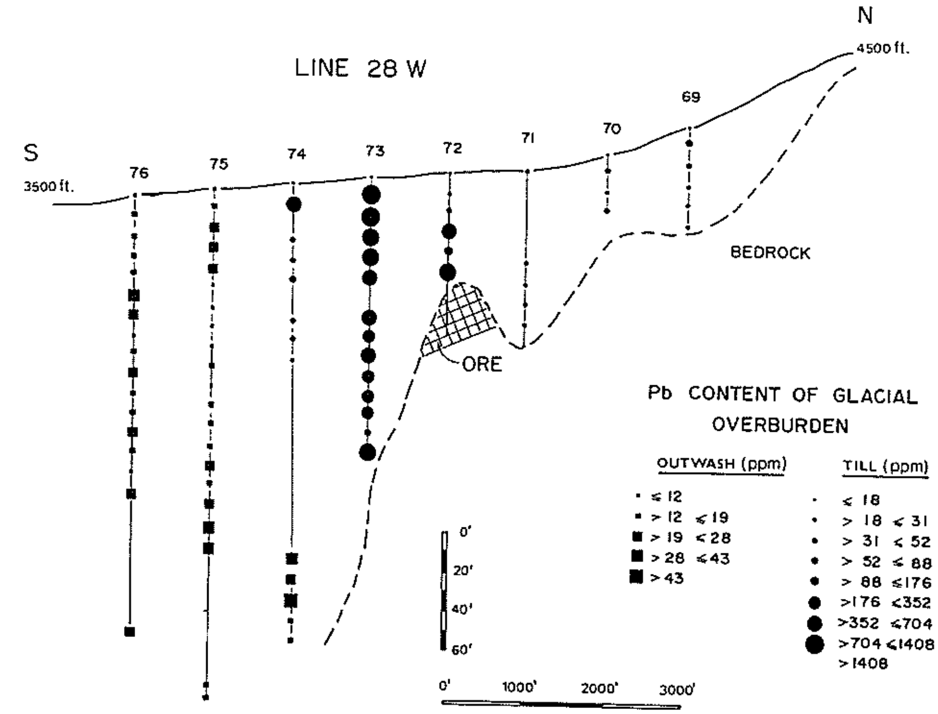

Fig.25. Distribution of total lead in the minus 10-mesh, plus 270-mesh fraction of glacial till, Anvil.

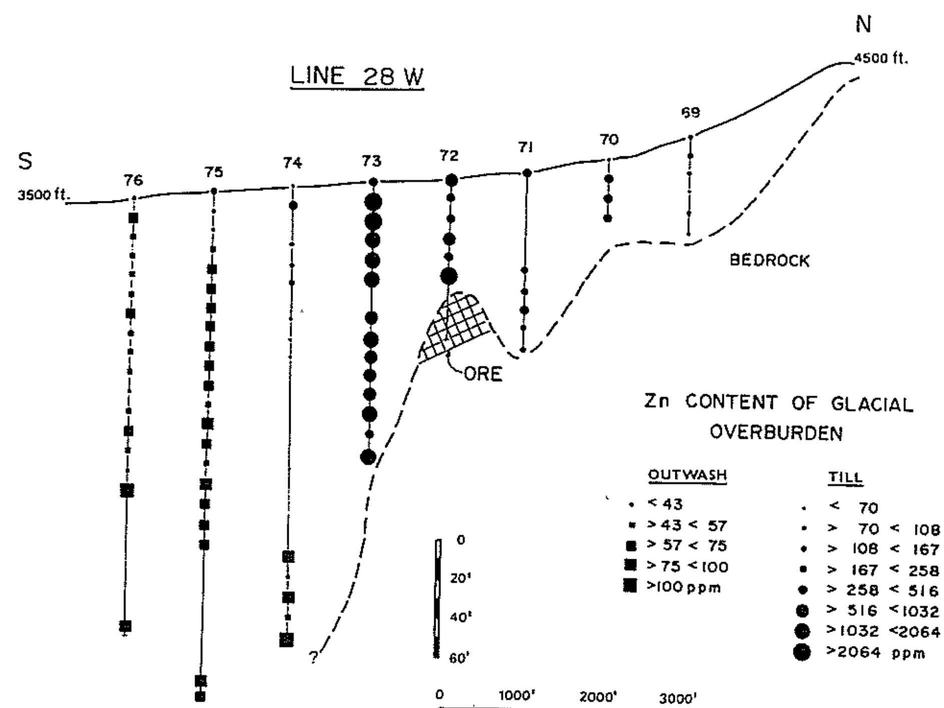

Fig.26. Distribution of total zinc in the minus 10-mesh, plus 270-mesh fraction of glacial till, Anvil.

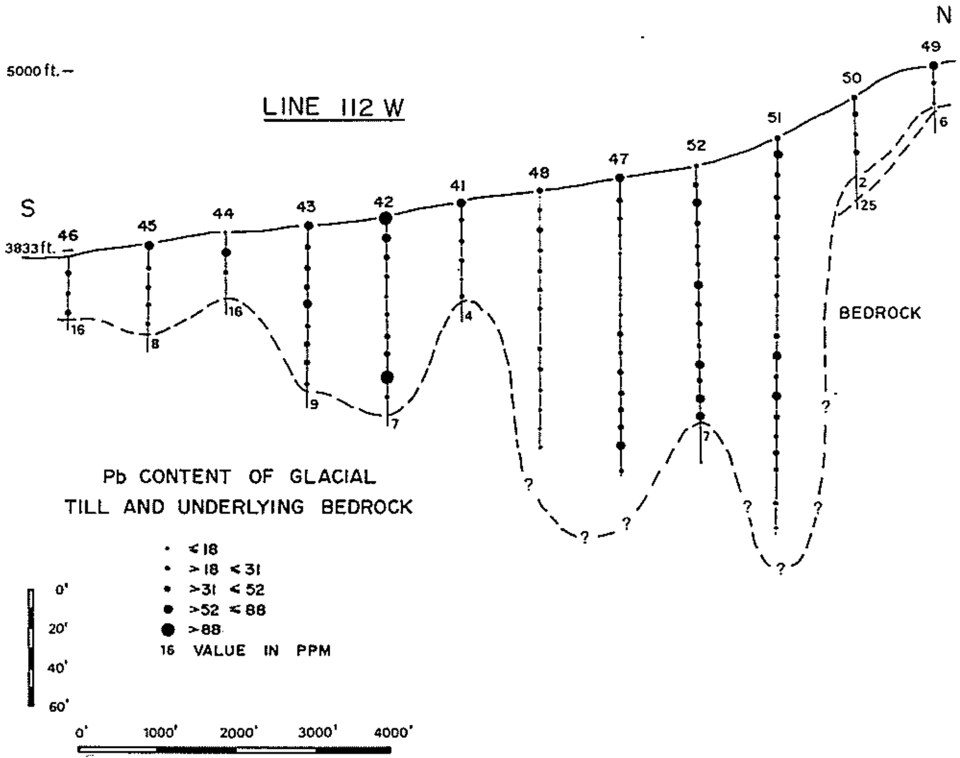

Fig.27. Distribution of total lead in bedrock in the minus 10-mesh, plus 270-mesh fraction of glacial till, Anvil.

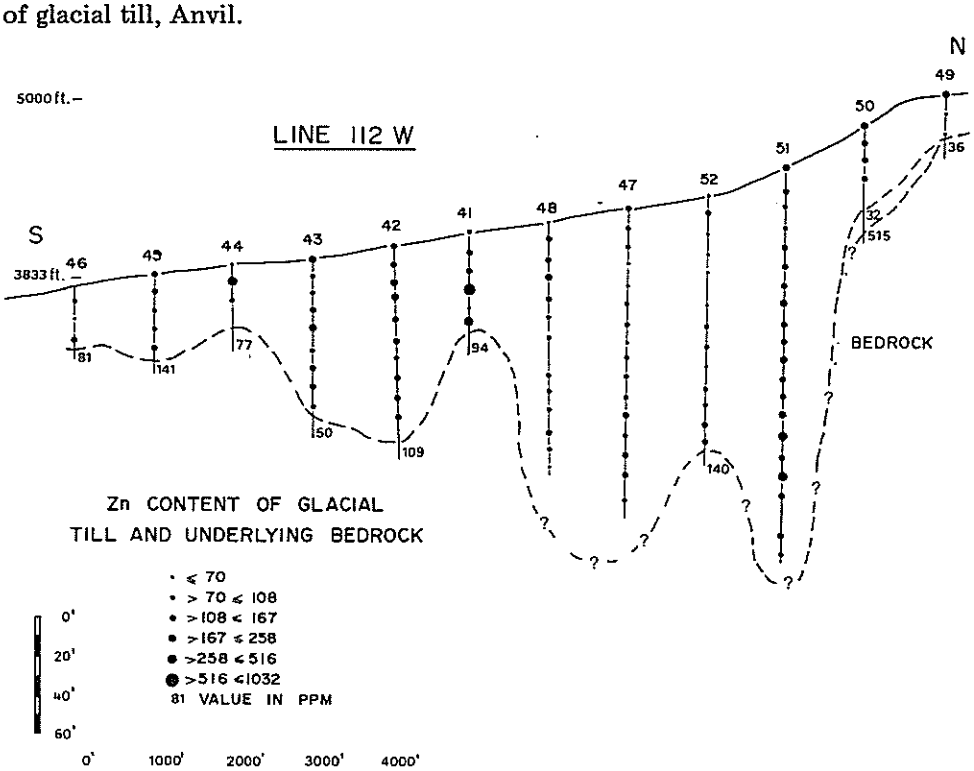

Fig.28. Distribution of total zinc in bedrock and the minus 10-mesh, plus 270-mesh fraction of glacial till, Anvil.

TABLE VI

Geometric means, log standard deviations, threshold and complete ranges of values for copper, lead and zinc in overburden

Element	Mean (ppm)	Range (ppm)	Log standard deviation (ppm)	Threshold (ppm)
All samples (n = 152)				
Cu	28	10—190	0.225	78
Pb	27	5—289	0.237	81
Zn	91	30—290	0.214	243
Till (n = 110)				
Cu	31	10—190	0.234	91
Pb	31	10—289	0.226	88
Zn	108	30—290	0.188	258
Outwash (n = 42)				
Cu	19	12—39	0.118	34
Pb	18.6	5—52	0.182	43
Zn	57	35—100	0.122	100

BELL COPPER (NEWMAN), BRITISH COLUMBIA

J.D. Knauer (*Noranda Exploration Company Limited*)

(1) Bell Copper is on Newman Peninsula on the east side of Babine Lake about 40 miles east-northeast of Smithers, British Columbia (lat. 54°59′N, long. 126°14′W).

(2) Economic mineralization is associated with a small Tertiary biotite feldspar porphyry plug intruding Mesozoic volcanic and sedimentary rocks.

(3) A supergene chalcocite zone is developed for depths up to 400 feet below the surface. Chalcopyrite, bornite, pyrite, and minor molybdenite occur in fractures, in quartz veins and as disseminations. Published ore reserves are 50 million tons of 0.5% Cu.

(4) Topography ranges from an elevation of 2,340 feet at Babine Lake to 2,570 feet in the vicinity of the orebody which underlies an overburden-covered bench. Surface drainage is poor and streams are poorly developed. The overburden over the orebody varies from 4—5 feet on the northwest to 40 feet towards the southeast. The climate is characterized by short, cool summers with considerable moisture and by long, cold winters. Vegetation is thick in low-lying areas along the lake to less dense on ridges. The intrazonal hydromorphic soils are moderately to well developed and frequently show A and B horizons, except in bogs. The B horizon is clay-rich reflecting the underlying glaciolacustrine overburden.

(5) Stream sediment samples taken after discovery of the deposit contained anomalous levels of hot HCl-extractable copper (172 ppm versus a background

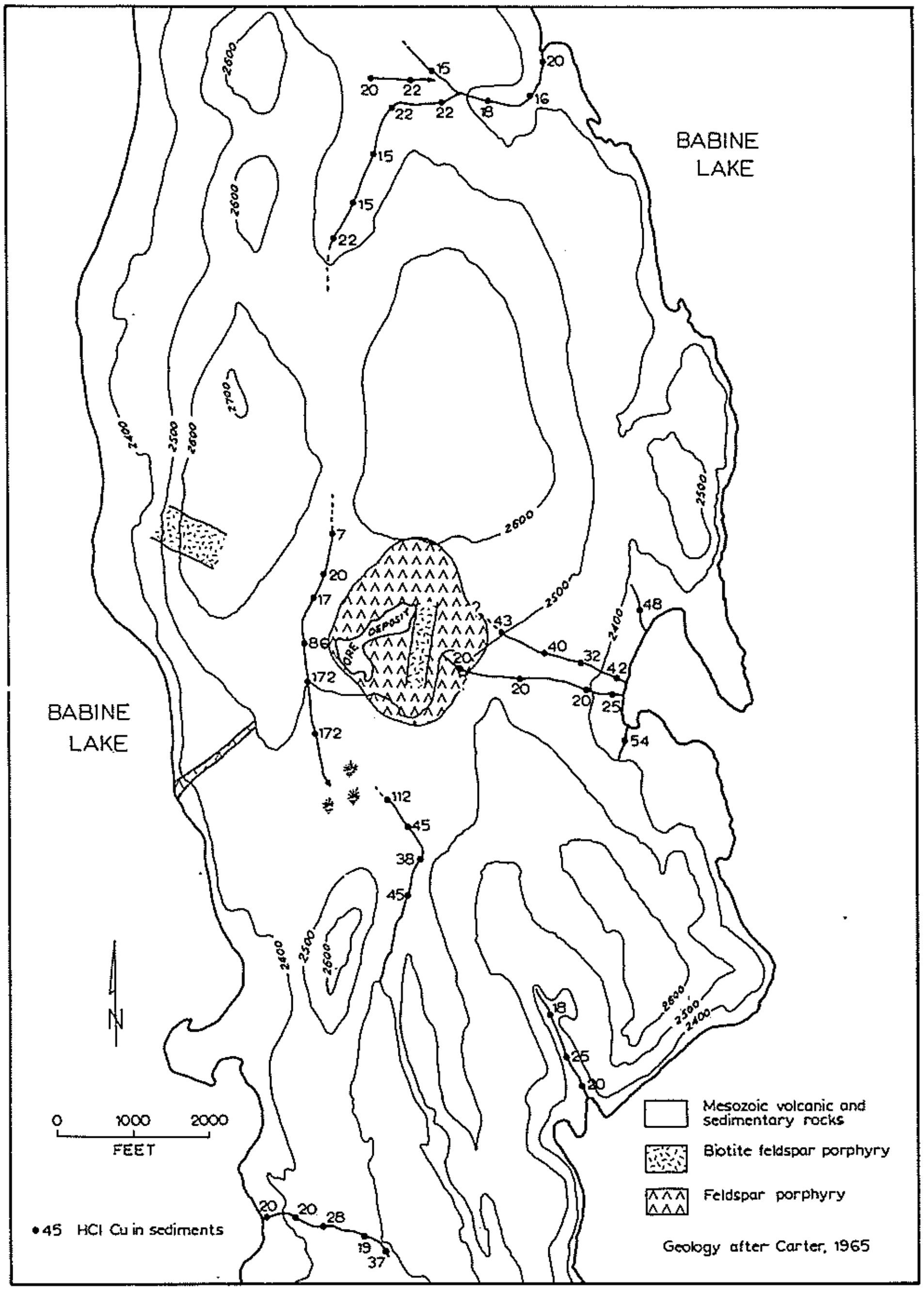

Fig.29. Distribution of HCl-extractable copper in stream sediments, Bell Copper, British Columbia. (Reproduced by permission of Noranda Exploration.)

of approximately 30—40 ppm). The position of the anomalous samples indicates hydromorphic movement beneath the transported overburden (Fig.29).

(6) Initial soil sampling in 1963 indicated several values, up to 500 ppm cold HCl-extractable copper, immediately west and south of the ore deposit. The results shown in Fig.30 are from a more detailed orientation undertaken in 1966 and 1967, and include soil profiles. These soils, analysed for $KHSO_4$

TABLE VII

Soil profiles, Bell Copper (see Fig.29 for location)

Depth (inches	Hori-zon	Cu (ppm)	Depth (inches)	Hori-zon	Cu (ppm)	Depth (inches)	Hori-zon	Cu (ppm)	Depth (inches)	Hori-zon	Cu (ppm)
Profile 1			*Profile 2*			*Profile 3*			*Profile 4*		
5	A_3	17	2	A_2	15	3	A_3	20	6	A_3	25
9	A_3/B_1	20	5	A_3	25	7	B_1	25	12	B_1	25
16	B	40	10	$A_3/B_1/B_1$	35	11	B	45	18	B?	55
21	B?	50	15	B_1	45	16	B	45	24	B?	50
26	B?C?	55	20	B	43	20	B_2/C?	55	30	B?	60
32	C	60	25	B/C?	55	26	C	50	36	B?	65
			28	B/C?	60	30	C	200			
			30	B/C?	210	37	C	1,200			
			36	B/C?	400						
Profile 5			*Profile 6*			*Profile 7*			*Profile 8*		
5	A_3	25	5	A_3	25	4	A_3	17	6	A_3	95
8	A_3/B_1?	20	6	A_3/B_1?	20	6	A_3/B_1?	20	12	B	90
14	B_1	20	12	B	25	12	B_1	20	18	B	100
20	B?	45	18	B	33	18	B	22	24	B	90
26	B?	53	24	B	40	24	B	35	30	B	70
32	B?	55	30	B	45	30	B	40	36	B/C?	80
38	B?	60	36	B?	50	36	B	35			
						40	B	45			
Profile 9			*Profile 14*			*Profile 15*			*Profile 16*		
6	A_3	20	5	A_3	20	4	A_3	17	6	A_3	50
12	B	30	13	B	55	8	B_1	25	12	A_3	100
18	B	45	19	B/C?	400	18	B/C?	80	18	B	160
24	B?	70	25	C	700	28	B/C?	65	23	B/C	220
30	B?	90				38	C	175	29	C	230
36	B/C?	100							35	C	480
									38	C	280
Profile 17			*Profile 18*			*Profiles from open pit during excavation* (29 inches to surface removed)			(36 inches to surface removed)		
9	A_3	130	9	B?	220	21–29	C	38	18–36	C	70
13	B_1	100	11	B/C	320	9–21	C	38	10–18	C	1,500
18	B_2	120	27	C	480	3–9	C	560	0–10	R	8,000
23	C	120				1–3	R	3,300			
31	C	85				0–1	R	1,600			

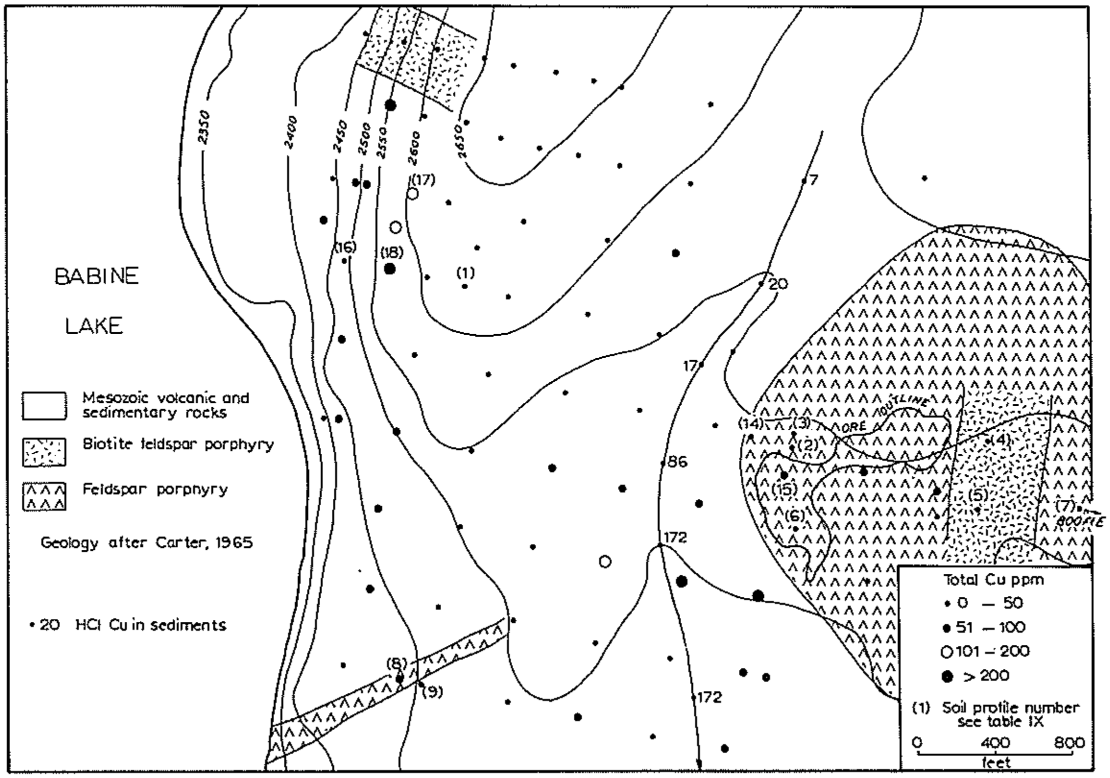

Fig.30. Distribution of copper in near-surface soils, Bell Copper. (Reproduced by permission of Noranda Exploration.)

fusion-extractable copper, also gave a few high values (maximum 1,600 ppm Cu) slightly downslope from the orebody. Profile results from the orientation survey (Table VII) indicate an absence of any anomaly at surface directly over the orebody due to the masking effect of the transported glacial overburden. Samples collected from till within a few inches of the weathered bedrock are, however, strongly anomalous (e.g. profiles 2, 3, 14, and 15).

BOSS MOUNTAIN Mo DEPOSIT, BRITISH COLUMBIA

A.E. Soregaroli (*University of British Columbia*)

(1) On the east slope of Takomkane (Big Timothy) Mountain at the headwaters of Molybdenite Creek about 35 air miles northeast of 100 Mile House (lat. 52°06′N; long. 120°56′W).

(2) Breccia and vein deposits in Triassic granodiorite host rock of Takomkane batholith adjacent to Cretaceous (100 m.y.) quartz monzonite stock (Boss Mountain stock).

(3) Molybdenite occurs in breccia pipes as well as in single and multiple quartz vein systems. Pyrite is ubiquitous and is accompanied by lesser amounts of chalcopyrite, magnetite, and sphalerite with very minor amounts of bismuth and tungsten minerals.

Reserves are not published, but production from 1965 through 1971 was 3,298,601 tons of ore from which 16,867,640 pounds of molybdenum were recovered. Remaining reserves possibly equal this production.

(4) Topography ranges from steep cirque walls on the west to flat, swampy areas on the east. Local relief is about 2,000 feet with alpine conditions above 6,500 feet.

Climate is humid continental with short, cool summers and cold, snowy winters.

Most soils are poorly developed on glacial till of variable thickness with thick organic accumulation in low-lying areas.

Vegetation is predominantly spruce in swampy, low-lying areas and balsam fir on slopes to 6,500 feet. Thick underbrush covers most wooded areas.

(5) A molybdenum geochemical train in stream sediments extends down Molybdenite Creek for a distance of 6 miles. Molybdenite Creek cuts across the main breccia zone and stream sediments immediately below this point contain several hundred parts per million molybdenum.

(6) Anomalous molybdenum values in soils define a very large target area (Fig.31) that generally agrees with the distribution of hydrothermal biotite. Highest soil values do not correlate with mineralization, but in general terms the 200-ppm contour essentially encloses all known molybdenum ore.

Total copper values in soils clearly define a northwesterly trending anoma-

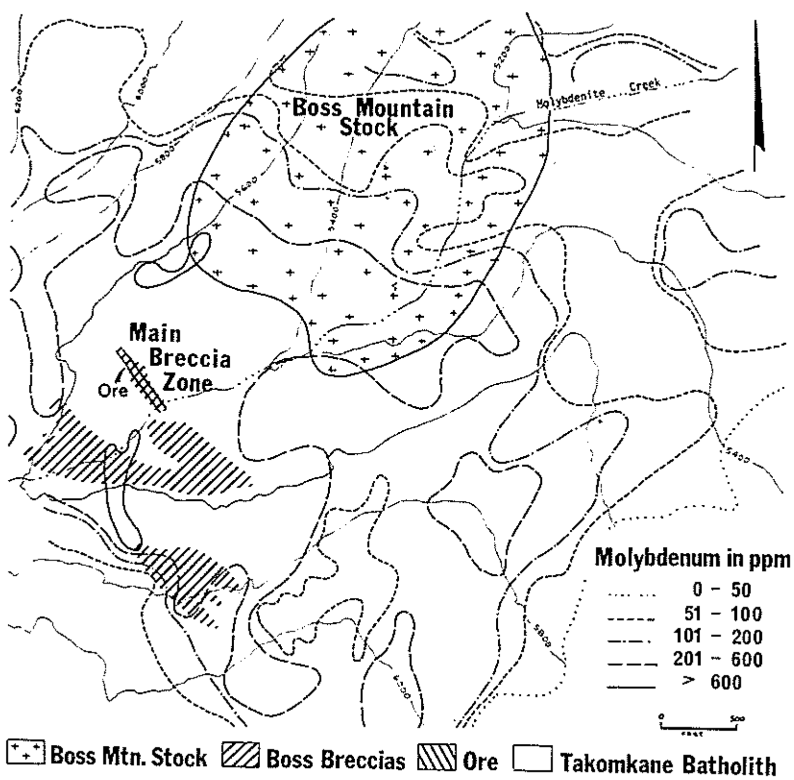

Fig.31. Distribution of molybdenum in B horizon soils, Boss Mountain, British Columbia.

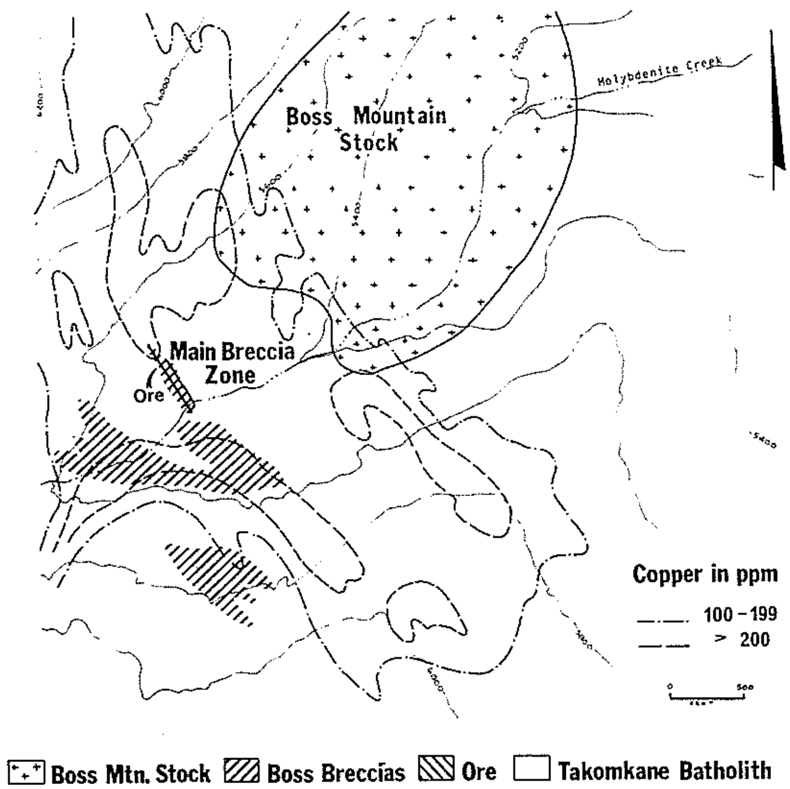

Fig.32. Distribution of copper in B horizon soils, Boss Mountain.

lous zone (7,100 ppm) that agrees in general with the 200-ppm Mo zone (Fig.32).

BRENDA Cu—Mo DEPOSIT, BRITISH COLUMBIA

A.E. Soregaroli (*University of British Columbia*)

(1) The Brenda Cu—Mo deposit is 14 miles northwest of Peachland.

(2) The deposit is entirely within the Brenda stock, a composite quartz diorite body of Jurassic age which intrudes Upper Triassic sedimentary and volcanic rocks of the Nicola Group. Pre-mineral, intermineral, and post-mineral dykes with widely divergent compositions cut the stock.

(3) Primary mineralization, predominantly chalcopyrite and molybdenite with minor pyrite and magnetite in a gangue of quartz, potash feldspar, epidote, calcite, and/or biotite, generally is confined to fracture fillings (veins). Disseminated sulphides are rare. Grade is a function of fracture density and mineralogy of the filling material.

Several chronological stages of veins with specific attitudes and mineralogy formed as a result of east—west regional compression. Intramineral trachyte porphyry dykes were emplaced after the earlier veins were formed, but prior to development of the later veins.

Hydrothermal alteration is notably weak in and around the deposit. Potassic alteration (potash feldspar and biotite), which occurs as envelopes adjacent to mineralized veins, is directly related to sulphide mineralization. Argillic and propylitic alteration appear less important.

Surface weathering leached significant molybdenum from the upper part of the orebody with concomitant development of limonite and minor quantities of other secondary minerals.

(4) The topography is generally rolling with relief less than 1,000 feet. The vegetation across the property varies from thick conifers to fairly open jackpine.

The area has been glaciated and the glacial overburden is up to 100 feet thick. The bedrock is glacially polished and so there is no residual soil in the area. However, the overburden is generally till of local origin, except in the deeper valleys (particularly in the southwest) where it is fluvial-glacial. The soils in the area are generally sandy.

(5) Sediments from streams draining the deposit range from 250 to 1,344 ppm total Cu and from 50 to 550 ppm Mg. Background values are 30—50 ppm Cu and 0 ppm Mo.

(6) A soil survey of the Brenda property conducted by Noranda Exploration Company Limited in 1963 defined a large area of interest centred on the Brenda deposit. Anomalous copper values (> 200 ppm) coincide with the area of known mineralization (Fig.33). Background values range from 10 to 80 ppm.

Molybdenum values in the soil show a remarkable coincidence with copper values. Fig.34 shows the distribution of 20 ppm or greater molybdenum values. Background values range from 0 to 10 ppm Mo.

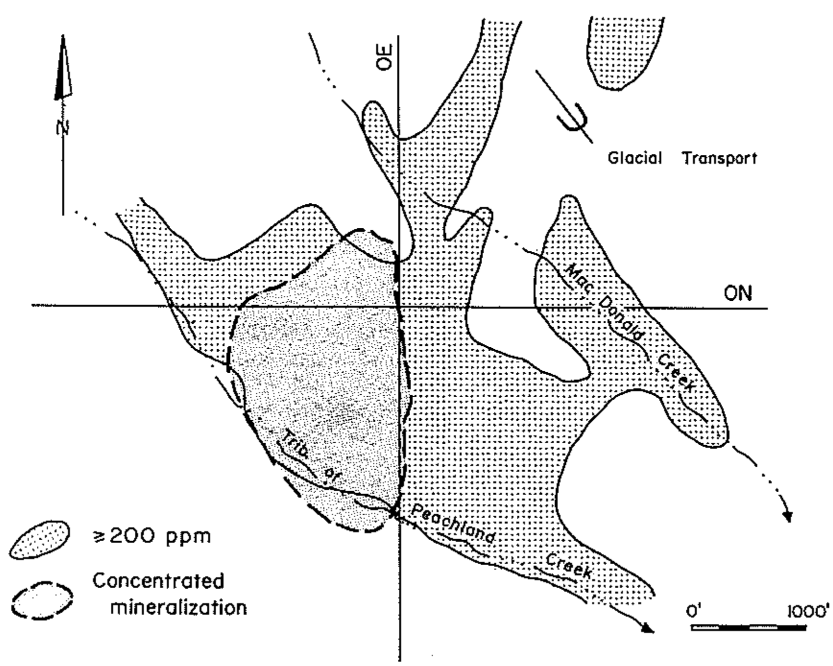

Fig.33. Copper in soils, Brenda mine, British Columbia.

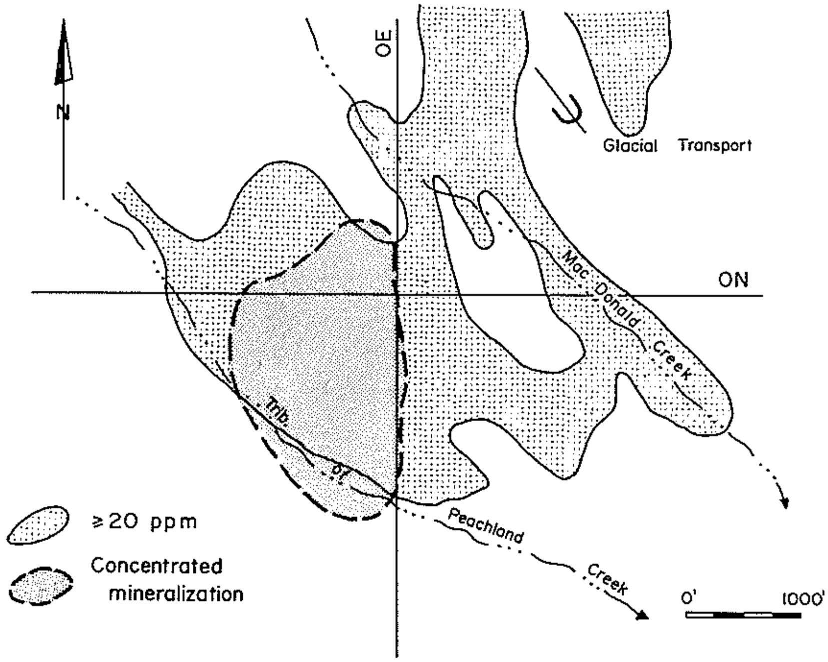

Fig.34. Molybdenum in soils, Brenda mine.

The soil results show extensions to the east and northeast, but are cut off very sharply on the west. The cut-off agrees well with a rapid decrease in mineralization in the bedrock, but probably more significantly, there is a rapid increase in the depth of overburden in this area. Southeasterly trends in soil values probably are due to glacial smearing as well as downstream migration of metal ions along Peachland and MacDonald Creeks. Changes in the nature and depth of overburden have also affected the distribution of metal values in the soil.

CARIBOO BELL Cu DEPOSIT, BRITISH COLUMBIA

J.M. Carr (*Highmont Mining Corporation Limited*)
P.M.D. Bradshaw and B.W. Smee (*Barringer Research Limited*)

(1) Situated 57 miles east-southeast of Williams Lake, British Columbia.

(2) The mineralization is semi-oxidized chalcopyrite-pyrite, both as fracture fillings and disseminated. The deposit as a whole consists of a close-spaced group of Cu—Au deposits with accompanying magnetite. The wall rock is syenite and diorite porphyries and porphyry breccia within northeast-dipping Triassic/Jurassic volcanic and pyroclastic strata.

(3) The deposit contains 28 million tons (drill-indicated) ore available for open-pit mining, averaging 0.49% Cu and 0.025 oz. Au.

(4) The soil on the property consists of three main types. The most prevalent is a brunisol which, when freely drained, becomes a podzol. The horizons for the most part are indistinct. The second soil type is found in the many

bogs on the property and may be classed as a chernozem. The LH horizon is usually 6—10 inches in depth, followed by a 4- to 6-inch A horizon and then a clay-rich or sandy B. The water table is generally close to the surface. The third type is a gleysolic soil which is found near the edges of the bogs and in the valley bottom near Bootjack Lake. This soil is water saturated, and has a hard-packed grey clay layer between 8 and 12 inches from the surface.

The relief is about 1,000 feet. The property is heavily forested, but the undergrowth is generally sparse. The property is covered with glacial till of varying thickness.

(5) No data.

(6) Only a partial soil grid has been completed on this property (Fig.35). This shows a number of erratic highs which are controlled very much by topography and development of seepage anomalies. The anomalous soil values show only a weak coincidence with the sub-outcropping mineralization, the strongest values generally occurring in seepage zones downslope. The eastern part of the soil grid is generally low but is protected from hydromor-

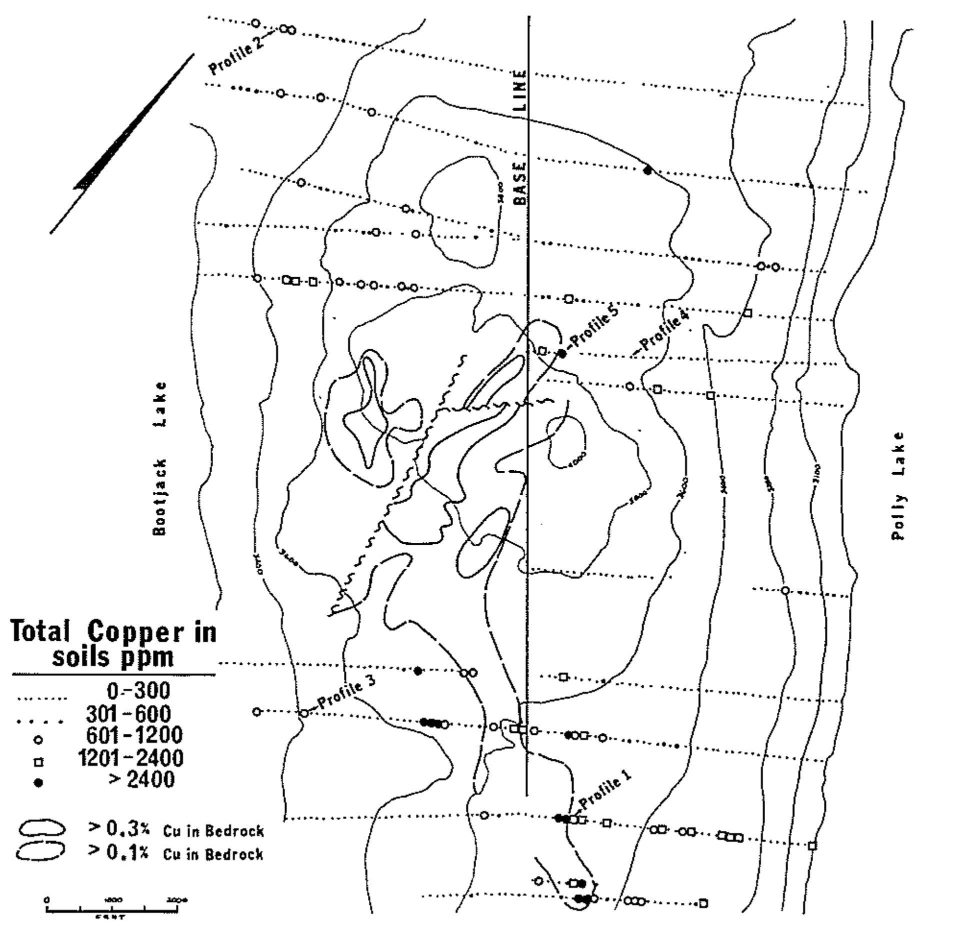

Fig.35. Distribution of copper in B horizon soils and location of soil profiles shown in Fig.36, Cariboo Bell, British Columbia.

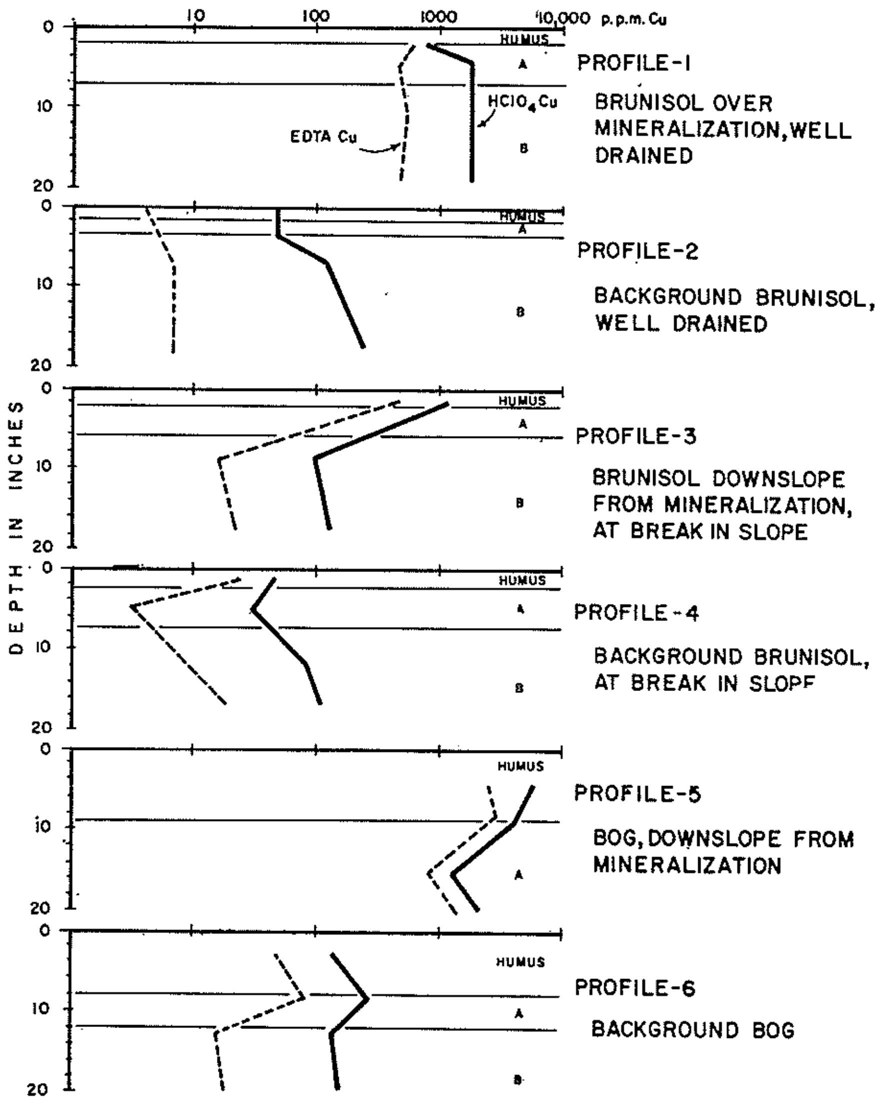

Fig.36. Distribution of total and EDTA-extractable copper down selected soil profiles (for location of profiles see Fig.35), Cariboo Bell.

phic movement from mineralization by the height of the land. Six profiles which form three pairs of anomalous and background profiles from three different situations; well-drained soil on a slope, soil at the break of slope, and material from boggy ground were collected (Fig.36). All background samples (profiles 2, 4 and 6) are characterized by having no values above 300 ppm total Cu while the profiles affected by mineralization are generally above 1,000 ppm. Profile 1, collected from well-drained soil over mineralization, shows a uniform level of copper content with depth in the mineral soil, (the uppermost A horizon is slightly lower). Profile 3, taken at the break in slope, shows an order of magnitude decrease in total copper concentration with depth down to background values. Profile 5, collected from a bog, although strongly anomalous throughout its depth, also shows a significant drop in metal content with depth.

CHUTANLI Mo PROSPECT, BRITISH COLUMBIA

M.B. Mehrtens (*Riocanex Limited*)

(1) The property is located in the Nechako Range, 70 air miles south of the town of Burns Lake within the central interior of British Columbia.

(2) The Nechako Range is underlain by Lower and Middle Jurassic andesitic and basaltic lavas, tuffs, and pyroclastics, interbedded with clastic sediments. These rocks have been intruded by granitic stocks and small batholiths of presumed Upper Cretaceous age. The bedrock is obscured by ground moraine deposited by sheet ice which moved toward the northeast.

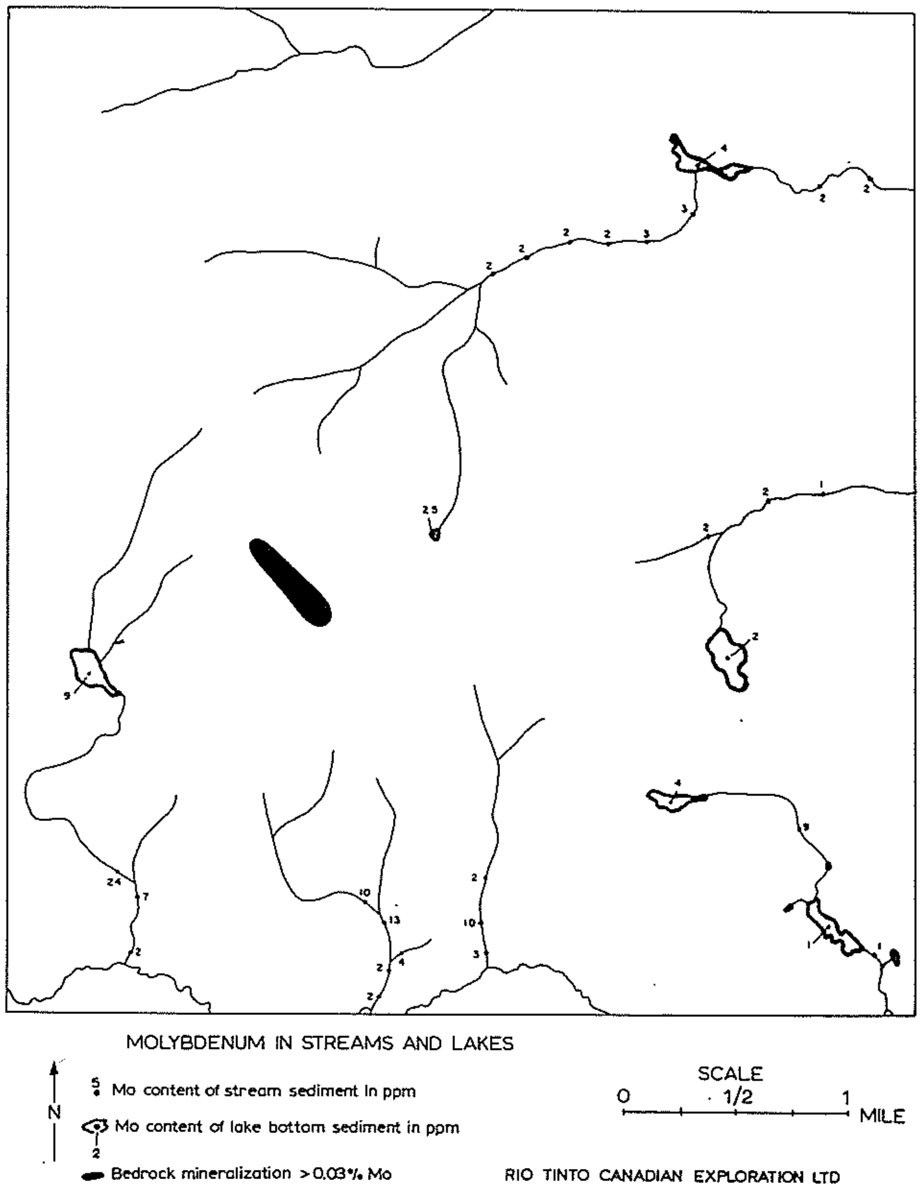

Fig.37. Distribution of molybdenum in stream sediments, Chutanli, British Columbia.

(3) The mineralization consists of stockwork pyrite and molybdenite within altered siliceous sediments adjacent to a granitic intrusive. Preliminary diamond drilling indicates grades up to 0.1% Mo.

(4) The area is characterized by rolling topography in which the elevation varies between 5,000 and 3,000 feet above sea level. The climate is temperate with 25 inches of precipitation annually. An immature podzolic soil approximately 12 inches thick has developed upon the ground moraine. Vegetation consists of coniferous forest within which grassy meadows surround most of the surface drainages.

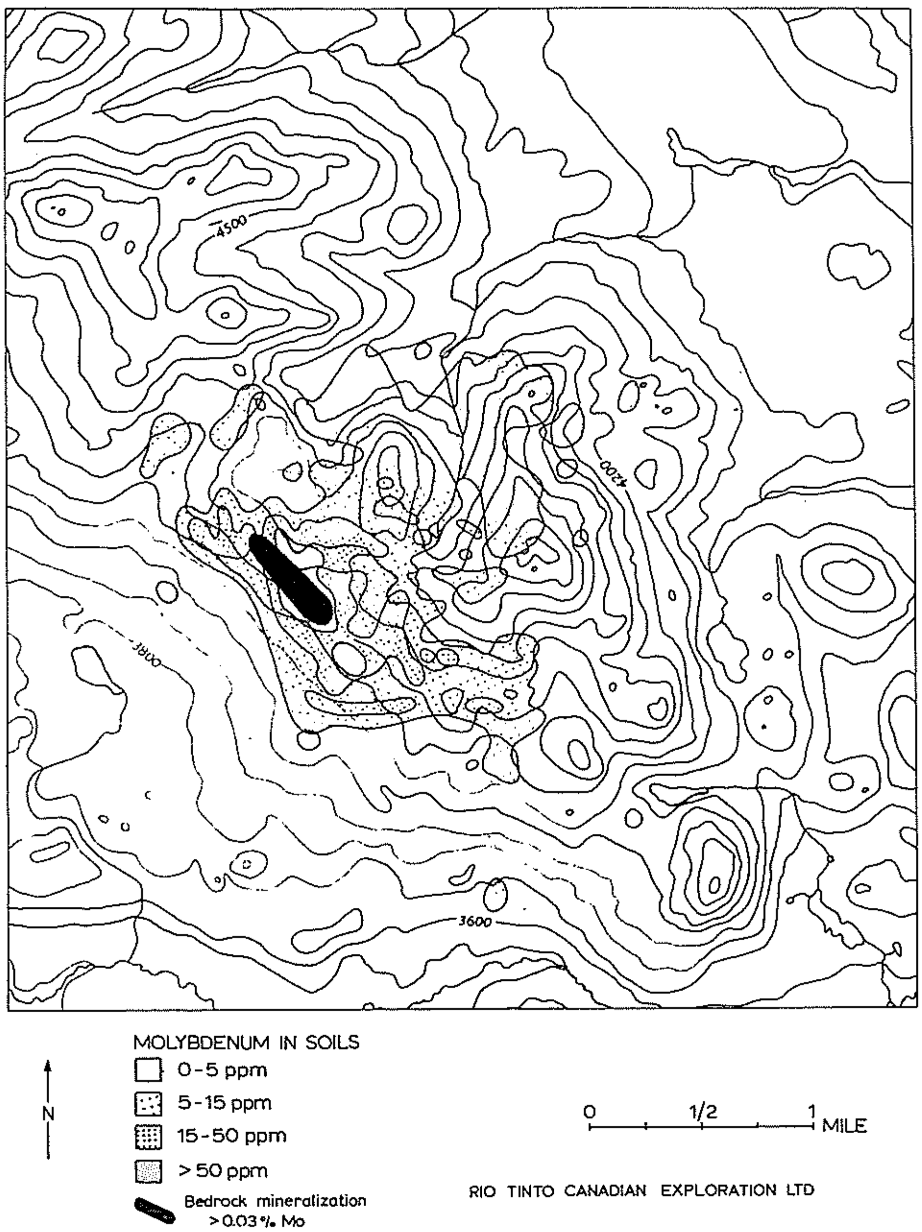

Fig.38. Distribution of molybdenum in soils, Chutanli.

(5) Molybdenum anomalies are developed in the active stream sediments down drainage from the point of emergence of shallow groundwaters. Thus, there is a "barren gap" between the anomalous drainages and the mineralized bedrock zone (Fig.37).

The results of a lake sediment survey are consistent with the foregoing, inasmuch as anomalous molybdenum values are recorded in lakes which receive drainage from mineralized ground.

(6) An extensive soil anomaly (Fig.38) characterized by an anomaly to threshold contrast up to six fold is developed immediately over the mineralized bedrock and spreads for 6,500 feet in the direction of ice transport (which is opposed to that of the drainage). This anomaly is interpreted to have formed by mechanical (ice) dispersion processes. Immediately downslope of the bedrock metal source, intensely anomalous molybdenum values are detectable in the overburden having a maximum anomaly to threshold contrast of forty-eight fold. The mode of occurrence of these intensely anomalous molybdenum values is indicative of a hydromorphic origin.

GIBRALTAR Cu—Mo DEPOSIT, BRITISH COLUMBIA

P.M.D. Bradshaw and B.W. Smee (*Barringer Research Limited*)

(1) The Gibraltar mine is situated 38 miles north-northeast of Williams Lake, in south-central British Columbia.

(2) The Cache Creek metamorphosed sedimentary and volcanic rocks of Permian age are intruded by a mineralized Triassic/Cretaceous quartz diorite pluton, the "Granite Mountain" pluton. This has been metamorphosed by a cataclastic deformation which foliated the rocks on a regional scale with simultaneous saussuritization.

(3) Mineralization is of the porphyry copper type. At least four ages of veining form a stockwork structure with pyrite, chalcopyrite, molybdenite, and bornite. The four mineable zones combined have an open-pit reserve of 358 million tons with an average of 0.37% Cu and 0.016% Mo. All four zones lie within the Granite Mountain quartz diorite pluton.

(4) The pluton forms a prominent topographic high. The mineralized area approaches very close to the peak of Granite Mountain on a plateau where drainage is slow, many bogs are developed, and the stream sediment samples are high in humic matter. On the flanks of the pluton the streams are very fast flowing until the flood plains on the Fraser River on the west and the Quesnel River on the east are encountered. Here, the gradient of the stream is lower, but sediment is still well-sorted mineral matter, low in organics. The area has been glaciated with ice movement from south to north.

(5) Sediment samples were collected at approximately $\frac{1}{4}$-mile intervals along all streams. This survey was conducted after completion of much of the drilling, but before the feasibility study was completed and the mine readied for production. Consequently, contamination is not thought to be a problem.

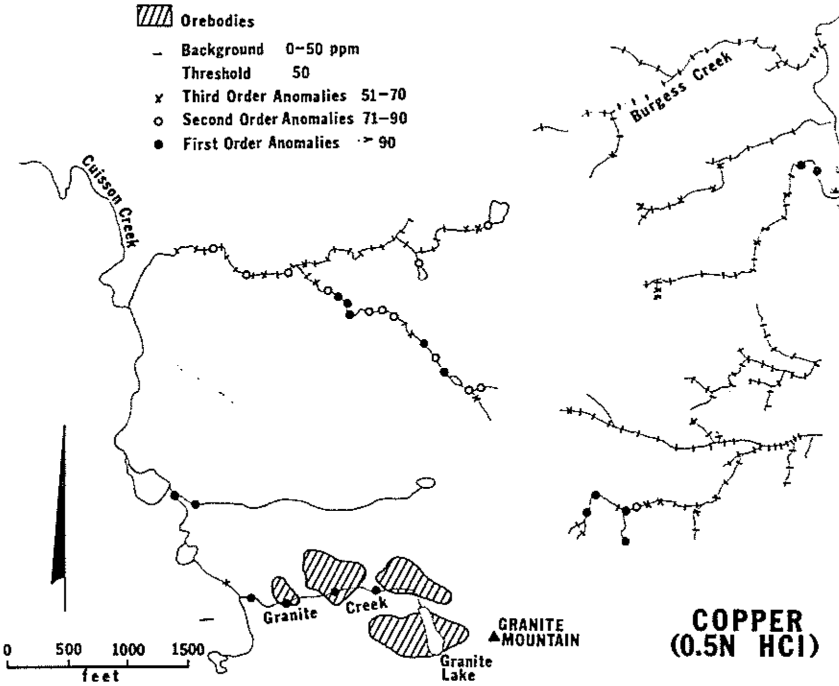

Fig.39. Distribution of 0.5N HCl-extractable copper in the minus 80-mesh fraction of stream sediments, Gibraltar mines, British Columbia.

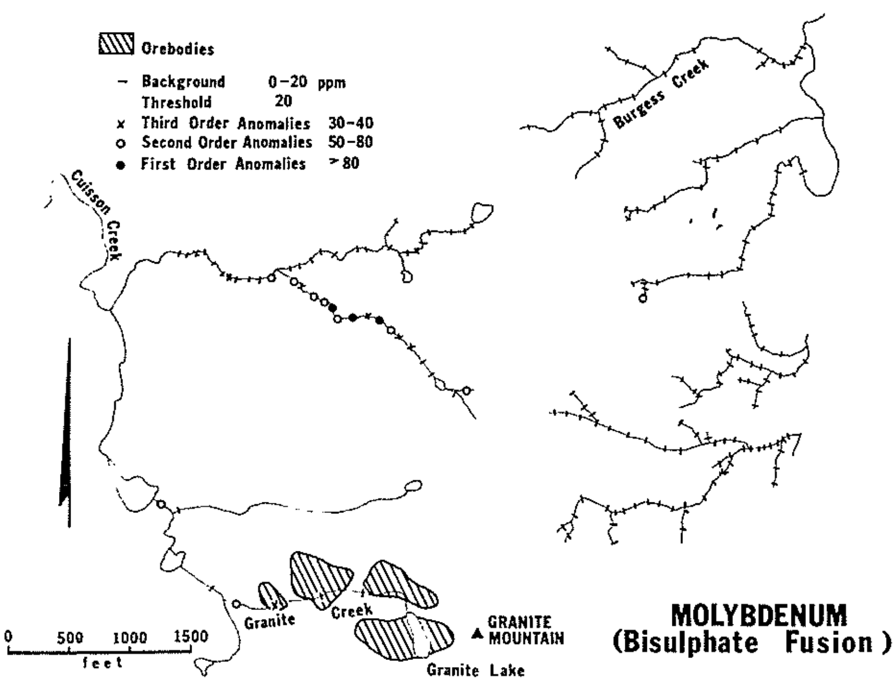

Fig.40. Distribution of bisulphate fusion-extractable molybdenum in the minus 80-mesh fraction of stream sediments, Gibraltar mines.

Copper (Fig.39) shows quite a pronounced anomaly in Granite Creek, but is also anomalous in the stream 4 miles to the north of the mineralized zones. Molybdenum (Fig.40) on the other hand is only weakly anomalous in Granite Creek, but like copper, is anomalous in the north.

The stronger copper anomaly in Granite Creek is probably due to the higher solubility of copper with respect to molybdenum in the weakly acidic conditions which exist over the pluton as a whole and around the mineralization in particular. The anomaly of both copper and molybdenum in the stream to the north is probably largely derived by glacial mechanical transport of mineralized material, although minor mineralization in the immediate area may have contributed to the stream sediment anomaly.

(6) No data.

Reference: Drummond et al., 1973.

HIGHMONT Cu—Mo DEPOSITS, BRITISH COLUMBIA

R.F. Horsnail (*Amax Exploration Incorporated*)

(1) The Highmont Cu—Mo deposits are in the southern part of the Highland Valley porphyry copper district, 125 miles northeast of Vancouver.

(2) The geology has been described in some detail by Bergey et al. (1971), and reference should be made to their article. In brief, the six Highmont ore zones occur near the centre of the Lower Jurassic Guichon batholith, where a north-trending swarm of porphyry dykes is crossed by a west-northwesterly structural belt in which fracturing, intrusion of porphyry and breccia and mineralization are concentrated.

(3) The deposit consists of six separate ore zones. The largest (No.1 zone) is 123.5 million tons, averaging 0.287% Cu and 0.042% Mo, and the No.2 zone is 26.5 million tons, averaging 0.273% Cu and 0.093% Mo.

(4) The Highland Valley generally receives moderate to light precipitation. The soils clearly reflect variations in the landscape and drainage conditions. Brown-wooded earths occur on the steeper slopes with some podzolization where the parent material is sandy, giving better down-profile drainage. In low-lying areas, where the water table approaches the surface, humic gleysols are prevalent which pass with increased waterlogging into meadow bogs. Drainage is surface and external though interrupted by numerous small swampy areas and ponds. Vegetation is dominantly jackpine and spruce although nardus and sphagnum are dominant in waterlogged areas.

(5) No data.

(6) The soil-grid data have been given by Bergey et al. (1971). These data show the effect of mechanical movement by glacial action of mineralized rock fragments down-ice. This has resulted in a strong copper and molybdenum anomaly upslope from the main No.1 ore zone. This geochemical pattern has

been further disturbed by hydromorphic movement. As a consequence of these two effects, the strongest near-surface soil response frequently does not directly overlie the best mineralization.

In a study separate from the soil-grid results reported by Bergey et al. (1971), two catenas of overburden profiles were taken, one in the north and one in the southeast. In both cases, samples were taken from freely drained, gently sloping hillsides covered by podzolic soils, and from adjacent lower-lying, poorly drained areas where humic gleysols and basin peats occur.

One of the most striking features of the data is that there is a marked variation in copper content between freely drained and poorly drained soils (Table VIII). This is clearly illustrated by two profiles taken to the northwest of Gnawed Lake from sites approximately 200 feet apart. The freely drained profile exhibits a depletion of copper in the upper horizons whilst in the imperfectly drained profile, copper accumulates markedly in the organic-rich topsoil.

A further example is afforded by two profiles taken from sites only 30 feet apart in this same general area. One is a podzolic profile from the freely drained site of a small valley whilst the other soil, which shows an approximate twenty-fold enhancement in copper content, is an imperfectly drained humic brown earth adjacent to a small creek in the valley floor (Table IX). Several profiles were taken in the southeast of the area; one was from a trench over mineralized bedrock, two were from a freely drained hillside, and three from a poorly drained seepage basin.

In the soil over mineralized bedrock, which is only 18 inches deep, anomalous copper and molybdenum values are present throughout, although some accumulation of copper is noted in the organic litter-rich topsoil (Table X).

The two podzolic profiles in this area are both of notably acid reaction. They exhibit some depletion of copper in the topmost few inches, but the samples are clearly anomalous being 300—450 ppm (Table XI). Molybdenum shows little variation with values of 20—16 ppm through both profiles. Two rock chips from the subsoils carry malachite stains and have copper contents of 250 and 990 ppm. The damp soil at the break in slope on the edge of the basin bog shows some evidence of gleying and the beginning of humus accumulation; the water table here is within a few inches of the surface. Copper values are at a maximum in the near-surface soil (2,120 ppm) but decrease with depth (to 1,150 ppm at 20 inches). This is the reverse of the pattern shown in freely drained soils upslope.

In the swamp profiles, where the water table lies at the surface, extremely high copper values are recorded ranging from 0.5 to 2.6%. Molybdenum also shows some, though less marked, enhancement with values of from 30 to 110 ppm. The highest copper values are in the top 12 inches of the profiles (Table XII).

In summary, the occurrence of mineralized rock fragments in the glacial till suggests that the original mode of secondary dispersion on the property was mechanical by means of glacial scouring. Much of the fine-grained frac-

TABLE VIII

Comparison between freely and imperfectly drained soil profiles to northwest of Gnawed Lake

No.	Horizon	Depth (inches)	Mo (ppm)	Cu (ppm)	EDTA Cu (ppm)	Organic (%)	Mn (ppm)	Fe (%)	Zn (ppm)	Pb (ppm)	pH
Podzol (freely drained)											
69Z341	LH	1	2	88	16	50	640	1.6	52	20	6.0
342	Aej	2	2	200	12	1	140	2.1	36	16	—
343	Bf	12	2	780	8	1	140	2.2	36	16	6.6
Podzol (imperfectly drained)											
69Z344	Ah	1	2	14,300	8,800	70	340	3.3	56	16	—
345	Bh	4	2	6,400	2,040	20	220	2.3	40	12	6.2
346	BC	15	1	1,000	184	1	180	1.7	20	8	—
347	till	26	1	1,150	260	0	240	2.0	28	8	6.6
347	till	48	1	930	236	0	240	1.9	28	12	—

TABLE IX

Comparison between freely and imperfectly drained soils

No.	Horizon	Depth (inches)	Mo (ppm)	Cu (ppm)	EDTA Cu (ppm)	Organic (%)	Mn (ppm)	Fe (%)	Zn (ppm)	Pb (ppm)	pH
Podzol (freely drained)											
69Z353	LH	1	10	62	24	50	600	1.1	64	16	—
354	Ae	2	6	52	4	2	120	2.0	80	14	6.5
355	Bf	12	6	55	4	2	120	1.9	64	8	—
Humic brown earth (imperfectly drained)											
69Z356	Ae	1	15	1,000	244	70	120	3.5	40	16	6.6
357	Bh	6	18	1,080	308	50	480	3.8	40	16	—
358	Bm	12	22	1,290	380	10	680	4.4	52	16	6.9

TABLE X

Freely drained soil overlying mineralization

No.	Horizon	Depth (inches)	Mo (ppm)	Cu (ppm)	EDTA Cu (ppm)	Organic (%)	Mn (ppm)	Fe (%)	Zn (ppm)	Pb (ppm)	pH
69Z360	Ah	2	42	10,500	5,800	50	500	4.0	120	20	—
361	Bf	6	38	6,100	1,640	5	300	3.4	88	20	6.6
362	till	10	34	2,320	1,000	0	120	2.5	40	8	—
363	till	18	38	8,000	7,400	0	160	2.8	60	12	6.5

TABLE XI

Podzolic profiles in the southeast of the Highmont property

No.	Horizon	Depth (inches)	Mo (ppm)	Cu (ppm)	EDTA Cu (ppm)	Organic (%)	Mn (ppm)	Fe (%)	Zn (ppm)	Pb (ppm)	pH
69Z381	LH	1	14	92	20	30	640	1.1	72	20	5.2
382	Aej	3	16	370	12	3	100	1.8	52	14	—
383	Bf	10	14	360	24	5	100	1.6	48	8	5.4
384	Bm	20	16	450	22	7	120	1.6	44	20	—
385	rock		8	990	480	—	260	1.8	32	14	—
69Z386	LH	1	12	32	16	90	360	0.5	52	14	4.5
387	Ae	1.5	16	230	20	10	100	1.8	56	16	—
388	Bf	9	16	310	20	5	90	1.8	60	12	5.1
389	Bm	15	14	290	20	10	30	1.6	56	16	—
390	rock		2	250	84	—	140	1.0	16	12	—

TABLE XII

Swamp profiles in the southeast of the Highmont property

No.	Horizon	Depth (inches)	Mo (ppm)	Cu (ppm)	EDTA Cu (ppm)	Organic (%)	Mn (ppm)	Fe (%)	Zn (ppm)	Pb (ppm)	pH
69Z363	FH	2	112	6,400	5,000	70	740	2.6	20	12	—
366	Ah	10	80	9,500	7,400	70	540	2.1	22	16	6.3
367	Ah	24	40	5,300	3,680	40	280	1.0	20	16	—
368	BhG	33	32	1,900	1,360	5	180	1.7	44	8	6.5
69Z369	FH	1	48	26,000	14,000	70	960	3.1	48	20	—
370	Ah	6	40	20,000	14,000	70	540	2.1	40	16	6.4
371	Ah	16	66	14,300	11,400	40	640	2.0	44	16	—
372	BhG	30	32	6,900	5,800	15	460	2.2	56	8	6.8

tion of the till is, however, probably relatively near to its point of origin.

At the present time, hydromorphic dispersion followed by organic chelation and accumulation is operative and this produces considerable distortion of the original till anomaly. Copper is readily leached from the upper horizons of acid freely drained soils and migrates with groundwater to seepage depressions where it is greatly concentrated by a fixation process — possibly chelation. Molybdenum appears affected by the same process to some degree but less markedly so than does copper.

HUCKLEBERRY Cu–Mo DEPOSIT, BRITISH COLUMBIA

A. Sutherland-Brown (*British Columbia Department of Mines and Petroleum Resources*)

(1) Just north of Tahtsa Reach and south of Sweeney Lake (lat. 53°40'N, long. 127°10'W).

(2) An elliptical cylindrical pluton of granodiorite porphyry of Late Cretaceous age (82 m.y.) cuts Jurassic andesitic tuffs and greywackes of the Hazelton Group and is surrounded by an annular orebody that is largest on the east.

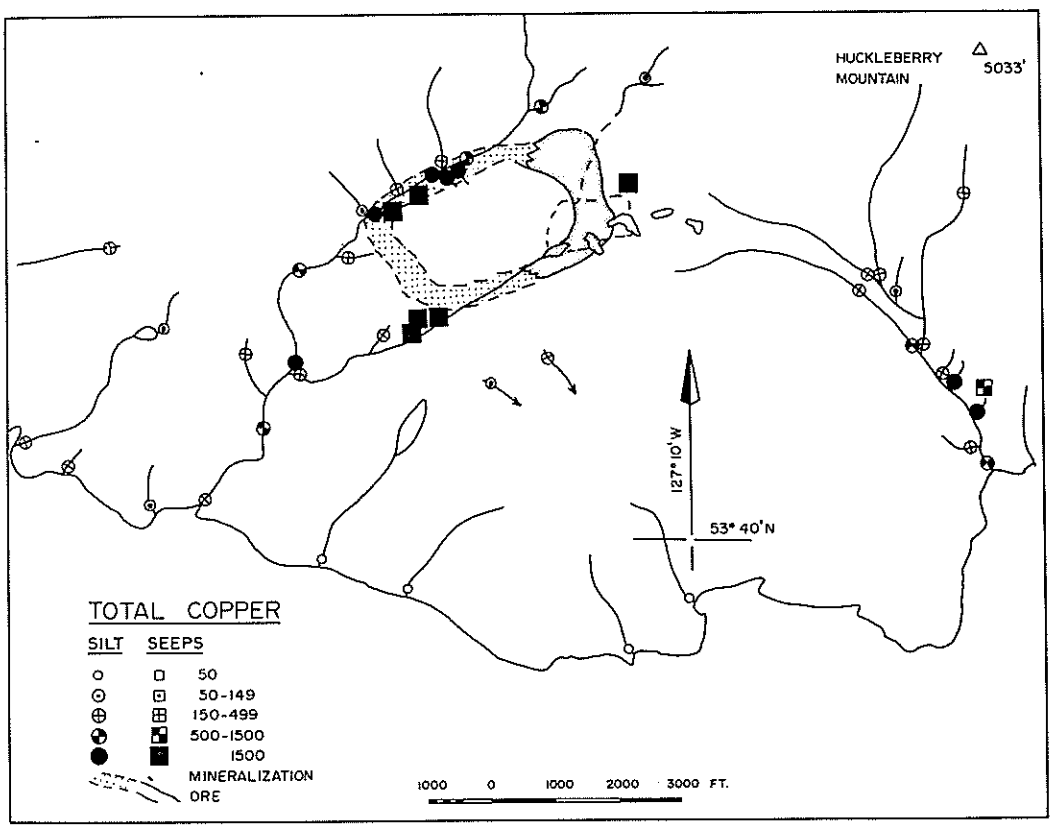

Fig.41. Copper in stream sediments and seepages; Huckleberry, British Columbia (after Kennco Exploration).

(3) The mineralization consists of pyrite, chalcopyrite, and lesser molybdenite and the proven reserves are of the order of 50 million tons of 0.50% Cu, and 0.025% molybdenite.

(4) The area has been intensely glaciated, has a local relief of only 2,000 feet but is on the fringe of an alpine area. The pluton and orebody occur largely on a knobby bench of minor relief approximately 500 feet above Tahtsa Reach. The property has a humid continental climate with a cool, short summer. Thin till covers 75% of the property and bogs and ponds occur over the mineralized body east of the knob on which the porphyry pluton is poorly exposed. A podzolic soil with a B horizon of 8—15 inches is developed exclusive of the bogs. The main area is covered with a young forest of alpine fir and lodgepole pine, and the bogs with sedge and meadow grass.

(5) Total copper, zinc, and molybdenum results in stream sediments, and in certain cases, in seepage areas, are shown in Figs.41—43. All three elements show anomalous dispersion with the two ore-forming metals — copper and molybdenum — giving the strongest and largest dispersion train. Zinc shows only a weak association. In general, the seepage samples show significantly higher metal values than the adjacent stream sediment samples.

The high metal values in the eastern drainage are related to a probable covered porphyry body.

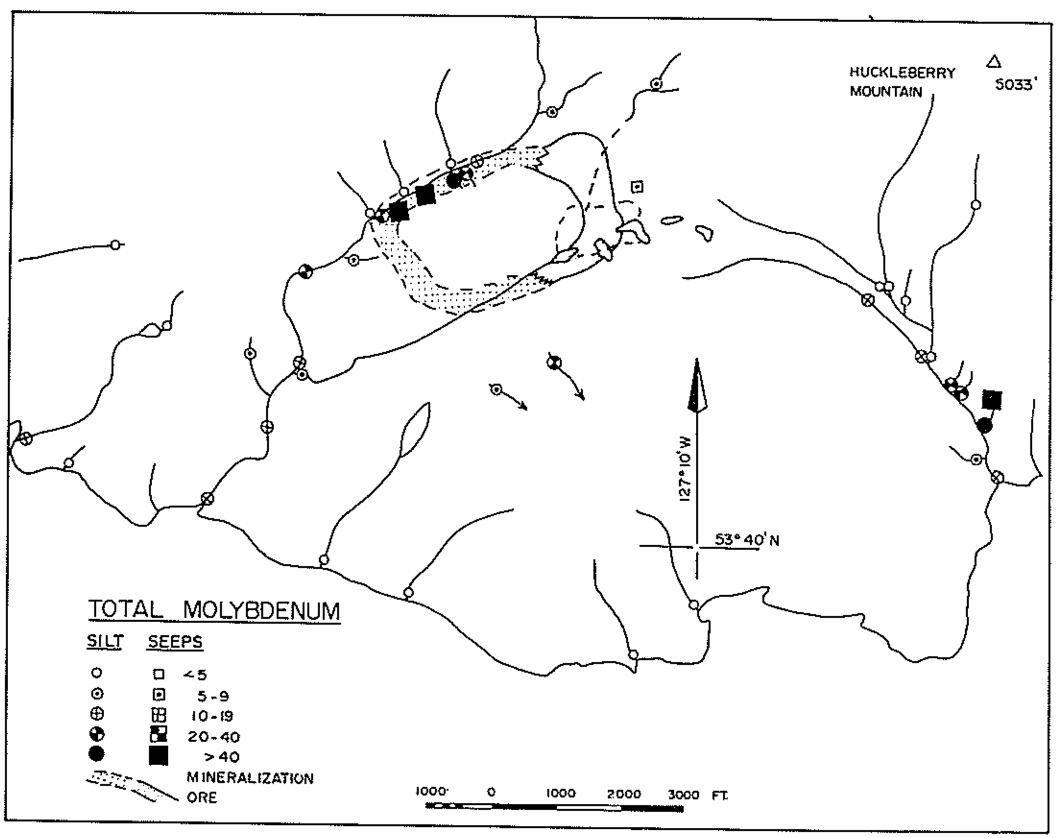

Fig.42. Molybdenum in stream sediments and seepages, Huckleberry (after Kennco Exploration).

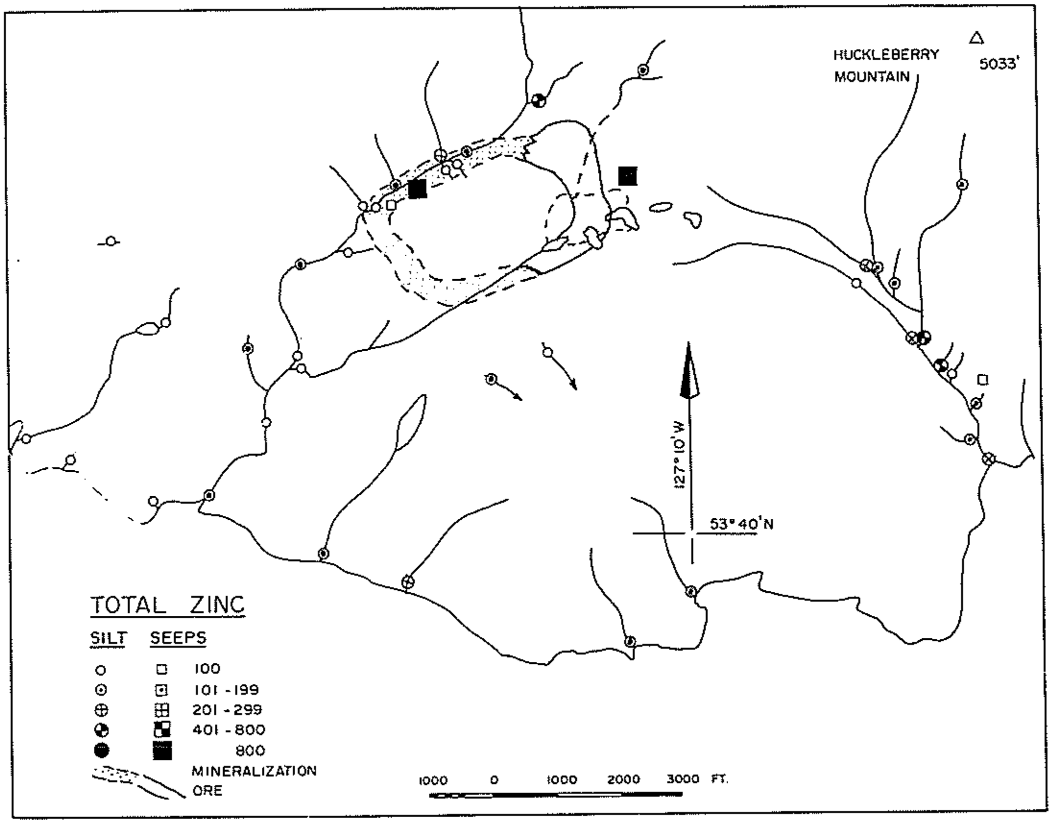

Fig.43. Zinc in stream sediments and seepages, Huckleberry (after Kennco Exploration).

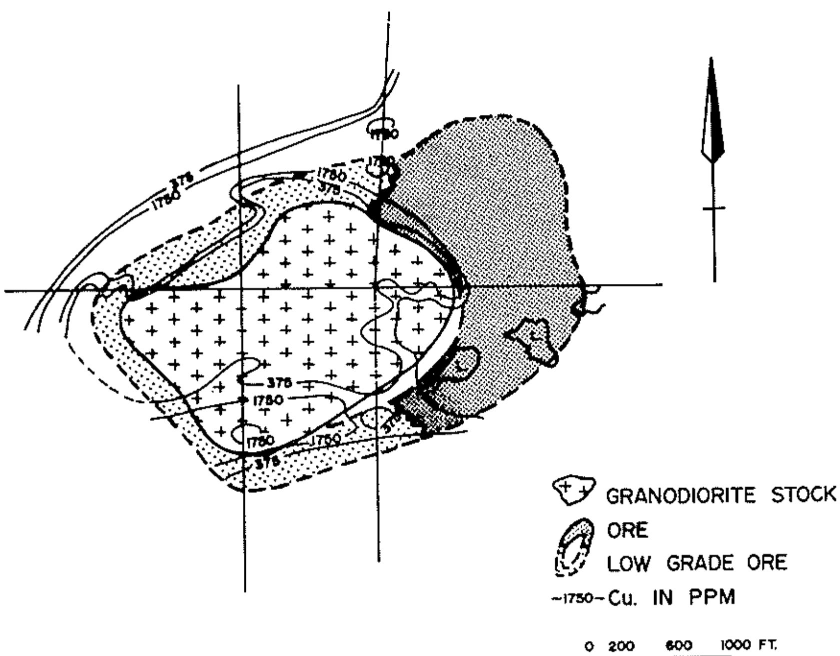

Fig.44. Distribution of copper in soils, Huckleberry (after Hornbrook, 1970).

(6) Detailed soil sampling has only been undertaken over the claims surrounding the best mineralization after successful drilling undertaken on the basis of the reconnaissance sediment survey and geology. The Ah and B horizon soil samples were analyzed for total copper and molybdenum (HF, HNO_3, $HClO_4$ digestion). The results for copper in the B horizon only, modified from Hornbrook (1970), are shown together with the position of the known mineralization (Fig.44).

The soil anomaly clearly defines the location of the Cu—Mo mineralized zone peripheral to the stock. However, this anomaly also coincides with the circumfluent drainage pattern about the stock and may be modified metal-rich seepage zones. There is no indication of modification of the soil anomaly by glacial action.

References: Stevenson, 1970; D.A. Barr, personal communication, 1973.

INGERBELLE Cu DEPOSIT, BRITISH COLUMBIA

J.A. Coope (*Newmont Mining Corporation*)

(1) Located 11 miles south of Princeton, British Columbia.

(2) The oldest rocks in the Ingerbelle area are the Nicola Group consisting of andesitic volcanic agglomerates, tuffs, and flows with small sedimentary lenses. Extensive alteration has produced tough massive rocks and most of the copper mineralization occurs in this group of rocks. Intruding the Nicola rocks on the south is the Copper Mountain stock which carries only traces of mineralization.

(3) Sulphide minerals are mainly chalcopyrite and pyrite in amounts up to 5%. The ratio between these two minerals changes gradually or abruptly from one part of the orebody to another. Pyrrhotite and molybdenite occur locally. The sulphides are finely disseminated through the host rock with some coarser blebs and veinlets.

(4) The Ingerbelle area is located on the eastern side of the Cascade Mountain Range and is bounded on the south by the deeply incised valley of the Similkameen River. Relief variations in the vicinity of the mine are of the order of 1,000 feet. The mineral deposit is overlain by glaciofluvial gravels and the gravel depth varies from 0 to approximately 50 feet. Soil development is shallow (to 20 inches) and podzolic. The climate is relatively dry with an annual precipitation of about 14 inches. Temperatures range from 90°F in summer to a few days of —20°F in winter. The district is well forested, the vegetation being dominated by the Ponderosa pine.

(5) No data.

(6) A single soil profile was collected through the transported glaciofluvial deposit and boulder clay into weathered bedrock (Table XIII) to a total depth of 104 inches. The bedrock at this point is weakly mineralized andesite with approximately 0.15% Cu. The transported glacial material completely masks all geochemical response in the overlying soil.

TABLE XIII

Profile through fluvioglacial deposits overlying mineralized bedrock Ingerbelle Copper deposit, Princeton, British Columbia

Depth (inches)	Description	Cu (ppm)
0—13	Grey loam with angular rock fragments. Many roots. Leached zone below surface vegetation.	30
13—26	Continuation of above passing down into waterlain glacial sands. Little evidence of B horizon development. Roots numerous.	119
26—39	Brown sandy loam — waterlain glacial sediments.	97
39—52	Distinct lower contact at 52 inches.	104
52—65	Light brown clayey rubbly loam. Rounded rock fragments prominent (boulder clay).	201
65—78	As above (52—65 inches) but containing iron-stained patches of weathered bedrock. Sharp lower contact.	216
78—91	Deeply weathered yellow-brown iron-stained and altered andesite?	1,540
91—104	Altered andesite? As above, cut by flat lying minor fault.	1,666

ISLAND COPPER DEPOSIT, BRITISH COLUMBIA

A. Sutherland-Brown (*British Columbia Department of Mines and Petroleum Resources*)

(1) Immediately north of west end of Rupert Inlet, Vancouver Island; 6 miles south of Port Hardy (lat. 50°36′N; long. 127°28.5′W).

(2) A volcanic porphyry deposit in which the orebody is centred on an altered lineal quartz-feldspar porphyry pluton of Mid-Jurassic age but is largely contained within the hornfelsic aureole in gently south-dipping pyroclastic rocks of the Bonanza Formation that are virtually coeval with the pluton.

(3) Mineralization consists of very fine-grained chalcopyrite and abundant pyrite in an intense fracture stockwork with minor molybdenite in siliceous zones. The orebody was stated to contain 280 million tons, averaging 0.52% Cu, and 0.029% molybdenite.

(4) The area is an intensely glaciated lowland with elevations varying from sea level to 500 feet. It has a marine west-coast climate and is covered by a dense mature growth of hemlock, sitka spruce, red cedar with some alder. The deposit is covered by a highly variable thickness of overburden consisting of a thin till overlain by up to 250 feet of glaciofluvial sands and gravels. Soil development consists of a thick organic layer (2 feet) over about 4 feet of brunisol (?)B horizon.

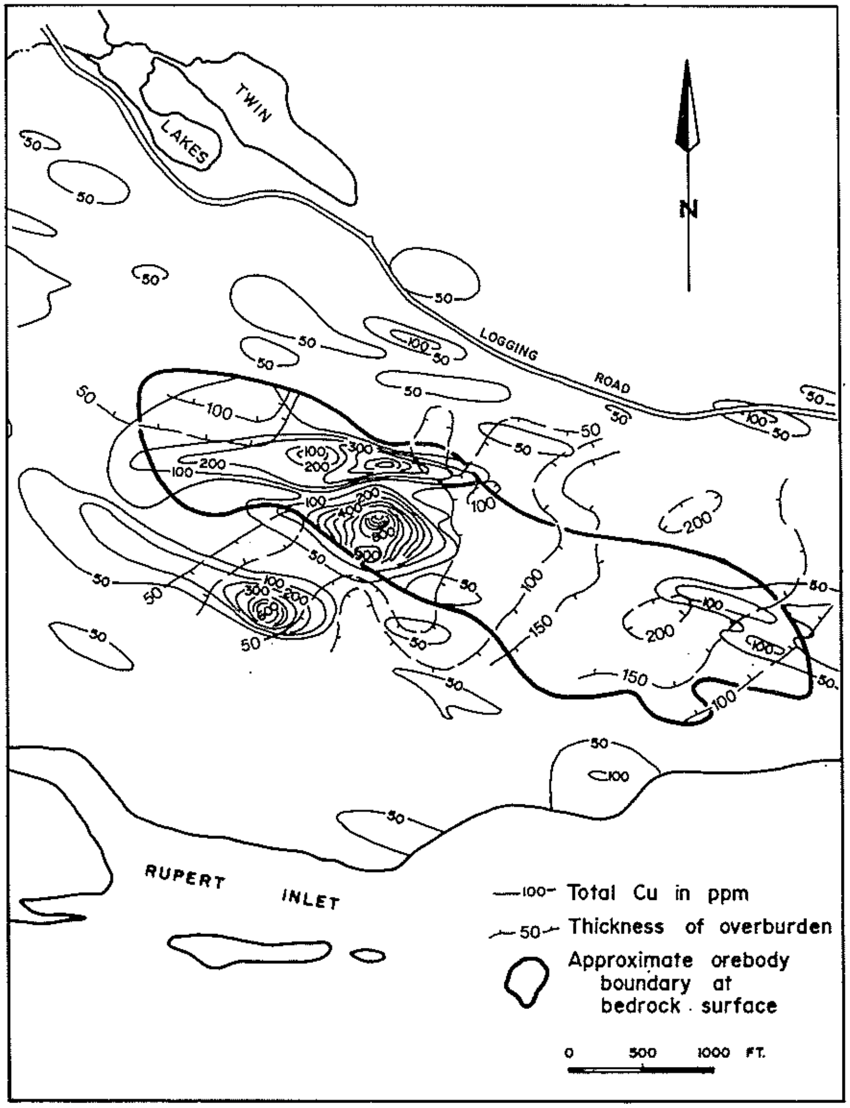

Fig.45. Copper distribution in soils, Island Copper, British Columbia (after Young and Rugg, 1971).

(5) No data.

(6) A regular soil grid was sampled over the entire area (Fig.45) collecting samples from the B horizon or its equivalent, as far as was possible. The distribution of copper in the soil is directly related to overburden type and thickness. The presence of glaciofluvial material of foreign provenance completely masks the copper anomaly in the upper soil. In areas where the glaciofluvial material is absent, and particularly where the till is thin, a moderate soil anomaly is found. As well as the soil grid, two individual soil profiles are also shown (Table XIV).

References: Young and Rugg, 1971; M.L. Young, personal communication, 1973.

TABLE XIV

Copper content in soils, Island Copper

Horizon	Description	Depth (inches)	Background (ppm)	Anomalous (ppm)
Shallow till overburden				
A	organic	0—2		
B	red brown, sandy	2—3	40	90
B	red brown	3—4	40	170
B_2	gray brown	4—5	40	190
B_2	gray brown	5—6	40	—
Till	gray brown	6—8	55	880
Bedrock			50	1,680
Medium depth till and stratified drift				
A	organic	0—1.5	40	50
B	red brown, sandy	1.5—4	40	50
Glaciofluvial	stratified sand and gravel	4—13	50	70
Mixed	mixed till and glaciofluvial	13—20	60	450
Mixed	mixed till and glaciofluvial	20—28	50	170
Till	gray brown	28—55	40	5,000
Bedrock				

KENO HILL Pb—Zn—Ag AREA, YUKON TERRITORY

R.W. Boyle (*Geological Survey of Canada*)
C.F. Gleeson (*C.F. Gleeson and Associates*)

(1) This area is located in central Yukon, 35 miles northeast of Mayo, and 220 miles due north of Whitehorse.

(2) The regional geology has been described by Bostock (1947, 1964), and Green and Roddick (1962). More detailed geological studies have been made by Green (1957, 1958), McTaggart (1960), Kindle (1962), and Poole (1965). The geology, geochemistry, and origin of the mineral deposits in the Keno Hill and Dublin Gulch areas have been described by Boyle (1965). Reports by Aho (1964) and Cockfield (1921) provide further information on mineral deposits of the area.

The map area is underlain by a series of metamorphosed sedimentary rocks, mainly quartzites, phyllites, slates, chlorite, sericite and graphite schists, also grits and minor limestone. The age of these rocks is uncertain and appears to range from Precambrian to Mesozoic (Poole, 1965).

A dolomite and limestone unit outcrops in the northeast part of the area. Fossils from these rocks range in age from Late Cambrian to Late Silurian or Early Devonian (Green and Roddick, 1962).

Mafic igneous sills and lenses now altered to greenstones are interlayered with the metamorphosed sediments. Quartz-feldspar porphyry sills and lamprophyre dykes are present locally. Granitic stocks cut the metamorphosed sediments east and north of Mayo Lake, northwest of Hanson Lake, south of Dublin Gulch and in the vicinity of Mount Haldane. These granitic rocks are of Cretaceous age.

(3) Most of the Pb—Ag ore deposits in the Keno- Galena Hills area occur along northeasterly striking vein faults in thick-bedded quartzite and occasionally in greenstone (Boyle, 1965). In the Dublin Gulch area quartz arsenopyrite-gold veins with a general northeast strike are present near the contacts of the granitic stocks. Also easterly striking vein faults are mineralized with siderite, jamesonite, boulangerite, pyrite, arsenopyrite, galena, tetrahedrite and chalcopyrite. Two cassiterite-tourmaline veins occur on the right limit of Dublin Gulch near its mouth (Boyle, 1965; Poole, 1965). Also northerly striking Pb—Zn—Ag veins are present in the Davidson Range (Cockfield, 1921; Aho, 1964). Placer gold has been recovered from Dublin Gulch, Haggart Creek, and Duncan Creek since 1898.

Skarn zones containing scheelite occur in the vicinity of some of the granitic masses particularly around Dublin Gulch, on Mount Haldane, and east of Mayo Lake.

(4) The area has been subjected to at least two periods of glaciation, whose activities were largely restricted to the valleys. Above 3,500 feet the soil cover

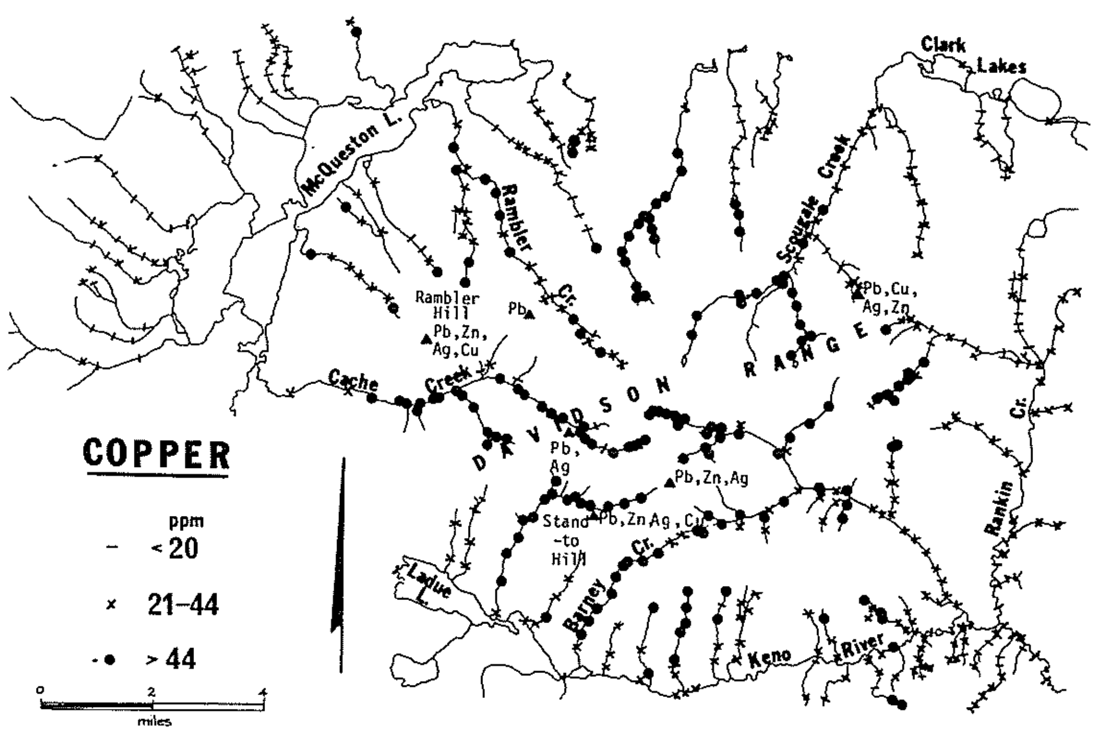

Fig.46. Distribution of total copper in the minus 80-mesh fraction of stream sediments, Keno Hill area, Yukon Territory (modified from Gleeson, 1965).

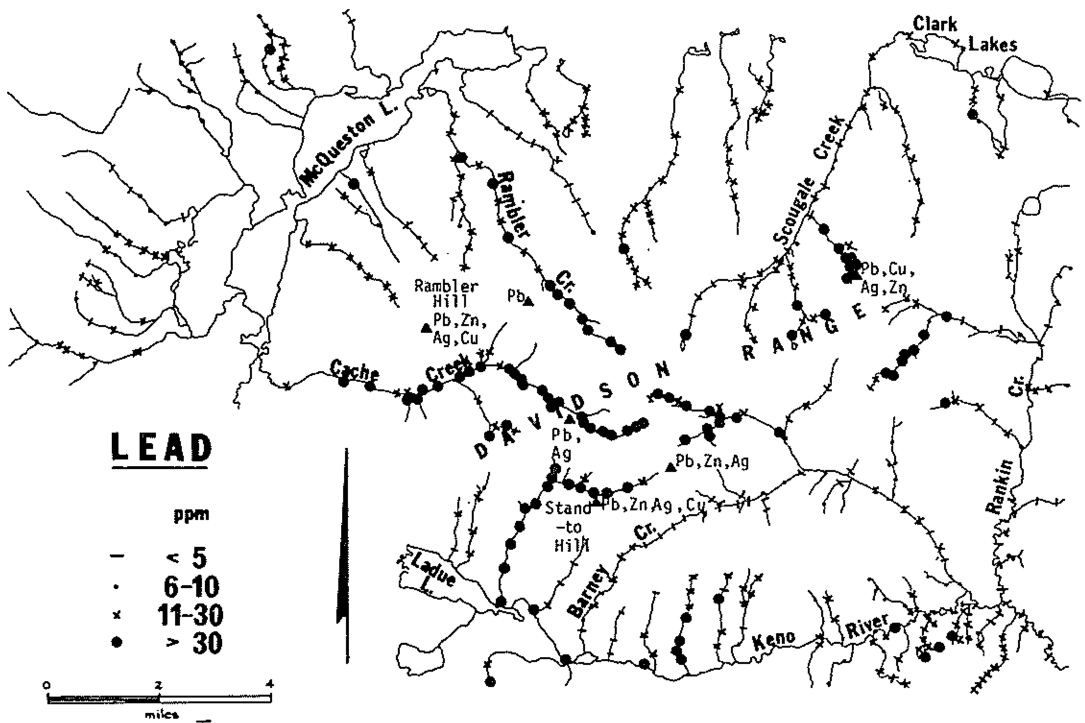

Fig.47. Distribution of total lead in the minus 80-mesh fraction of stream sediments, Keno Hill area (modified from Gleeson, 1965).

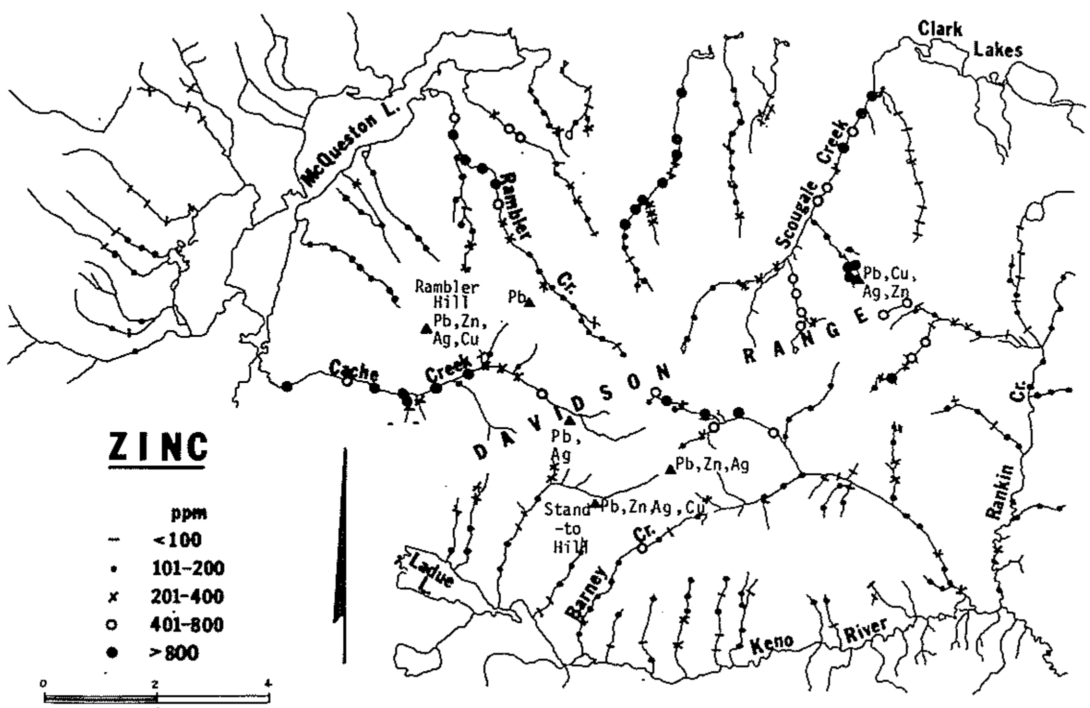

Fig.48. Distribution of total zinc in the minus 80-mesh fraction of stream sediments, Keno Hill area (modified from Gleeson, 1965).

is essentially residual. There are four distinct types of cover in this area:

(a) Residual soils whose thickness varies, depending upon the slopes of the hills. On the tops of the hills they are rarely more than 3 feet thick and in places are entirely absent; lower down on the slopes the soils, thickened by slope wash and land creep, may exceed 10 feet. In most areas they are highly disturbed by solifluction and frost-boiling, and their profile development is either immature or non-existent.

(b) Tills which are rarely more than a few feet thick and are absent in places. They are grey or greenish buff and consist of a heterogeneous mixture of fine sand, clay, small particles of schist, quartzite, and greenstone, and variously sized stones and boulders.

(c) Glaciofluvial deposits on the lower slopes and valley floors which range from a few feet to tens of feet in thickness. In places they are stratified, in others they consist of unsorted, washed gravels containing sand lenses. The gravels contain well-rounded pebbles, stones, and subangular schist fragments of local derivation. The mineral constitution of the sand lenses and fine fractions of the gravels is similar to that of the other glacial deposits described above.

(d) Muck and peat and half-bog soils are developed on all of the foregoing overburden types especially on the north slopes of the hills and on low-lying poorly drained ground.

(5) A large amount of information on the geochemistry of the Keno Hill area is contained in the references quoted in this paper. Only those aspects

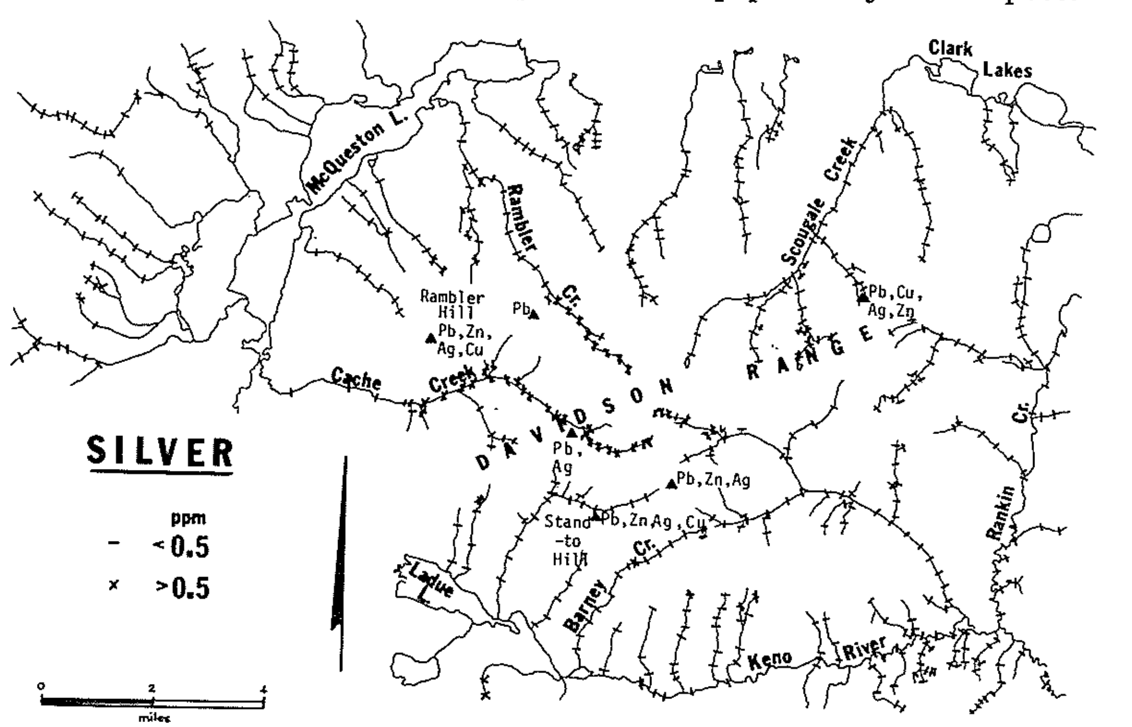

Fig.49. Distribution of total silver in the minus 80-mesh fraction of stream sediments, Keno Hill area (modified from Gleeson, 1965).

which are quoted in direct support of the idealized models are presented here. Figs.46—49 show the total copper, lead, zinc and silver analyses of the minus 80-mesh fraction for stream sediment samples collected around Stand-To Hill and Zahn Hill area, where the mineralization comprises lead, zinc, silver, copper veins, and contamination from mining activity is low. Because of the large number of mineralized veins of varying width, grade, and mineralogy in this area, interpretation is complex. However, the following points can be made: Zinc shows the longest dispersion train decreasing in the order of copper, lead and silver. This is the normal order of mobility observed elsewhere as well. Zinc probably also reflects bedrock lithology changes. This is particularly evident in the streams draining the northern slopes of the Davidson Range where there are strong zinc anomalies. These generally have a sharp cut-off, but do not coincide with anomalies for copper, lead or silver. They are thought to be related to local zinc-rich beds (probably graphitic and pyrite-rich phyllites) in the sedimentary sequence and unrelated to sulphide mineralization.

(6) A considerable amount of information on the soil geochemistry is given by Boyle (1965). This paper is readily available, and the data will not be reproduced here. Some of the more important conclusions reached by Boyle, which affect the discussions in the body of this paper are as follows:

(a) In background areas the muck and half-bog soils developed on glacial tills show a slight enrichment of silver and zinc, and the organic layers overlying residual soils exhibit a general enrichment in copper and zinc. Other trace elements in the organic materials are either about equal to or lower in amount than in their parents. All residual soils show an enrichment in most of the metallic trace elements compared with schists, quartzites, and greenstones underlying them. The highly aluminous soils and weathered debris overlying parts of the Dublin Gulch granodiorite are greatly enriched in arsenic, antimony, tungsten (Boyle, 1965, tables 4 and 5).

(b) A soil traverse over the No.6 vein fault on Keno Hill shows a pronounced silver, antimony, zinc, lead and arsenic anomaly with displacement downslope. The soils here average 1—3 feet deep and are residual. Sampling depth was 1—2 feet. The results from this and a number of different areas show that in residual soil, the silver, lead, zinc, antimony, arsenic, and manganese contents of the soil rise several times above background and give broad anomalies with strong contrast. Where lead deposits are present, the anomalies are particularly marked and metal values tens, and in places hundreds, of times greater than background were obtained.

(c) In depth, in residual soils over mineralization, the silver, lead, zinc, copper, arsenic, tin, antimony, and cadmium contents increase consistently (Boyle, 1965; table 11).

(d) Analysis of soil developed on glacial till taken across known vein faults failed to detect the presence of the vein fault. Spot samples of glacial material taken close to bedrock, however, contained large amounts of all metals near the veins, indicating that deep sampling may be effective.

Reference: Gleeson, 1965.

MacMILLAN PASS REGION, YUKON TERRITORY

P.J. Doyle and K. Fletcher (*University of British Columbia*)

(1) The study area covered approximately 200 square miles of the tributary valleys of the South MacMillan River, in the eastern Yukon, near the Northwest Territories border. In detail, profile 30 was collected 10 miles northeast of MacMillan Pass; profile 48 in a tributary valley of the South MacMillan River approximately 1 mile north of the Canol Road, 5 miles southwest of MacMillan Pass; and profile 72 on the Canol Road near the eastern end of Dragon Lake.

(2) Profile 30 and 72 are underlain by Proterozoic metasediments; and profile 48 by Paleozoic shales.

(3) There is no known mineralization close to any of these profiles.

(4) Profile 30 is situated in a broad glacial drift-filled valley east of the crestline of the Hess Mountains. The vegetation is dwarf birch, caribou moss and grasses. Profile 48 was collected in a gently sloping floor of a small valley (elevation 4,700 feet) with alpine meadow vegetation. Profile 72 was collected from an area of moderate relief (elevation 3,000 feet) covered with aspen, birch and grasses.

(5) No data.

(6) The minus 10-mesh fraction (ground) was analysed by atomic absorption following $HNO_3/HClO_4$ digestion. The characteristics of the soil profiles and the trace metal results are shown in Table XV. In every case, the ash layer is low in metals (by up to a factor of 10) with respect to the overlying and underlying soil horizons. However, in no case does the ash layer appear to act as a barrier to the upward migration of metals, as the values above the ash layer are as similar to those below as can be expected, taking into account the normal variations between different horizons.

MALONEY CREEK ("POT" GROUP) Cu Mo PROSPECT, YUKON TERRITORY

R.F. Horsnail (*Amax Exploration Incorporated*)

(1) Dawson Range, southwest of Yukon Territory.

(2) The property is underlain by Precambrian/Early Paleozoic metamorphic rocks of the Yukon Group which are intruded by dioritic rocks related to the Mesozoic Coast Range complex. These in turn are intruded by Tertiary subplutonic rocks (quartz-diorite, quartz-porphyry, and quartz-porphyry breccia).

(3) Copper and molybdenum minerals occur mainly within the quartz diorite and its adjacent Yukon Group wall rocks. Metallic minerals comprise chalcopyrite, molybdenite, pyrite, and related oxidation products. Pervasive silicification is associated with the Cu—Mo mineralization as also is intense argillization with introduction of K-feldspar and fluorite. Tourmaline and scheelite occur peripherally to the Cu—Mo mineralization. Extensive leaching

TABLE XV

Distribution of molybdenum, copper, zinc, and manganese in soil profiles containing volcanic ash

Bedrock	Profile site	Hori-zon	Depth (inches)	Morphology	Mo (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppm)	pH
Shales	48	LH	5—0	chiefly lichens	14	55	730	415	4.2
		IC_1	0—4	very dark grayish brown, silty clay	17	95	570	210	5.3
		IC_2	4—6	very dark grayish brown, shaly silty clay loam, 15% coarse fragments	14	45	210	280	5.5
		ash	6—8	light yellowish brown, silty clay loam	1	10	25	30	5.9
		Bm	8—11	dark brown loam, 30% coarse fragments	14	80	495	165	5.9
		IIC	11—?	very dark grayish brown sandy loam, 20% coarse fragments	10	60	465	165	5.5
Meta-sediments	30	ash	0—3	yellowish brown silty loam	0.8	15	40	125	4.9
		Bm	3—6	dark brown silty loam	2.8	25	115	450	4.5
		IC	6—12	yellowish brown silty loam	2.0	30	190	830	4.6
		IIC	12—?	light olive brown slaty sand, 60% coarse fragments	3.6	30	250	435	4.8
Meta-sediments	72	LH	3—0	chiefly lichens	0.4	30	500	8,445	4.8
		ash	0—3	light gray silty clay	0.4	20	15	225	5.0
		C	3—?	brown cobbly sand, 45% coarse fragments	2.8	35	130	135	4.5

to a depth of at least 70 feet is suspected. No estimates of grade and tonnage are currently available. Peripheral to this mineralization are three skarn Cu—Mo zones consisting of minor disseminated chalcopyrite and molybdenite in association with epidote-garnet-diopside skarn in the Yukon Group.

(4) The area has moderate slopes and typical permafrost landscape features. Soils are mainly brown frost earths, pH 5.3—6.5, with considerable build-up of organic matter in the topsoils of less well-drained areas. A layer of volcanic ash 2—6 inches thick occurs below the topsoil. North- and south-facing slopes differ considerably. The permanently frozen layer lies near surface on the north slopes, and vegetation is mainly low brush. However, on the south-facing slopes, soils are unfrozen during summer to a greater depth and the ground is extensively covered by both deciduous and coniferous trees.

Drainage is by a network of small creeks and intermittently flowing seepages. Silty sediment is difficult to collect in turbulent stretches of the creeks and, where present, appears to contain an appreciable proportion of reworked volcanic ash. Iron and manganese hydroxide stains are common on the larger pebbles of stream beds.

(5) Highly anomalous molybdenum and copper levels in both sediments and water are evident in the small creeks draining the north-facing slope leading into Peace Creek and Chimo Creek (Table XVI). However, only weakly anomalous values (typically 2 ppm Mo and 70 ppm Cu) are evident in Peace Creek itself, and these fall to background in the main drainage channel of Montgomery Creek (Fig.50). Thus the maximum length of the anomalous Mo—Cu drainage dispersion train is approximately 2 miles.

The limited distance over which a drainage sediment geochemical anomaly is clearly recognizable will restrict the effectiveness of drainage reconnaissance

TABLE XVI

Metal content in sediments and waters

	Mo (ppm)	Cu (ppm)	Ni (ppm)	Mn (ppm)	Fe (%)	Zn (ppm)	Pb (ppm)	Ag (ppm)	As (ppm)	W (ppm)
Anomalous sediments										
70 XGL 81	44	890	16	80	2.0	28	12	0.5	1	1
70 XGL 65	48	332	26	1,040	3.9	44	16	1.0	1	1
70 XRL 527	28	56	28	1,400	4.3	144	25	0.5		

	Mo (ppb)	Cu (ppb)	Zn (ppb)	F^- (ppb)	SO_4^{2-} (ppm)
Anomalous water					
70 XGW 82	2	100	110	35	148
70 XGW 64	8	5	140	58	240

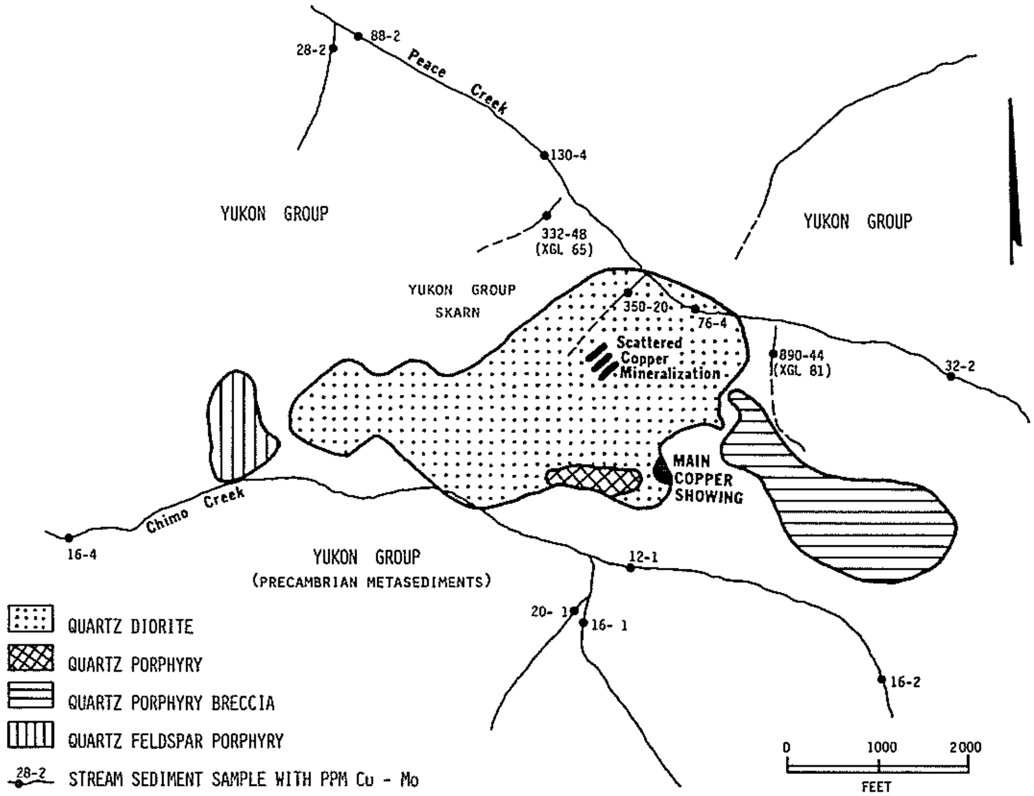

Fig.50. Distribution of copper and molybdenum in stream sediments, Maloney Creek, Yukon Territory.

TABLE XVII

Comparison of molybdenum and copper in rock chips and overlying soil

Sample No.	Mo (ppm)		Cu (ppm)	
	subsoil	rock chip	subsoil	rock chip
70 XGS 31 T 32	16	16	408	358
70 XGS 36 T 37	30	20	408	208
70 XGS 42 T 43	4	8	170	204
70 XGS 48 T 49	1	1	190	210
70 XGS 7 T 8	2	2	80	78
70 XGS 14 T 16	3	2	224	200
70 XGS 23 T 24	4	4	440	180

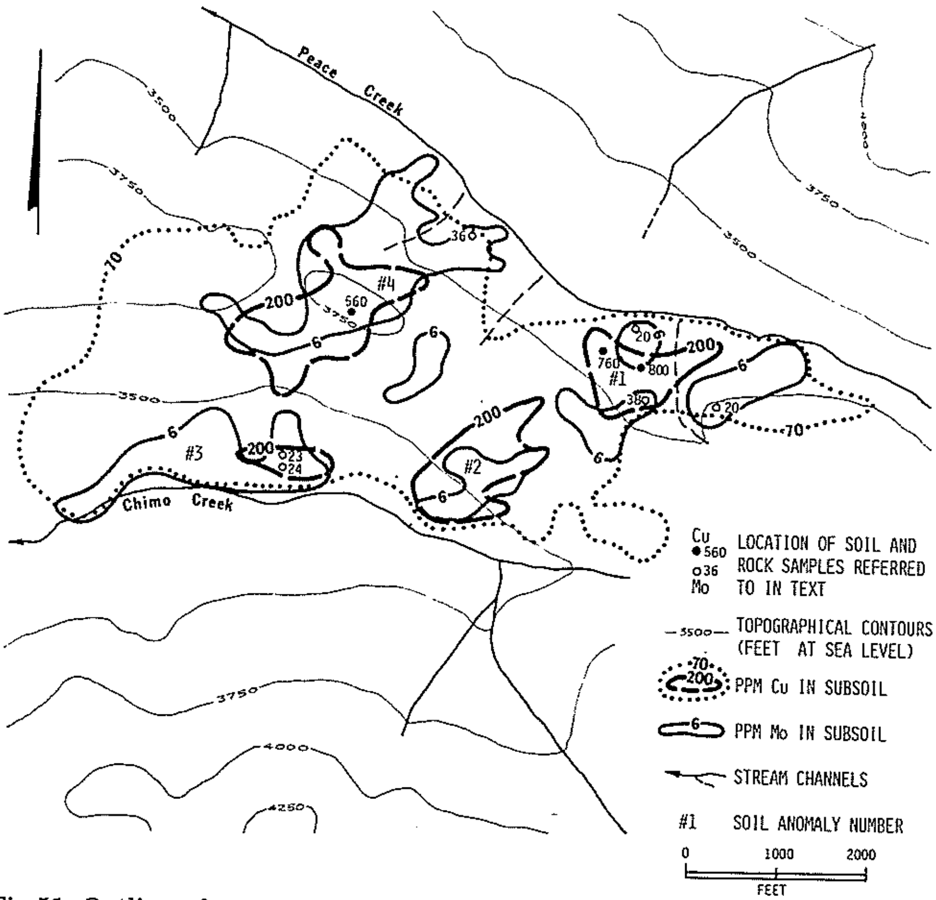

Fig.51. Outline of copper and molybdenum soil anomalies, Maloney Creek.

geochemistry in detecting Pot Group-type targets. In an environment such as this particular attention should be paid to small streams draining south-facing slopes. It appears that the slope aspect may influence the reflection of mineralization in the drainage system. The Mo—Cu drainage anomaly in Chimo Creek, below the south-facing slope, is considerably stronger than in Peace Creek to the north. This is possibly due to greater hydromorphic dispersion of metals from the more deeply unfrozen south-facing slope.

(6) Systematic subsoil sampling has been conducted over the area of the claim group. Four distinct Mo—Cu anomalies are present (Fig.51). Three are peripheral to the main intrusive body whilst a fourth is largely coincident with the quartz porphyry intrusive.

No association of anomalous lead, zinc, or silver is evident. A few isolated samples have high contents of manganese and iron.

Soil profiles generally show higher levels of molybdenum and copper in subsoils than in topsoils apparently owing to dilution of upper horizons with metal-barren volcanic ash.

Molybdenum and copper levels in subsoils are generally similar to the associated bedrock, as shown in Table XVII.

TABLE XVIII

Geological setting and induced polarization (I.P.) response of different anomalies

Soil anomaly	Geologic setting	Mineralization	I.P. response
2	largely over diorite and quartz-porphyry intrusives	disseminated chalcopyrite with some molybdenite	strong metal factors based on frequency effect and resistivity
1	fringing both intrusive types	skarn Cu—Mo	weak metal factors based on resistivity contrast only
3	fringing both intrusive types	skarn Cu—Mo	none
4	fringing quartz-diorite	skarn Cu—Mo	weak metal factors based on resistivity contrast only

The Cu—Mo soil anomalies of the Pot Group show a clear, spatial association with the distribution of chalcopyrite and molybdenite in bedrock; however, the geological settings of the anomalies and their I.P. responses vary considerably (Table XVIII). From the table mentioned, it is clear that soil anomaly 2 differs considerably from the other three major anomalies in terms of its geological setting and apparently associated I.P. response. However, no significant difference in soil chemistry is evident between the four anomalies.

It is suggested that anomaly 2 reflects disseminated chalcopyrite and molybdenite mineralization in the intrusive rocks, whereas the three other anomalies reflect skarn Cu—Mo mineralization in Yukon Group rocks fringing the intrusive bodies.

Little evidence is seen for extensive downslope soil anomaly migration by solifluction, although some downslope elongation of anomalies may have occurred in the vicinity of drainage channels.

Considerable solution of metallic cations is evident in the active layer of the frozen frost soils. This causes precipitation of manganese and iron hydroxides in drainage channels and as encrustations on boulders. Some accumulation of zinc and molybdenum occurs in iron- and manganese-rich samples presumably due to scavenging.

The pH, copper, and SO_4 contents of seepage waters do not indicate that extensive oxidation and leaching of metallic sulphide minerals is currently in progress.

References: Horsnail, 1970; Lodder and Godfrey, 1970.

MOUNT NANSEN FIELD AREA, YUKON TERRITORY

J.A. Coope (*Newmont Mining Corporation*)

(1) The Mount Nansen field area is located in the Dawson Range 120—125 miles north-northwest of Whitehorse and 28 miles due west of Carmacks in the Yukon Territory.

(2) The oldest rocks in the field area are a series of highly metamorphosed acidic schists and amphibolites of Precambrian and possibly Paleozoic age. Basalts, andesites, volcanic breccias, and agglomerates of Mesozoic age unconformably overlie the highly folded basement rocks. These volcanics are collectively known as the Mount Nansen Group. Igneous rocks of later Mesozoic age intrude both the Mount Nansen Group and the older Precambrian and Paleozoic rocks. These intrusives are of variable composition and include diorite, granodiorite, syenite, and granite. They occur as dykes and irregularly shaped bodies.

The youngest rocks recognized are a group of acid intrusives of Tertiary age. These intrusives also occur as dykes and irregular bodies and are mainly emplaced in the basement rocks. Petrographically, the Tertiary rocks are felsites, quartz porphyries, and rhyolite porphyries and are particularly significant because of their apparent genetic association with the Au—Ag-bearing veins in the Mount Nansen district.

(3) The mineralized veins are localized along northwesterly striking shears and faults affecting, predominantly, the older basement formations. Although the faults are extensive along strike, mineralization is restricted to lenticular bodies of variable strike length and width. At the surface, the mineralization is highly oxidized, although galena and stibnite are commonly recognizable in the felsitic or quartz gangue. Scorodite, plumbo jarosite, cerussite, and sulphantimonides have also been recognized. Silver contents exceeding 200 oz./ton and gold values up to 9 oz./ton have been detected in channel and grab samples collected from selected veins.

(4) Although the Mount Nansen area is included in the broad physiographic region of the Yukon Plateau, later erosion has developed relief variations of over 2,000 feet; the highest peaks, Mount Nansen and Victoria Mountain, exceed 6,000 feet. The hills and ridges are generally smooth and rounded. Outcrops are virtually restricted to the highest points along these ridges, the smooth, rolling, brush-covered slopes being characterized by a general lack of exposures.

Detailed climatic data for the Mount Nansen area are not available, but the climate is comparable with other areas in the central part of the Yukon Territory. During winter, temperatures commonly fall many tens of degrees below zero and individual temperatures during the summer may rise to over 80°F. The annual precipitation is approximately 10—15 inches.

The higher parts of the Mount Nansen district escaped glaciation during the Pleistocene period and glacial deposits are restricted to lower elevations along the major drainage courses. Boulder clay deposits are present in placer workings in the Nansen Creek Valley and sandy, possibly lacustrine or glaciofluvial deposits occur on the lower slopes bordering this stream and its tributaries. At higher elevations the overburden cover is local in origin. The overburden and weathered bedrock are permanently frozen throughout the year. The ground thaws out to depths greater than 2 feet in only a few locations during the summer months.

(5) No data.

(6) The Mount Nansen area was prospected previous to 1963; the work included trenching across a vein structure and a geochemical survey. The geochemical work involved the collection of surface soil samples, but no significant anomalous indications were obtained. Because of this, it was decided to make a thorough orientation survey over the known vein structure, sampling vertical profiles in the old trenches.

The orientation samples were collected from overburden profiles which had not been subjected to glaciation. At these higher elevations the overburden is local in origin, although gravity has influenced profile development. A volcanic ash layer, averaging 2—4 inches in thickness, underlies the shallow-rooted vegetation in almost all localities. The ash layer is underlain by a brown to dark brown loamy zone, 18—36 inches thick, containing rock fragments which increase in size and number with depth. Rootlets rarely penetrate through this loamy zone, and are generally concentrated within 6 inches of the base of the ash layer.

The rubble zones characteristic of the lower parts of the profile clearly reflect the influence of gravity, being sharply bent over in the downslope direction. The boundaries of these rubble zones are generally sharp, although locally a more transitional contact exists between the more sandy, but still rubbly, material surrounding them. In many places, rubble zones can be traced into the upper loamy parts of the profiles as "ghost" structures, suggesting that the loamy material is representative of a more advanced soil profile development. In the lowest horizons of the overburden cover, which are generally between 6 and 8 feet from the surface, the fragments of rubble are angular and vary in size from less than 1 inch to over 12 inches, the average being between 3 and 6 inches. Sandy, silty, and clayey material is sparse but can be found in the cementing ice between the fragments. Generally the fragments are heterogeneous, but locally there are concentrations of similar appearance and composition. These variations reflect similar variations in the underlying bedrock.

Prior to the orientation sampling, the walls of the old trenches were cut back 12—18 inches to provide a clean, unleached sampling surface, and the floors were deepened as much as possible. Owing to the compactness of the permafrost, true bedrock was not exposed along the whole length of one of the trenches, but picket markers, erected the previous year, were used to pinpoint the suboutcropping vein.

Soil profiles were sampled from three trenches. Results from the trenches are illustrated in Fig.52. The trench crosscuts the mineralized vein at right angles, and the maximum topographic slope is parallel to the trench direction. Earlier rock sampling of the trench gave the grades of Au—Ag mineralization as shown in Table XIX.

The vertical profiles were sampled at intervals of 3, 5, 10, or 20 feet, according to their position relative to the mineralization, the closely spaced profiles being located over the sub-outcropping vein. The individual samples in each profile were taken representing a vertical distance of 6 inches, the uppermost sample including the volcanic ash and some humic material. The trench wall was scraped before sampling and sample collection proceeded upwards from the base of the profile to minimize contamination from falling soil materials. An effort was made to sample only the finer-grained material in the profile.

After collection, the samples were dried and individually treated in a porcelain mortar and pestle to break up the soil structure. Larger rock fragments were discarded and care was taken not to pulverize the soil materials. The samples were then passed through a non-contaminating 80-mesh nylon sieve, and the fine sand/silt/clay fraction retained for analysis. The coarser sizes were discarded.

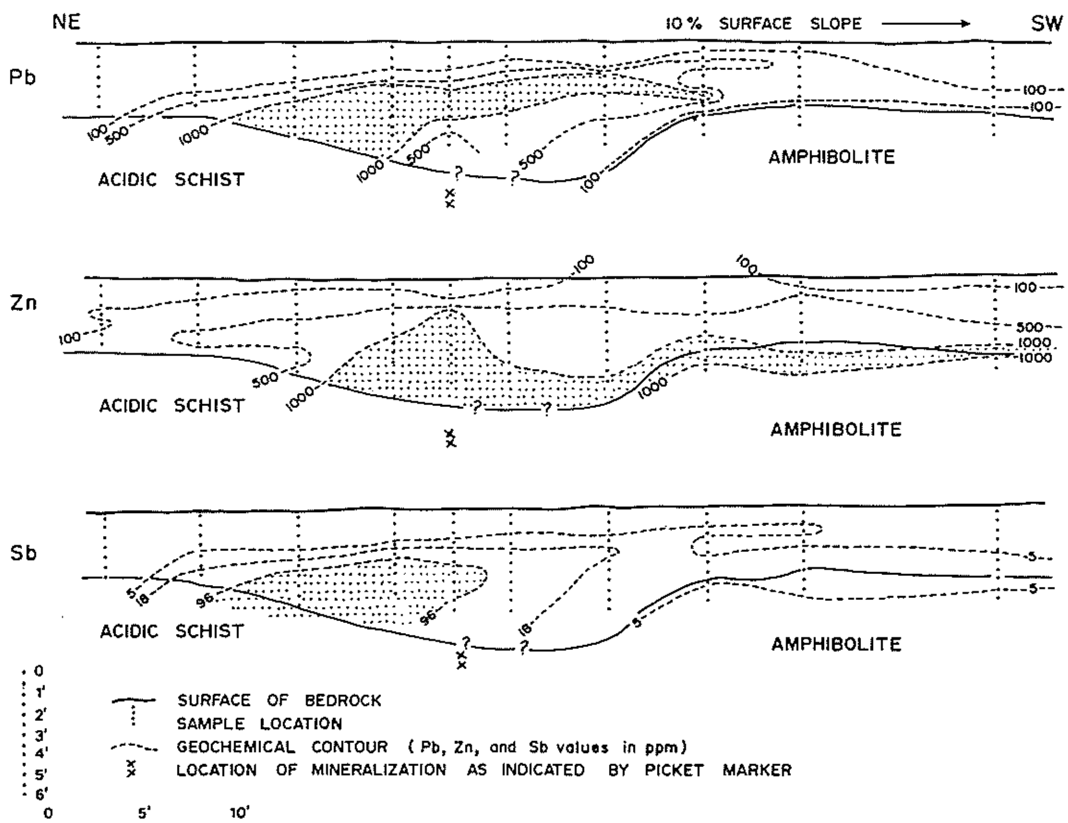

Fig.52. Distribution of lead, zinc, and antimony in Trench A, Mount Nansen, Yukon Territory.

TABLE XIX

Mount Nansen — distribution of gold and silver in Trench A

Au (oz./ton)	Ag (oz./ton)	Sample length (ft.)
0.50	0.90	4.0
0.76	1.94	grab

The samples were analyzed for total lead, zinc, and antimony using conventional dithizone and brilliant green techniques.

In Trench A (Fig.52), the lead values reach a maximum of over 2,000 ppm in the lower part of the profile, and the 1,000-ppm contour clearly reflects the shape of the rubble zones, being bent over in the downslope direction. The lead pattern apparently indicates the source of the anomaly to be 3—10 feet upslope from the picket marker. Upwards, the lead values decrease rapidly, and with decreasing depth the peak of the anomaly is displaced further and further downslope and becomes increasingly weaker.

The contrasting distribution of lead and zinc in Trench A is believed to be directly related to the difference in mobility of the two elements during the time of formation of the secondary dispersion patterns. Zinc is generally more mobile than lead in the majority of environments and consequently more widely dispersed. The high zinc values, which reach a maximum of 1,320 ppm, are concentrated along the base of the profile and extend over 30 feet from the sub-outcropping vein. This distribution strongly suggests movement of metal downslope in solution, and the high values in the amphibolite probably result from continued soaking of the weathered rock with waters rich in zinc. The zinc distribution indicates a metal source up to 6 feet upslope from the picket marker, although the more widespread distribution of metal makes the exact positioning of the bedrock metal source more difficult. It is quite possible that the zinc dispersion in the bedrock is more extensive than that of antimony and lead.

Despite the increased solubility and more widespread distribution of zinc, the values decrease rapidly upwards.

Antimony values strongly reflect the secondary dispersion patterns of lead and, to a lesser extent, show some similarity to the zinc pattern. The similarity with the latter metal is seen in the long tail of the 5-ppm contour along the surface and in the upper part of the amphibolite bedrock. Apart from this, all other features of the antimony resemble those of the lead anomaly.

Reference: Coope, 1966.

PAPOOSE LAKE AREA, BRITISH COLUMBIA

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

(1) In the Cariboo district of central British Columbia.

(2) The area is underlain by andesite which is cut by younger ultrabasics and quartz diorite. The andesite is porphyritic and has altered pyroxene phenocrysts. The ultramafic plutonic rocks consist of medium-grained pyroxenite and amphibolite cut locally by felsic veins. This in turn is cut by more acid intrusive rocks grading from hornblende-biotite quartz diorite and quartz monzonite. The ultrabasic and acid intrusive are separated within the sampled area by a coarse-grained hornblende gneiss.

(3) The area is essentially unmineralized. The andesite contains minor disseminated pyrite and for this reason is slightly higher in copper content than the surrounding rocks. No concentrations of sulphides have been located anywhere within the field area.

(4) The topography is generally rolling with moderate to locally steep relief and outcrop is moderate to poor. The surface drainage is poor with only a few streams of moderate size in the surveyed area. In the streams the sorting of the sediment is good, and there is generally ample sediment available for sampling. The streams have a moderate flow, and there is generally

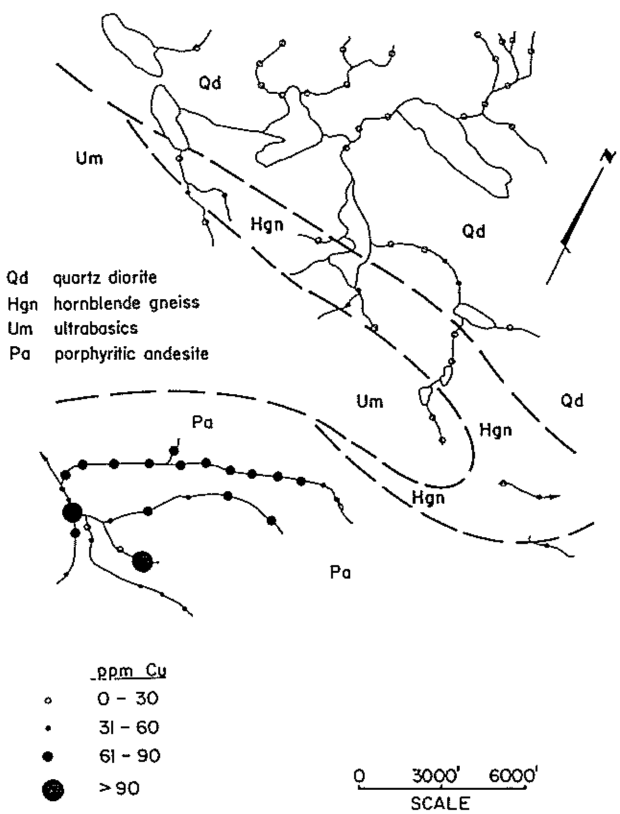

Fig.53. Distribution of HCl-extractable copper in the minus 80-mesh fraction of stream sediments, Papoose Lake, British Columbia.

little or no accumulation of organics. In a number of streams, a slight development of iron oxide and occasionally manganese oxide was observed. The area has undergone valley glaciation.

(5) Stream sediments were collected at $\frac{1}{4}$-mile intervals, from active stream sediment, along all drainage channels (Fig.53). The copper distribution shows two contrasting populations. In the northern half of the area over the hornblende gneiss and quartz diorite, the copper concentration averages 20 ppm and the highest recorded value is 60 ppm. In the southern half the average is 75 ppm Cu with a high of 162 ppm. This variation is related to bedrock change, and not mineralization, the andesite being slightly higher in copper than the other units.

(6) No data.

SAM GOOSLY Cu DEPOSIT, BRITISH COLUMBIA

A. Sutherland-Brown (*British Columbia Department of Mines and Petroleum Resources*)

(1) Located 22 miles southeast of Houston, British Columbia (lat. 54°11'N, long. 126°16'W).

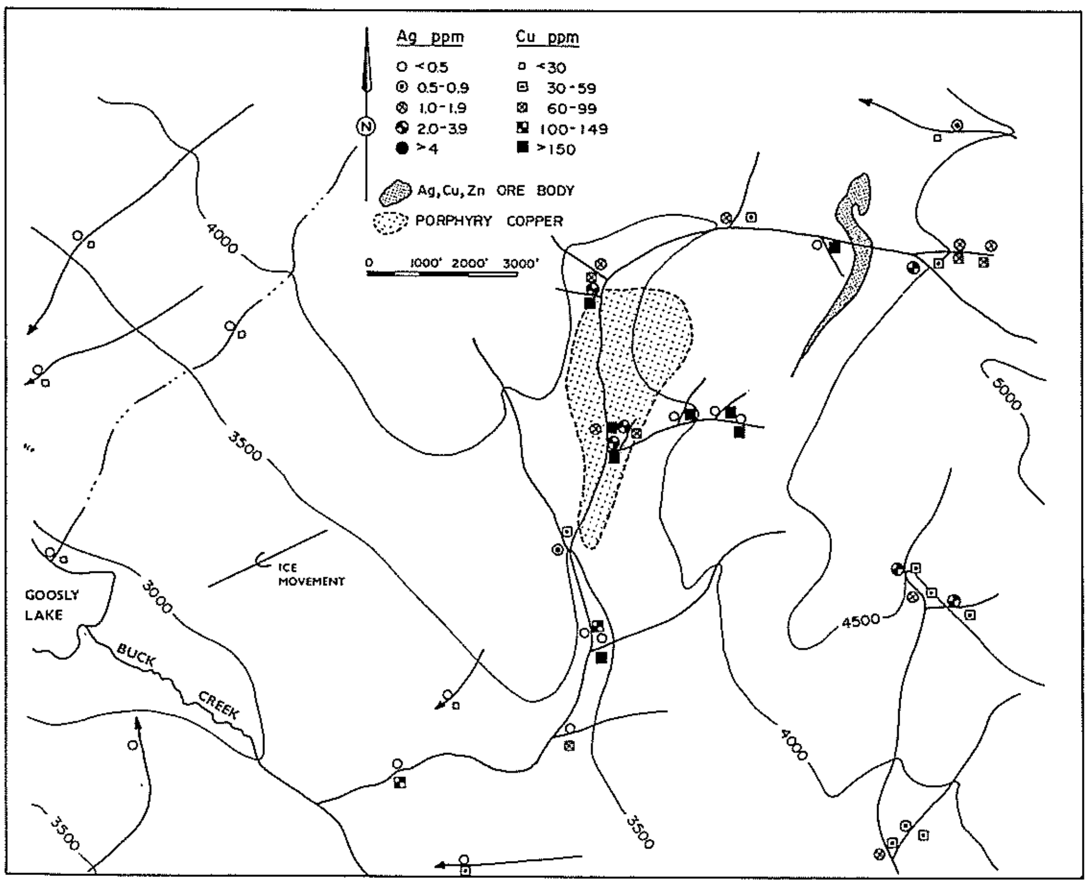

Fig.54. Distribution of silver and copper in the minus 80-mesh fraction of stream sediments, Sam Goosly, British Columbia (after Kennco Exploration).

(2) A stratiform, steeply west-dipping deposit of massive sulphide affinity is contained within Hazelton Group (Mid-Jurassic?) dacitic pyroclastic beds. A quartz-monzonite stock weakly mineralized with chalcopyrite and molybdenite occurs a mile to the west. Reserves of massive sulphide body are reportedly of the order of 50 million tons with a grade of 4 oz./ton Ag and about 0.5% Cu and minor zinc.

(3) Massive lenses of pyrite, chalcopyrite, and locally pyrrhotite with minor argentiferous tetrahedrite and sphalerite occur in the pyritic pyroclastic sequence.

(4) Local relief ranges from 3,000 feet at Sam Goosly Lake to 5,200 feet just east of the deposit, a western remnant of the Fraser Plateau surface. The glacial movement most affecting the local area was from northeast to southwest. The area is sub-alpine and has a sub-arctic climate. The shallow till has a thin podzolic soil developed from it. The area is partly burnt over but elsewhere has alpine fir, white spruce and meadow grass.

(5) Stream sediment data for total copper, zinc, silver, and molybdenum in the minus 80-mesh fraction of stream sediments are shown in Figs.54 and 55. All four elements show anomalous dispersion close to Sam Goosly although silver shows by far the strongest contrast. The porphyry body was

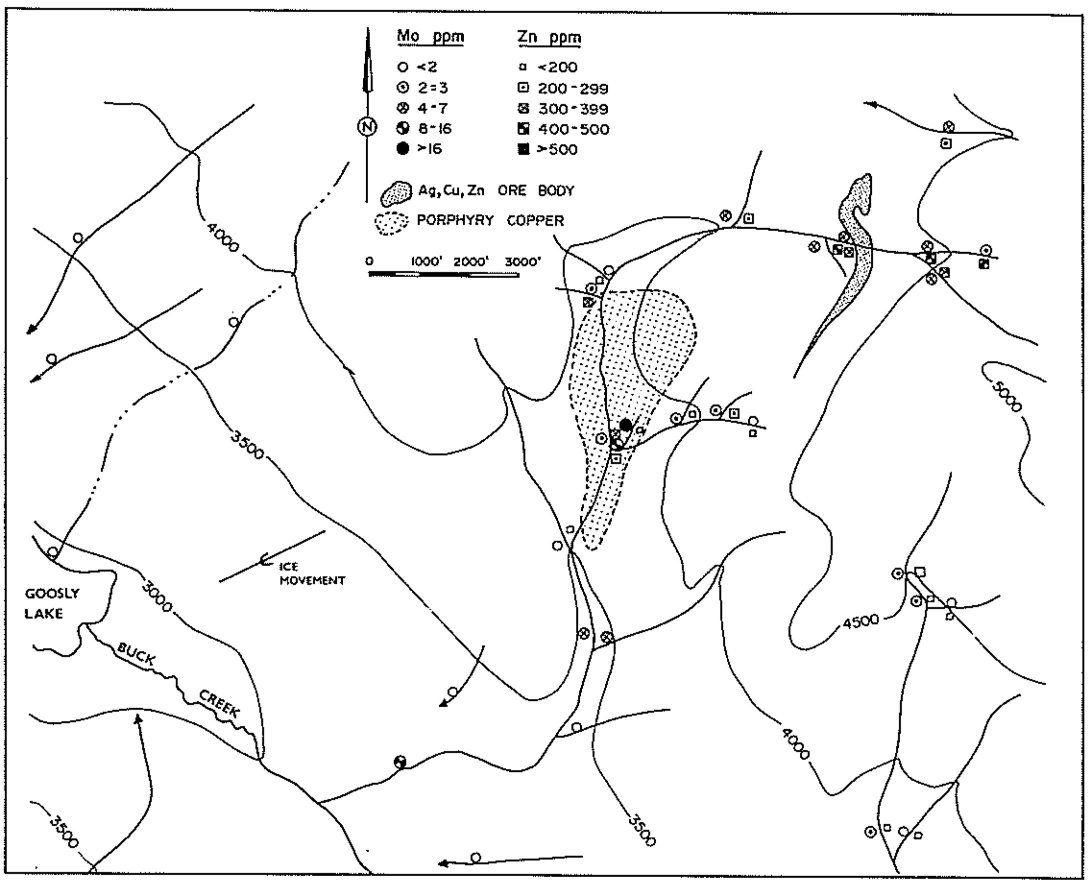

Fig.55. Molybdenum and zinc in stream sediments, Sam Goosly (after Kennco Exploration).

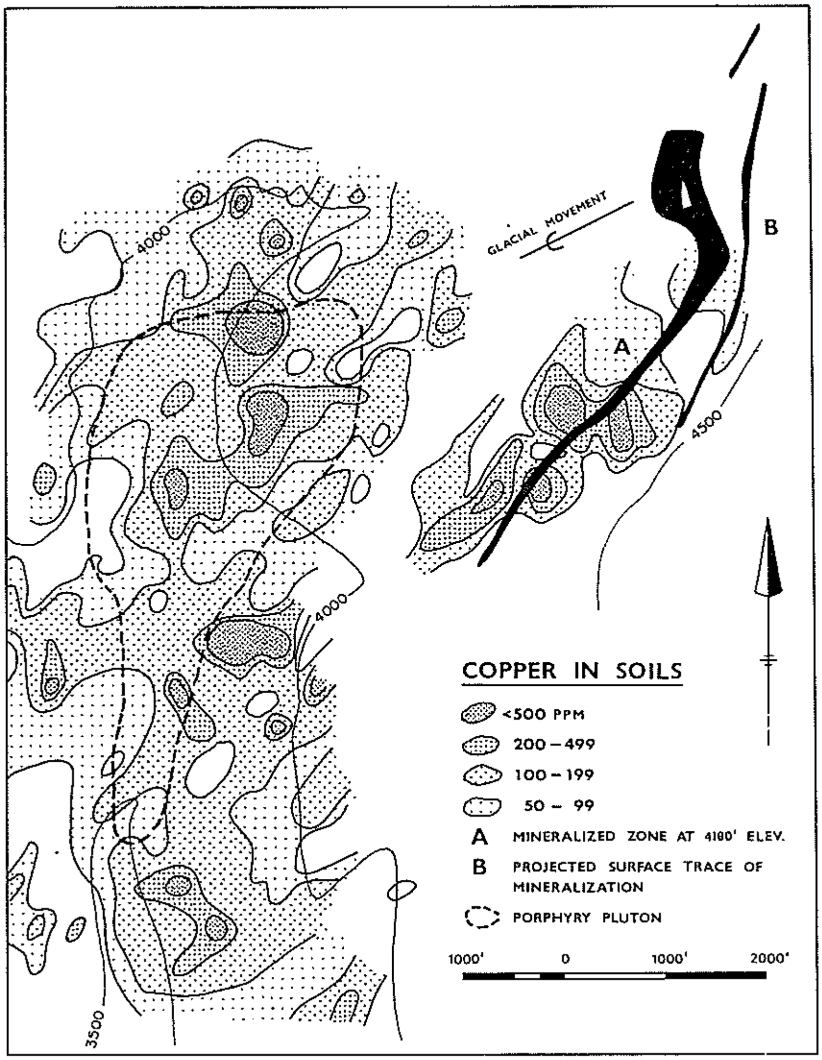

Fig.56. Distribution of copper in soils, Sam Goosly (after Kennco Exploration).

originally thought to be the source of the metal anomalies, those upstream were attributed to glacial smear until it was established that the glacial direction most affecting the overburden transport was from the northeast and not the northwest as expected.

(6) The original soil sampling was carried out at 500-foot intervals on lines 2,000 feet apart, with follow-up on a 100 X 400-foot grid. The soil data (Figs.56 and 57) show the marked effect of glacial smearing, although soil creep or hydromorphic movement may also have transported some metal in the direction. The silver anomaly has been transported up to 7,000 feet down-ice, while the up-ice limb of the anomaly coincides extremely closely with the surface projection of the deposit.

References: Panteleyev, 1968; Ney et al., 1972; D.A. Barr, personal communication, 1973.

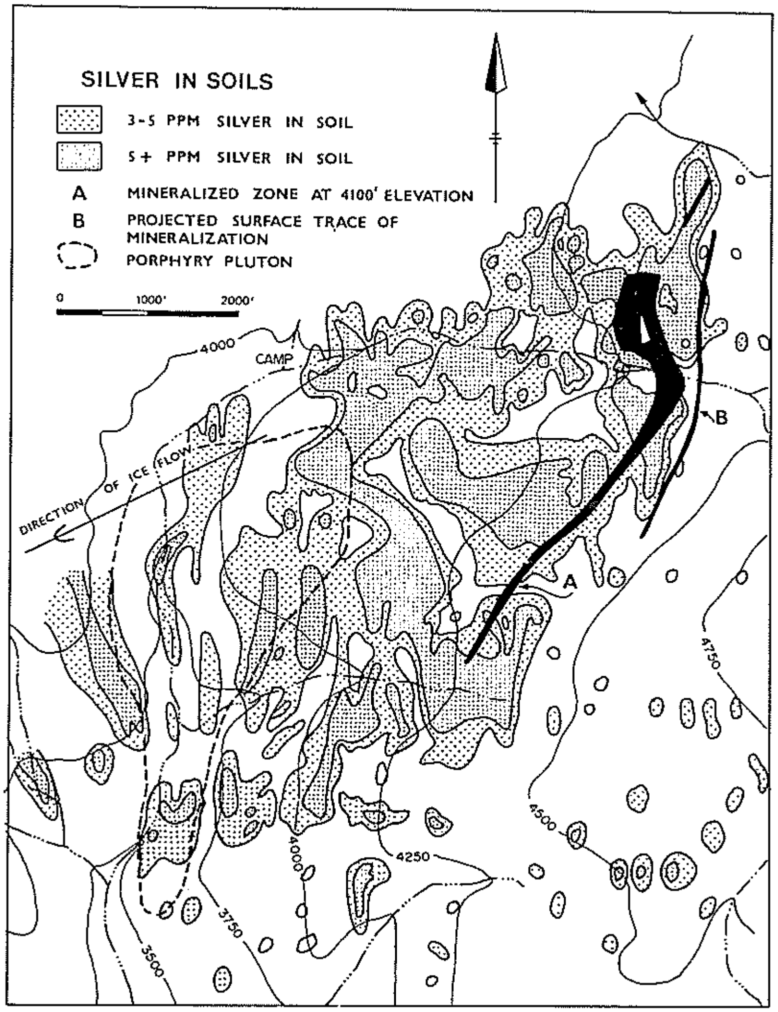

Fig.57. Distribution of silver in soils, Sam Goosly (after Ney et al., 1972).

SHESLAY Cu—Mo PROSPECT, BRITISH COLUMBIA

J.A. Coope (*Newmont Mining Corporation*)

(1) Located 48 miles northwest of Telegraph Creek, British Columbia.

(2) Highly altered zones of Triassic and earlier volcanic and sedimentary rocks that have been intruded by feldspar porphyry and foliated diorite.

(3) Widespread disseminated sulphides consisting of pyrite with lesser amounts of chalcopyrite and molybdenite are related to zones of feldspathization and silicification in volcanic sediments. Cu—Mo mineralization tends to occur in linear zones of variable grade.

(4) The field area is part of a rolling plateau area between the elevations of 4,000 and 5,000 feet. Rivers are deeply incised to elevations of less than 2,000 feet. Rainfall is estimated at 25—35 inches per year with temperatures ranging from approximately 70°F in the summer to as low as 40° below zero

in the winter. Permafrost is rare. The treeline is at approximately 3,500 feet. Soils are characteristically juvenile in the uplands with swampy zones in areas of flatter topography. Valley glacial deposits are present at lower elevations, but within the field area glacial till deposits are patchy and irregular.

(5) No data.

(6) Lines XL 88N (soil traverse B) and XL 32N (soil traverse A) are two traverses down a hillside from left to right in the Sheslay area of northern British Columbia. Both lines given information for cold-extractable heavy metals (cxHM), total copper, and total molybdenum. Traverse A is almost wholly well-drained residual soil with only minor transportation due to soil creep. Traverse B is on a similar slope, but about half way down this slope

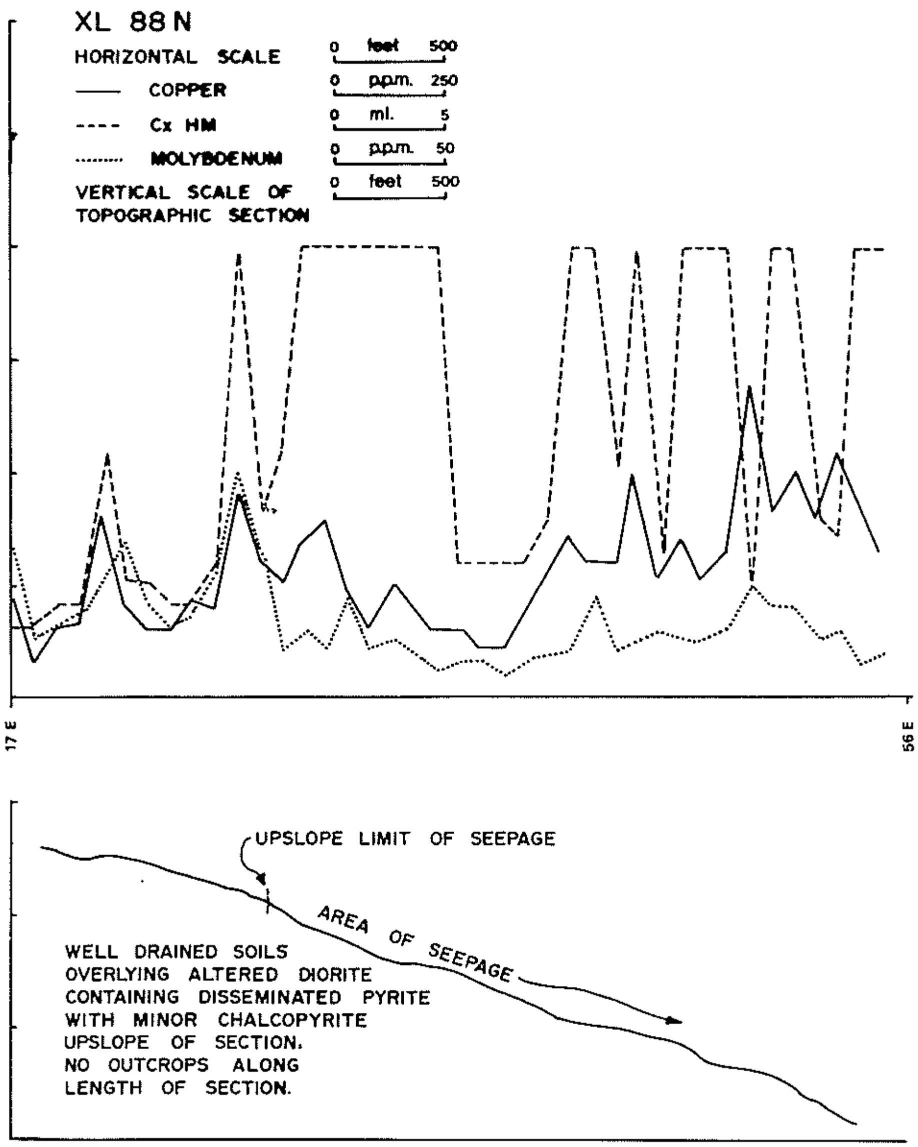

Fig.58. Distribution of copper, molybdenum, and cold-extractable heavy metals in soils, Sheslay area, British Columbia.

there is extensive seepage, and this is reflected in the very high values for cxHM. The cxHM is recorded in number of millilitres of dithizone required to titrate back to the blue-grey end point of the dithizone reaction. Values of 20 ml are equivalent to 20 ml or greater.

The data (Figs.58 and 59) clearly demonstrates the contrasting data obtained using total and cold-extractable metal techniques that can be obtained in areas where seepage is prevalent. Although cxHM data is presented, the predominant metal being measured by this technique is cold-extractable copper (cxCu).

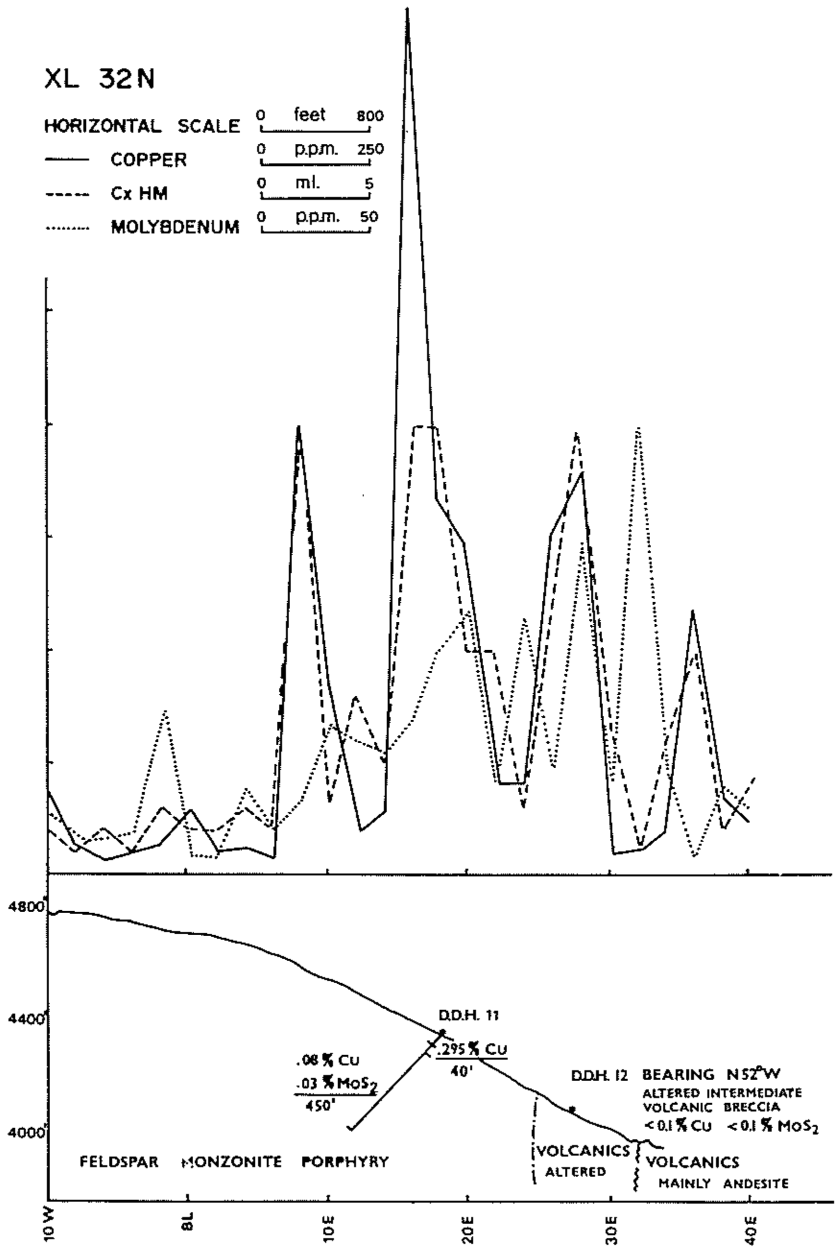

Fig.59. Distribution of copper, molybdenum, and cold-extractable heavy metals in soils, Sheslay area.

From this case history it is apparent that cold-extractable methods on drainage material as a reconnaissance technique would be the most satisfactory technique in the Sheslay area to prospect for disseminated copper mineralization of the porphyry copper type. However, the use of cold-extractable methods of analysis of soils is likely to give misleading results if the mobility of the copper in the environment and its concentration in seepage areas are not appreciated. From soil traverse B, it will be appreciated that cxCu and cxHM techniques will give broad, strong anomalous areas, whereas total copper analysis indicates less extensive anomalous zones which are pinpointed more clearly. In well-drained soils there is a correspondence between cxHM anomalies and total copper anomalies (see soil traverse A and the western part of soil traverse B), and the relative proportion of cxHM in well-drained soils is much less.

The molybdenum data tends to correspond with the total-copper data with some displacement downslope indicated. There is a singular prominent molybdenum high on soil traverse A without a corresponding copper anomaly which is unexplained.

In the exploration follow-up, drill holes beneath the total-copper anomalous zones encountered variable amounts of copper mineralization associated with pyrite.

VALLEY COPPER DEPOSIT, BRITISH COLUMBIA

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

(1) In the Highland Valley, southern British Columbia, approximately 30 miles southwest of Kamloops.

(2) Valley Copper is a porphyry copper deposit which occurs entirely within the Guichon batholith. This batholith is approximately 40 miles × 16 miles in size and is also host to the Bethlehem, Highmont, and Lornex deposits, as well as a number of smaller prospects. This batholith intrudes Upper Triassic and older volcanic and sedimentary rocks and is overlain unconformably by Middle Jurassic sedimentary rocks and by Tertiary basalt. The batholith is composed of several petrographically distinct phases, and the mineralization is associated with the youngest Bethsaida phase.

(3) The mineralization is fracture controlled and consists of chalcopyrite and bornite with minor chalcocite and molybdenite generally on fracture planes. The pyrite content is low. Published reserve figures are more than 1,000 million tons of 0.46% Cu.

(4) The Highland Valley lies in the central plateau of British Columbia. This is an area of moderate to low relief and low rainfall (generally less than 25 inches per year). On the tops and upper flanks of the hills the soil is generally sandy and well drained. On the valley floor the drainage is frequently poor, and boggy conditions are common. Vegetation over the Valley Copper deposit is generally open evergreen forest.

(5) No data.

(6) A soil traverse (Fig.60) run across the mineralization also crossed a major soil-type change. The traverse started near the top of the slope on well-drained ground where the soil was sandy. In the downslope direction the soil texture progressively changes from sandy silt to clay-silt and finally bog.

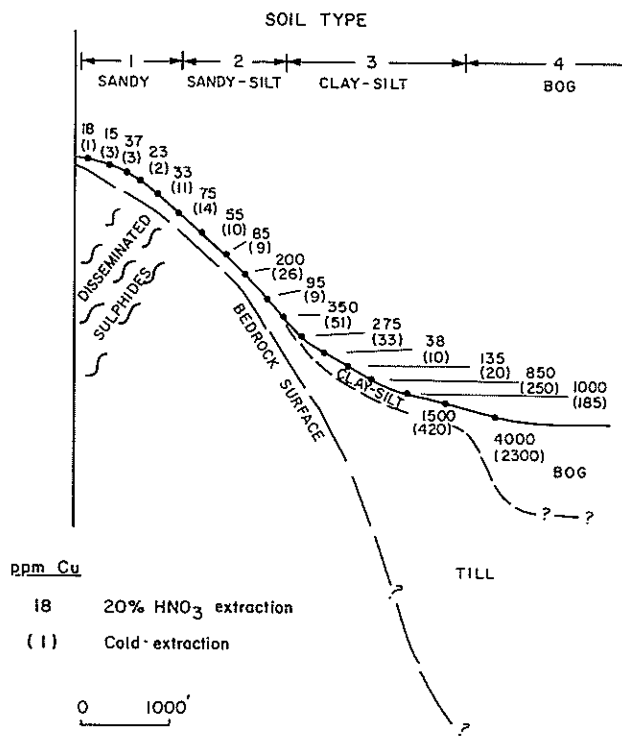

Fig.60. Total and cold-extractable copper in near-surface soils, Valley Copper, British Columbia.

Downslope movement of groundwater containing anomalous copper has resulted in a considerable accumulation of copper in the bog at the base of the slope. This is reflected by both "total" copper (hot 20% HNO_3 extractable) and to a more marked degree by cold-extractable copper. The change in percent cold extractable from 10% over the mineralization up to 60% in the bog is good confirmation of the hydromorphic transport of the copper.

WILLIAMS CREEK Cu PROSPECT, YUKON TERRITORY

R.F. Horsnail (*Amax Exploration Limited*)

(1) Located 20—30 miles northwest of Carmacks, Yukon.

(2) The mineralization is disseminated in a biotite diorite gneiss which appears to be enclosed in a granodiorite ("Klotassin" type) of probable Jurassic to Cretaceous age. The gneiss unit is a tabular steeply dipping body which, together with its associated sulphide zone, varies between 50 and 100 feet in width.

(3) Disseminated copper sulphides occur as extremely fine-grained disseminated chalcopyrite and bornite generally associated with fine-grained biotite in the gneiss. Pyrite is virtually non-existent and there is little evidence of hydrothermal alteration. The sulphides are highly oxidized to depths of up to 800 feet. Some enrichment of copper is suspected in the lower oxide zone. The deposit is situated on the north side of Williams Creek, near sample W47.

No estimate of grade and tonnage is yet available. The best drill intersections comprise (true width/percentage copper): 40 feet/1.51%; 134 feet/1.93%; 103 feet/1.46%; 104 feet/1.25%; and 105 feet/1.30%.

Two zones of surface copper mineralization are present. One extends over a width of approximately 100 feet and a length of 1,800 feet striking N35°W. A second zone has a length of some 400 feet and width of 100 feet.

(4) The environment is typical of the Central Yukon Plateau. The surface mineralized showings lie at an elevation of some 2,800 feet, approximately 300 feet above Williams Creek and 3,000 feet distant from it. Soils are dominantly residual, but a thin layer of volcanic ash is present near the surface. It appears probable that the groundwater table is at least 300 feet below the surface in the vicinity of the mineralized area.

(5) The Williams Creek property has no discernible geochemical expression in the drainage sediments. Typical results obtained from Williams Creek itself and minor tributaries are shown in Table XX. However, a weak molybdenum and fluorine anomaly is obtained in stream waters. Waters from several points in Williams Creek carry 2 ppb Mo and 240—350 ppb F whilst similar values are recorded in the main tributary to the north (Fig.61). A strong water anomaly is present in one small creek entering Williams Creek from the north, i.e. sample 47 containing 30 ppb Mo, < 1 ppb Cu, 10 ppb Zn, and 600 ppb F at pH 7.6. These molybdenum and fluorine values are among the highest recorded in the Dawson Range from tributary drainages.

It is evident that dispersion of metallic ions from the Williams Creek deposit is severely restricted — hence the very weak drainage anomaly. Although the deposit is extensively oxidized, very little leaching of metal into the drainage system appears to be taking place at present. The reasons for this are believed to be due to: (a) a lack of pyrite in the deposit — hence no marked acidification of groundwater, and (b) a deep water table resulting in little

TABLE XX

Williams Creek — analytical results of drainage sediments

Sample No.	Mo (ppm)	Cu (ppm)	Zn (ppm)	W (ppm)
39	⩽1	10	40	<1
42	⩽1	4	28	<1
44	⩽1	6	32	<1
48	⩽1	8	34	<1
52	⩽1	8	28	<1

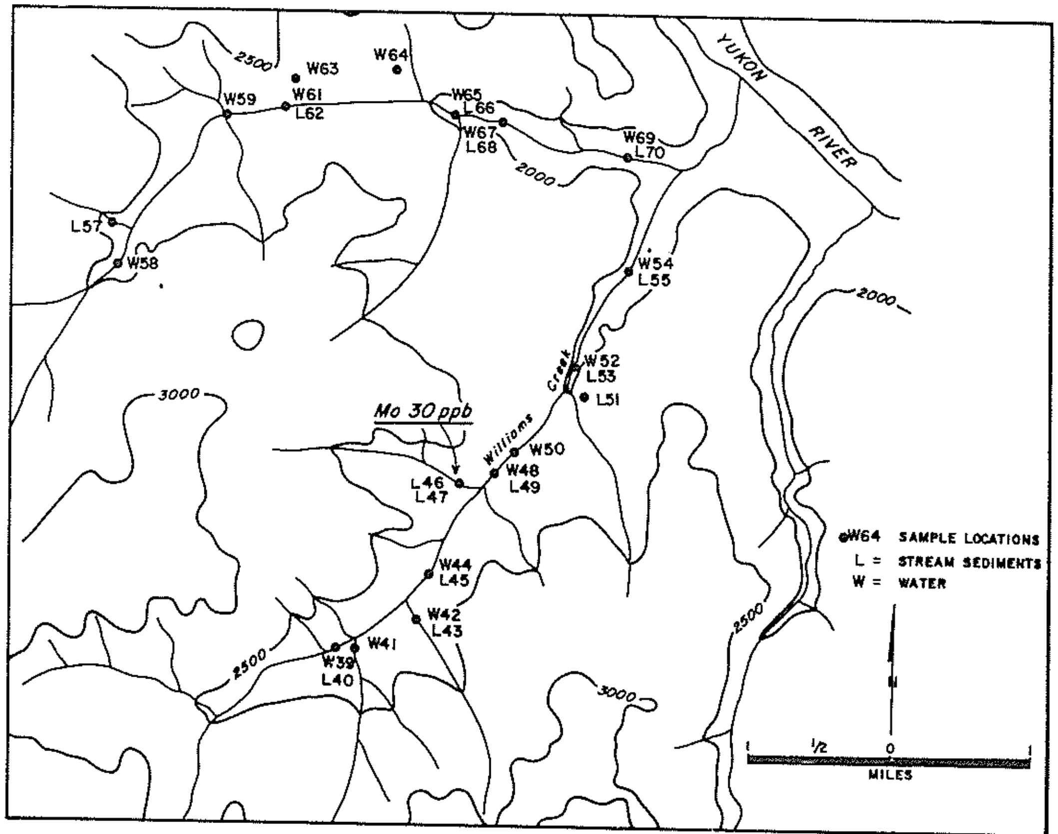

Fig. 61. Sample locations, Williams Creek, Yukon Territory.

groundwater being available for leaching reactions. However, the weakly alkaline drainage waters do appear capable of supporting a low intensity Mo anomaly despite an apparent scarcity of Mo mineralization in the deposit.

(6) No data.

TABLE XXI

Summary of length and strength of anomalies over different deposits*

Name (reference) Sub-outcrop size of mineralization Metals present	Overburden	Extraction and element	Sediments: max. dispersion length (miles)	Sediments: strongest contrast	Sediments: comments	Soils: anomaly size (length × width)	Soils: strongest contrast	Soils: comments
Porphyry-type mineralization								
Casino (Archer and Maine, 1971) 6000′ × 2500′ Cu, Mo	residual	tot Cu	8	16	highest values are in a window in the permafrost to one side of the best mineralization	8000′ × 3400′	10	highest values generally downslope from mineralization
		tot Mo	0.5	17		5500′ × 3400′	8	
		tot Au	0	2		3000′? × 3000′	5	
		tot Ag	0.3	3.5		3000′? × 3000′	2.5	
Gibraltar 5 separate zones Cu, Mo	glacial till	tot Cu	2	3	strong indication of glacial smearing			
		tot Mo	2	2				
Sheslay Size unknown Cu, Mo	mainly residual	tot Cu				? × ≤ 3000′	55	length is variable dependent on the extent of the mineralization; the width is greatly influenced by downslope creep
		tot Mo				? × ≤ 3000′	25	
		cxHM				? × ≤ 3000′	20	
Huckleberry 3000′ diameter with low centre	glacial till	tot Cu	1.75	50	anomaly extends to main drainage, seeps near mineralization up to 47,600 ppm Cu; 2000 ppm Zn, and 262 ppm Mo	4000′? × 2300′	40	orientation did not cover best mineralization
		tot Mo	1.75	100		4000′? × 2300′	26	
		tot Zn	1.75	5				

Island Copper 5000′ x 1000′ Cu, Mo	glacial till and thick glaciofluvial sediments	tot Cu				2300′ x 850′	50	restricted to area glacio-fluvial material absent
Maloney Creek Size unknown Cu, Mo	residual plus volcanic ash	tot Cu tot Mo	2 2	20 10	dilution appears rapid			
Luckey Ship (Hornbrook, 1969) 1000′ diameter with barren core Mo	glacial till with glacio-fluvial material in valleys	tot Mo				2000′ x 2000′	4	anomaly is roughly twice the size of the mineralization
Boss Mountain Main zone 500′ x 150′	glacial till	tot Mo	6	100		5000′ x > 5000′	60	molybdenum anom-
Mo		tot Cu				2000′ x 4500′	2	aly also due to hydrothermal biotite
Brenda 1600′ x 2600′ Cu, Mo	glacial till	tot Mo tot Cu				4000′ x 4000′ 4000′ x 4000′	2 3	
Highmont (Bergey et al., 1971) 5 zones over 8000′ x 4000′ Cu, Mo	glacial till	tot Cu tot Mo				>9000′ x >7000′	10 10	obvious down-ice smearing and also hydromorphic accumulation in seepage zones
Dansey-Rayfield R. (Hoffman and Fletcher, 1972) Size unknown Cu	glacial till	tot Cu		10	predominantly mechanical dis- persion of material derived from talus slopes			mineralized sye-nite float can be detected over approx. 4 sq. miles down-ice (SSE)
Chutanli Size unknown Mo	glacial till	tot Mo				8000′ x 6000′	48	both smearing down-ice and hydromorphic accumulation at the break in the slope

TABLE XXI (*continued*)

Name (reference) Sub-outcrop size of mineralization Metals present	Overburden	Extraction and element	Sediments: max. dispersion length (miles)	Sediments: strongest contrast	Sediments: comments	Soils: anomaly size (length × width)	Soils: strongest contrast	Soils: comments
Vein-type mineralization								
Mount Nansen		tot Pb				35′ wide	25	length of anomalies is dependent on, and reflects the length of the veins
		tot Zn				> 50′ wide	17	
		tot Sb				> 50′ wide	8	
Stand-to Hill, Zahn Hill, Keno Hill areas	residual on hill top, glaciofluvial in valleys	tot Pb	2	44	dispersion is quite complex due to large number of scattered veins			
		tot Zn	9?	15				
		tot Ag	1	2				
2′ × ?		tot Cu	4	10				
Multiple veins of Pb, Zn, Ag, Cu		tot B	9?	20				
		tot As	1	50				
Mt. Haldane region, Keno Hill area (Gleeson, 1965)	residual on hilltop, glaciofluvial in valleys	tot Pb	>4	35	dispersion is quite complex due to large number of scattered veins			
		tot Zn	>4	8				
		tot Ag	0.5	6				
2′ × ?		tot Cu	0.5	15				
Veins of Pb, Zn, Ag, and As		tot B	>4	20				
		tot As	>4	900				
No.6 vein, Keno Hill (Boyle, 1965)	residual	tot Pb				>225′ wide	20	the length of the anomaly is undetermined
		tot Zn				>225′ wide	6	
1—15′ × traceable over 3000′		tot Ag				>225′ wide	10	
		tot Cu				0′	—	
Pb, Zn, As		tot Sb				>225′ wide	20	
		tot As				>225′ wide	20	

Silver King vein, Keno Hill (Boyle, 1965) Approx. 15′ x 1500′ Pb, Zn, Ag (Au)	glaciofluvial	tot Pb				0	—	
		tot Zn				0	—	
		tot Ag				0	—	
		tot Ab				0	—	
		tot As				>100′? wide	0.5	
Ketsa River (Archer, 1967) 4′ x 600′	residual	tot Pb				1000′? wide	30	the soil grid covered 2 veins, 400′ apart
Skarn mineralization								
Deadwood Camp (White and Allen, 1954) Blind but weak malachite at surface Cu	glacial till 2—7′	tot Cu				1200′ x 600′	>10	minor displacement down-ice and also downslope; anomaly significantly larger than source
Summit Camp (White and Allen, 1954) 300′ x 100′ Cu	thin glacial till	tot Cu				300′ x 150′	>2	anomaly directly over and virtually same size as orebody
Massive sulphide-type mineralization								
Sam Goosly 4000′ x 400′ Ag, Cu, (Zn)	thin till	tot Cu	2?	14	dispersion distances of Cu, Zn, Mo are hard to estimate due to proximity of porphyry type mineralization	9000′? x 4800′	120	marked glacial smearing
		tot Zn	2?	2.5		—	—	
		tot Ag	2	75		10,000′ x 4500′	70	
		tot Mo	2?	2.5		7800′ x 2200′	70	
		tot F	—	1.5		—	—	

* Where no reference is given, the example is contained in the text of this volume.

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

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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

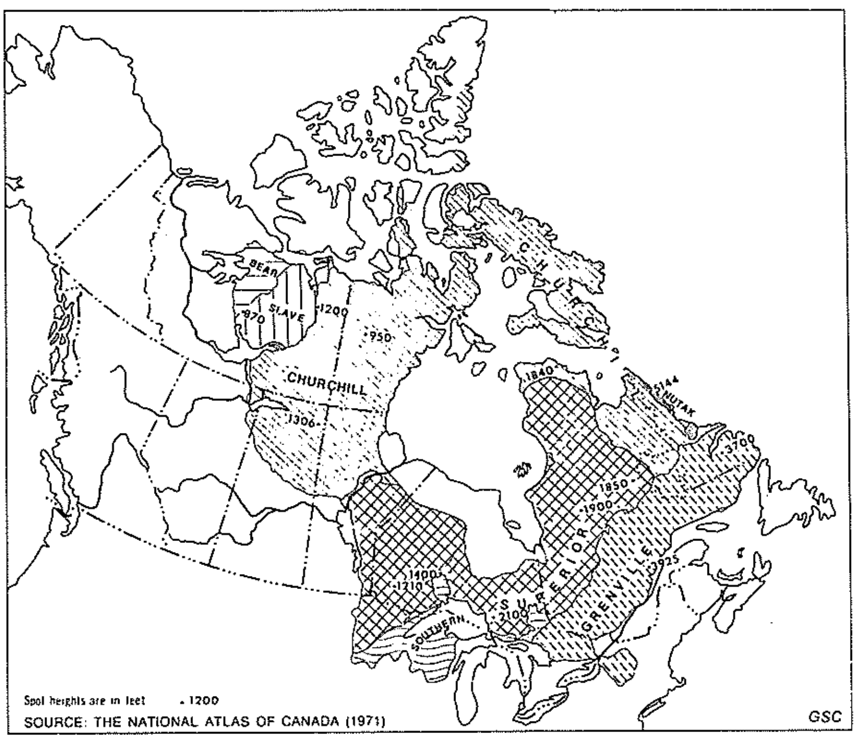

Fig.62. Canadian Shield showing the various structural provinces.

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)

Eon	Era	Sub-era	Orogeny (mean K—Ar mica age, m.y.)
Proterozoic	Hadrynian		
	Helikian	Neohelikian	Grenvillian (955)
		Paleokelikian	Elsonian (1370)
	Aphebian		Hudsonian (1735)
Archean			Kenoran (2480)

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, CO_2, 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 Nemegos, 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 comglomerates 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 Illionoian 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 Great Lakes 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).

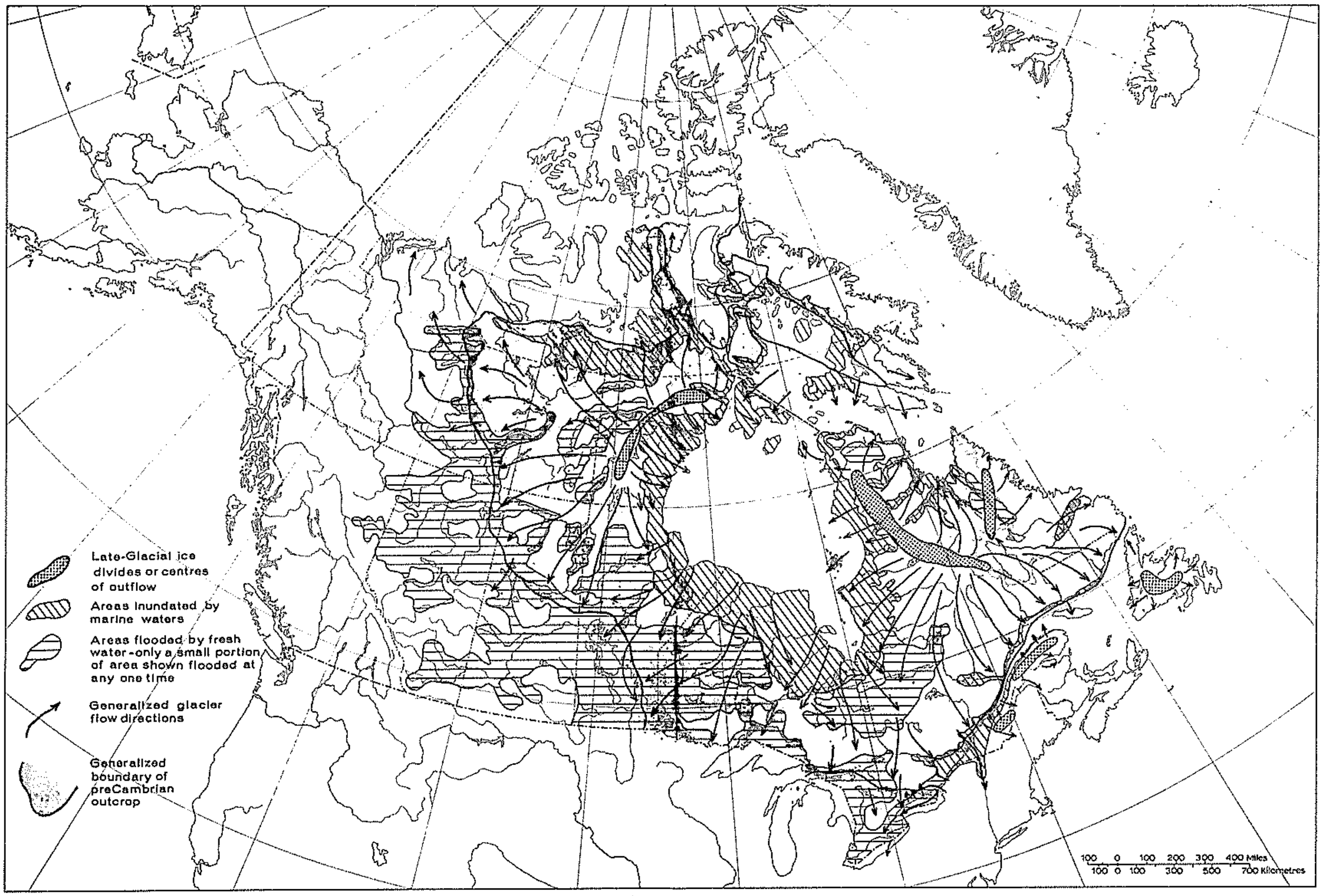

Fig.63. Generalized direction of glacier movement and distribution of marine and lacustrine depositional environments in the Canadian Shield.

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.

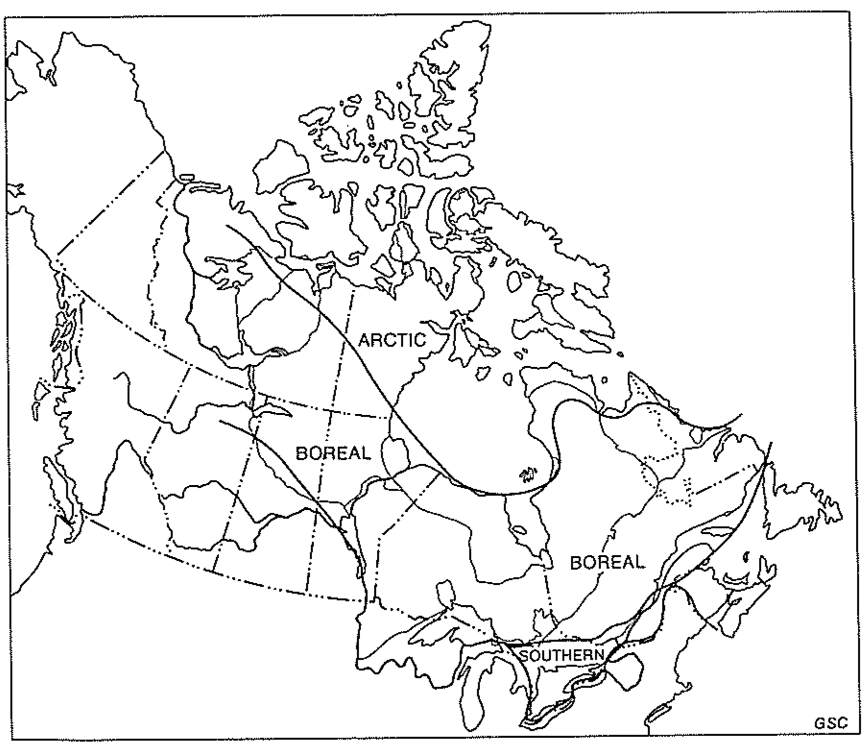

Fig.64. Climatic zones in the Canadian Shield.

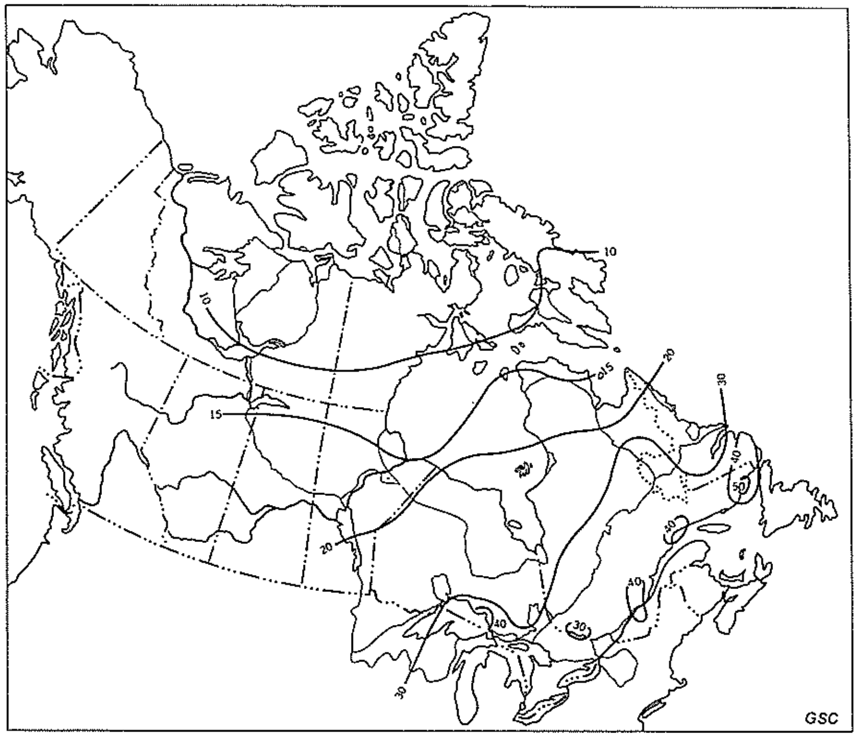

Fig.65. Mean annual total precipitation in the Canadian Shield (values are in inches).

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-

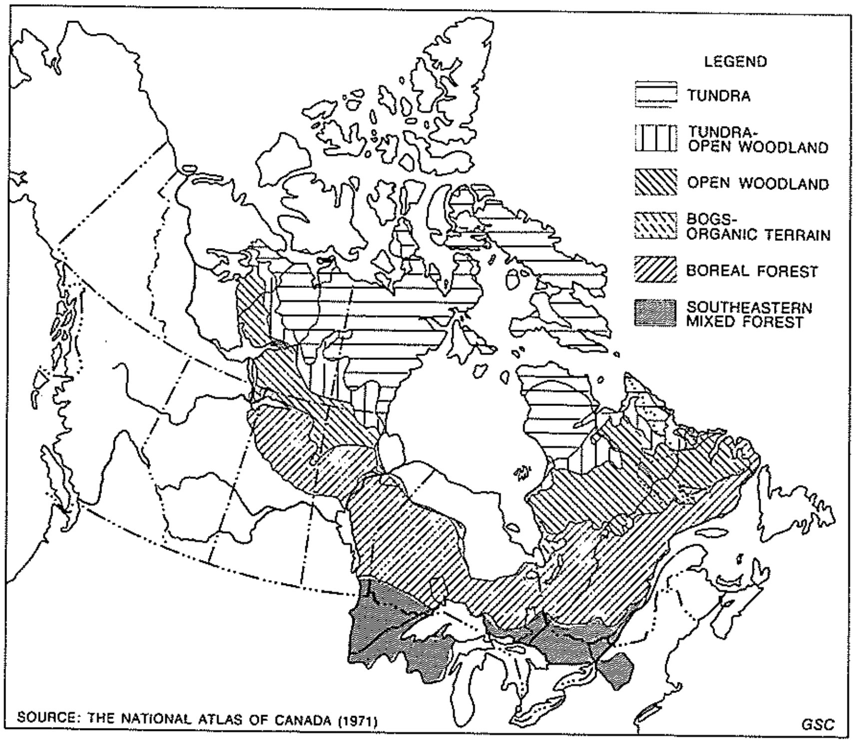

Fig.66. Vegetation regions in the Canadian Shield.

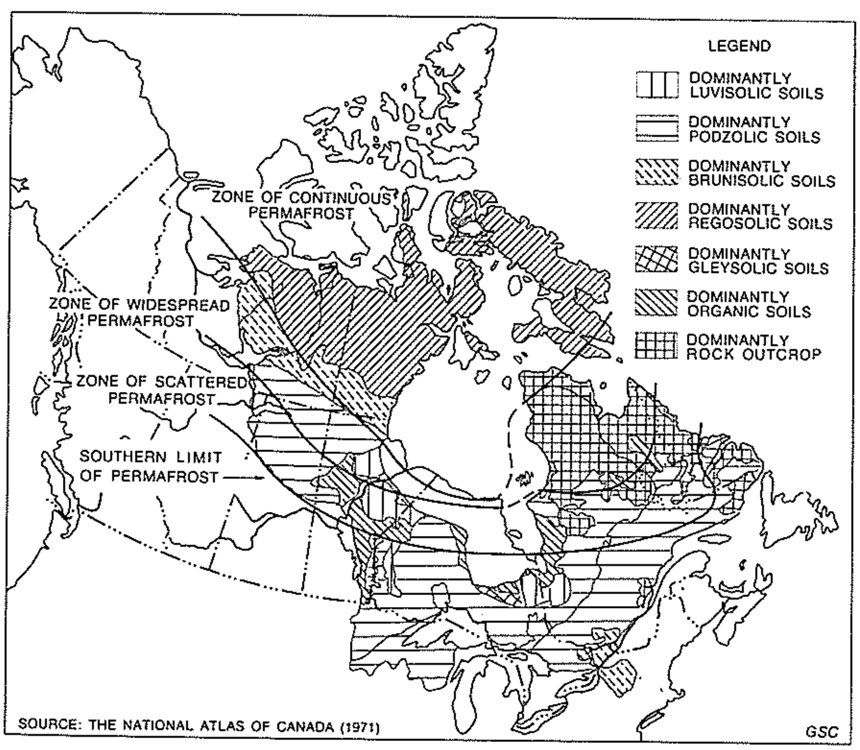

Fig.67. Distribution of permafrost and soil types in the Canadian Shield.

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 XXIII

Index of examples, Section C*

Till		Stratified drift		
1. lodgement till	2. ablation till	3. ice contact	4. outwash	5. glacial lake marine
A. General (Mobile elements in thin overburden)				
(A1)** Lac Albanel Beechey Lake Cachau-Herreillat and La Salle (1969) Chibougamau area (Ermengen, 1957) Cobalt Coppermine (Allan et al., 1972) Coronation mine (Scott and Byers, 1965) Limerick Ogden (1954) Otelnuk Lake area (Kish, 1968) Puskaskwa region (Wolfe and Wright, 1969; Wolfe, 1973) Shawinigan (Felder, 1974)		Cachau-Herreillat and La Salle (1969) Lee (1968, 1971) Shilts (1973)	Puskaskwa region (Wolfe, 1973)	(A5) Cobalt Consolidated Mogador Flin Flon Kidd Creek Magusi River Manitouwadge Ogden (1954) Pukaskwa region (Wolfe, 1973) Setting Net Lake (Wolfe, 1974) Troilus Wintering Lake
B. Effect of variation in overburden thickness				
(B1) Chibougamau area (Ermengen, 1957) Cobalt Coronation mine (Scott and Byers, 1965) Garrett (1969)			Pukaskwa region (Wolfe, 1973)	(B5) Manitouwadge Ogden (1954) Setting Net Lake (Wolfe, 1974)

C. Multiple episodes of glaciation	
(C1) Gleeson and Cormier (1971)	(C5)
Kidd Creel	
Louvem (Garrett, 1971)	
D. Effect of rock type change	
(D1) Beechey Lake.	(D5) Nighthawk Lake
Coppermine (Allan et al., 1972)	Pukaskwa region (Wolfe, 1973)
Otelnuk Lake area (Kish, 1968)	
Shawinigan (Felder, 1974)	
E. Chemical mobility	
(E1) Lac Albanel	
Beechey Lake	Manitouwadge
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)	Bradshaw et al. (1974)
Cobalt	Wintering Lake
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. Fore 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.,

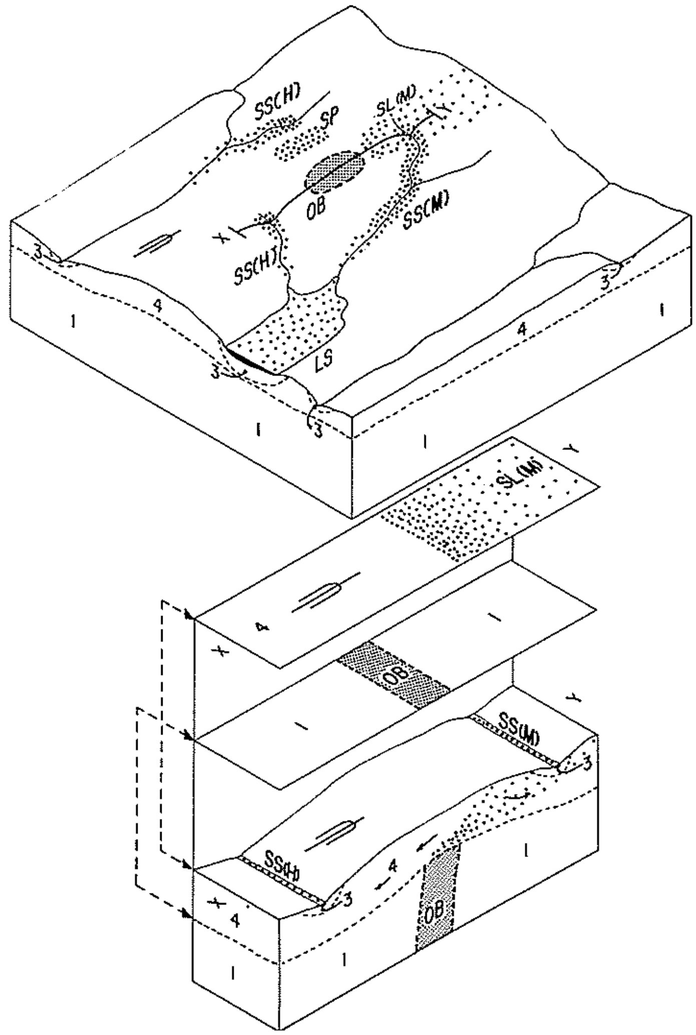

Fig.68. Model A1 (Shield). Idealized models for geochemical dispersion of mobile elements in areas of thin lodgement till.

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 rigin.

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;

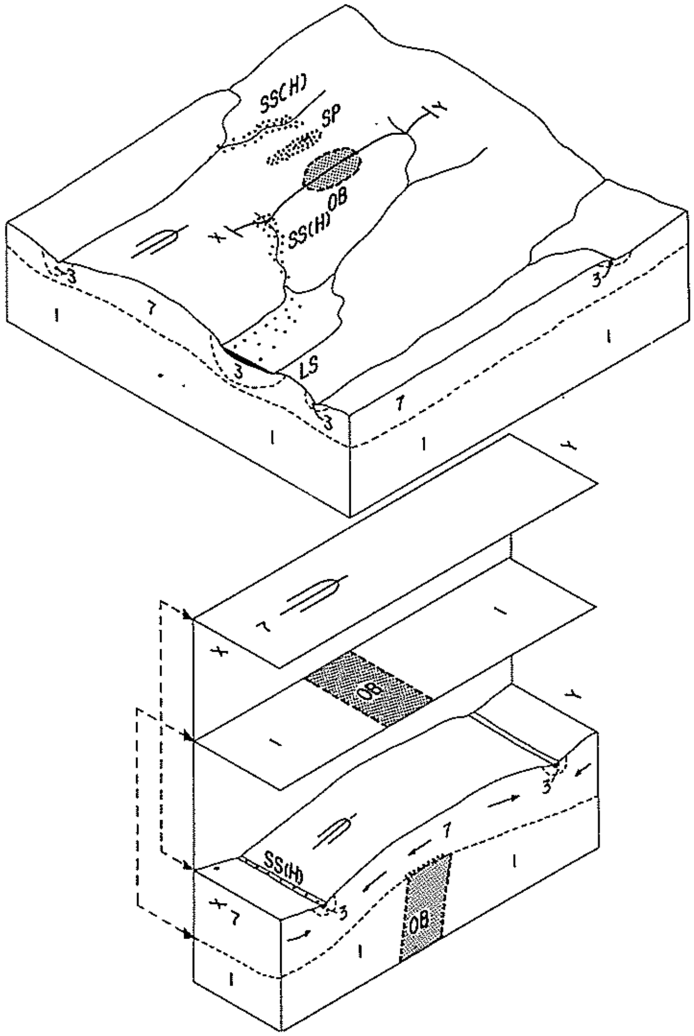

Fig.69. Model A5 (Shield). Idealized models for geochemical dispersion of mobile elements in areas of stratified drift (see Fig.68 for legend).

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.

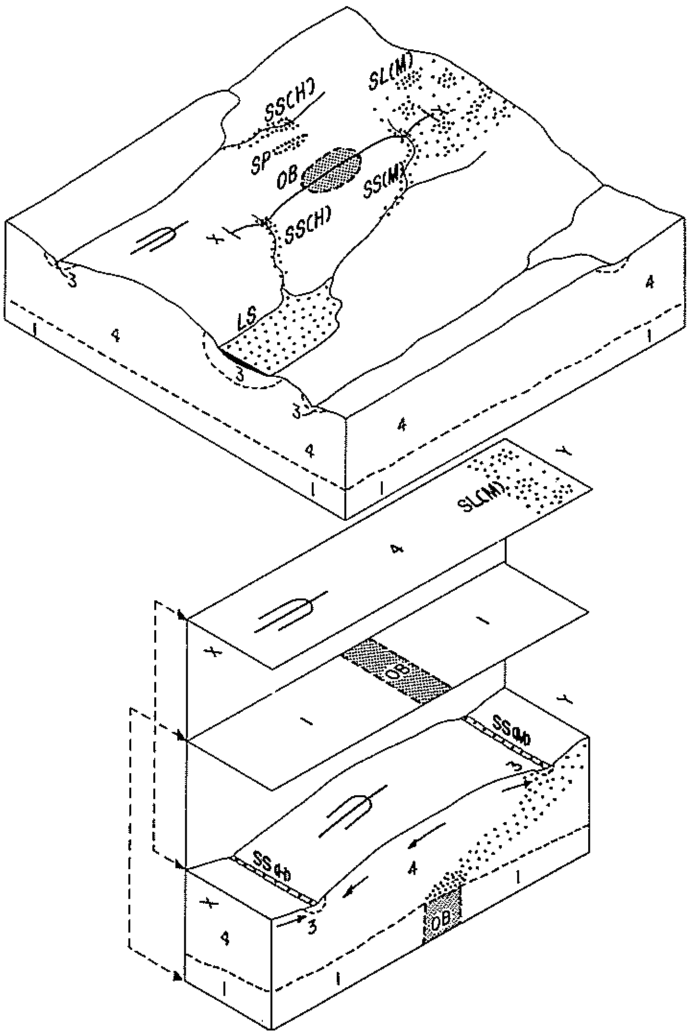

Fig.70. Model B1 (Shield). Idealized models for geochemical dispersion of mobile elements in areas of thick stratified drift (see Fig.68 for legend).

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. Similarily 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

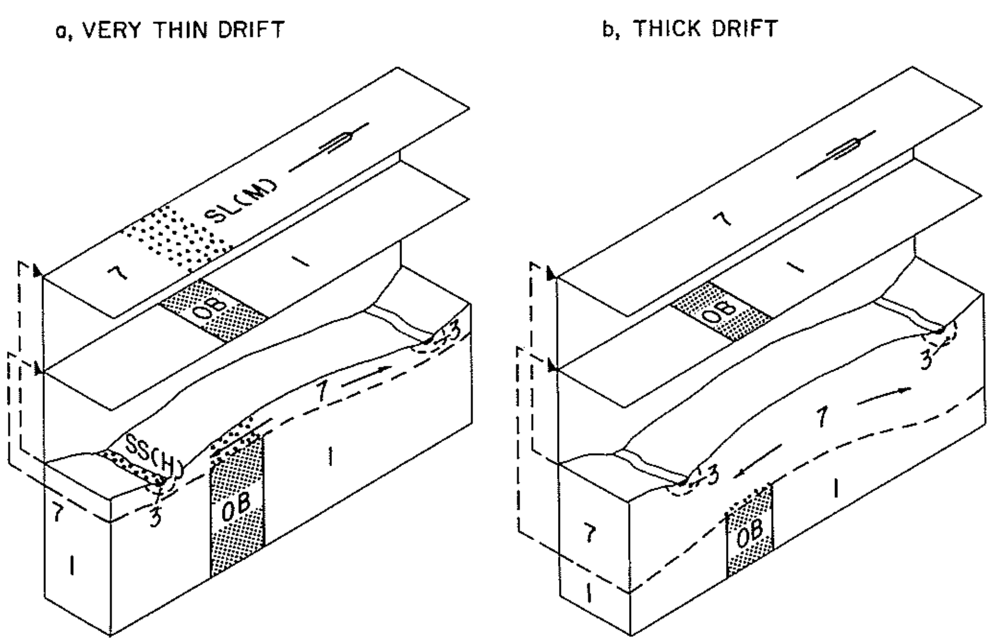

Fig.71. Model B5 (Shield). Idealized models for geochemical dispersion of mobile elements in areas of different thicknesses of stratified drift (see Fig.68 for legend).

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

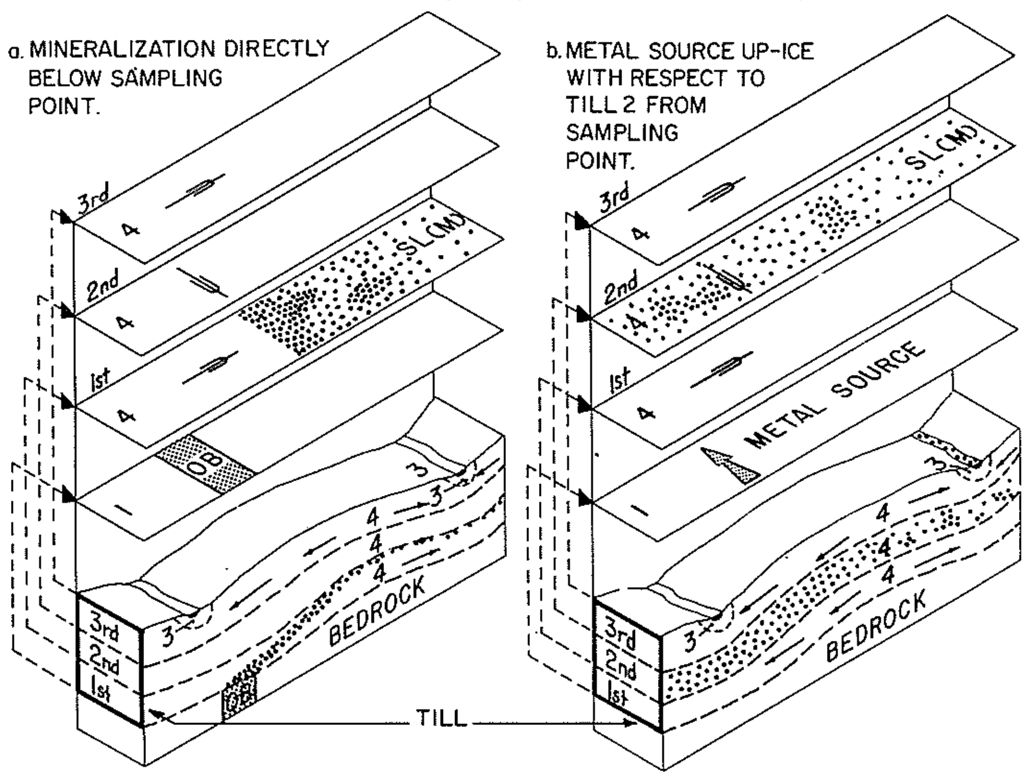

Fig.72. Model C1 (Shield). Idealized models for geochemical dispersion in several ages of lodgement till (see Fig.68 for legend).

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,

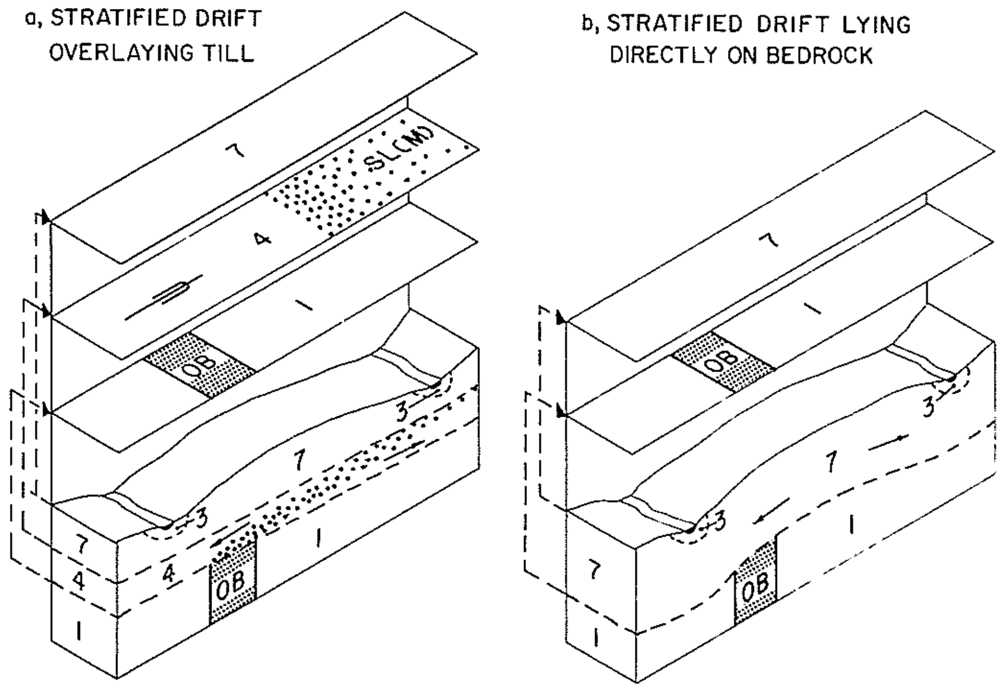

Fig.73. Model C5 (Shield). Idealized models for geochemical dispersion with stratified drift (a) overlying till, and (b) directly on bedrock (see Fig.68 for legend).

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

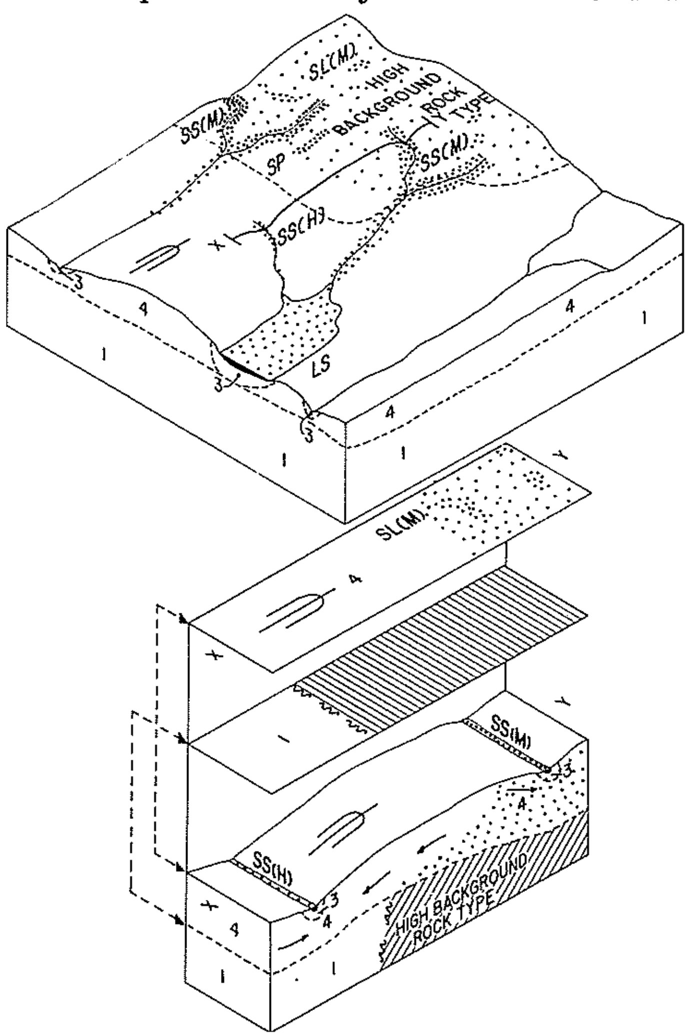

Fig.74. Model D1 (Shield). Idealized model showing the effect of rock-type change on glacial dispersion for mobile elements in stratified drift-covered areas (see Fig.68 for legend).

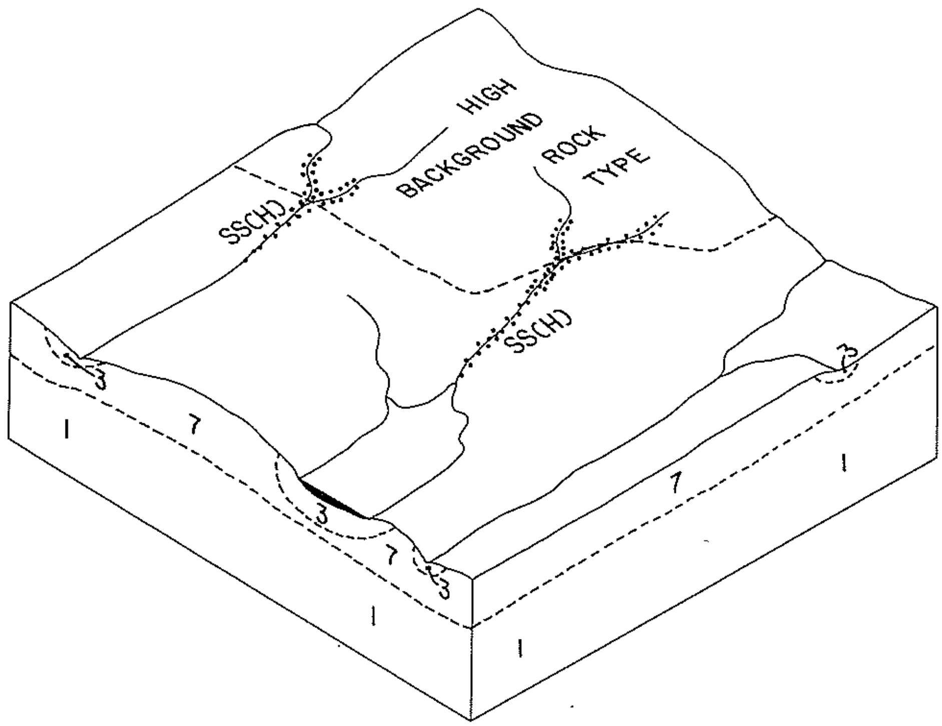

Fig.75. Model D5 (Shield). Idealized model showing the effect of rock-type change on glacial dispersion for mobile elements in stratified drift-covered areas (see Fig.68 for legend).

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-

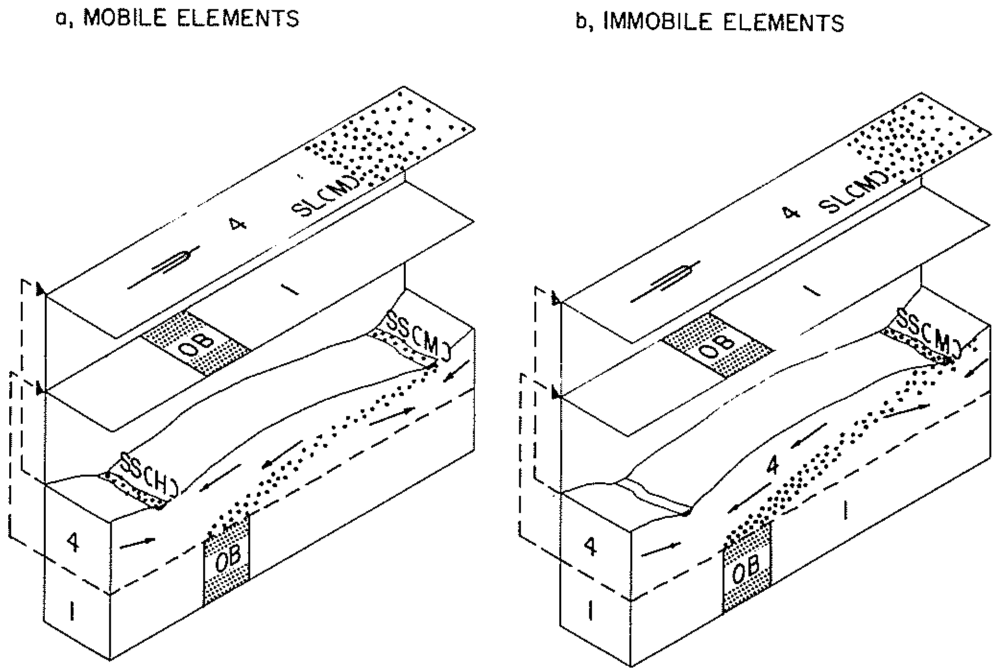

Fig.76. Model E1 (Shield). Idealized model showing the effect of differing chemical mobility of elements on this dispersion pattern in till-covered areas (see Fig.68 for legend).

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.

F. Mobile elements in bogs

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

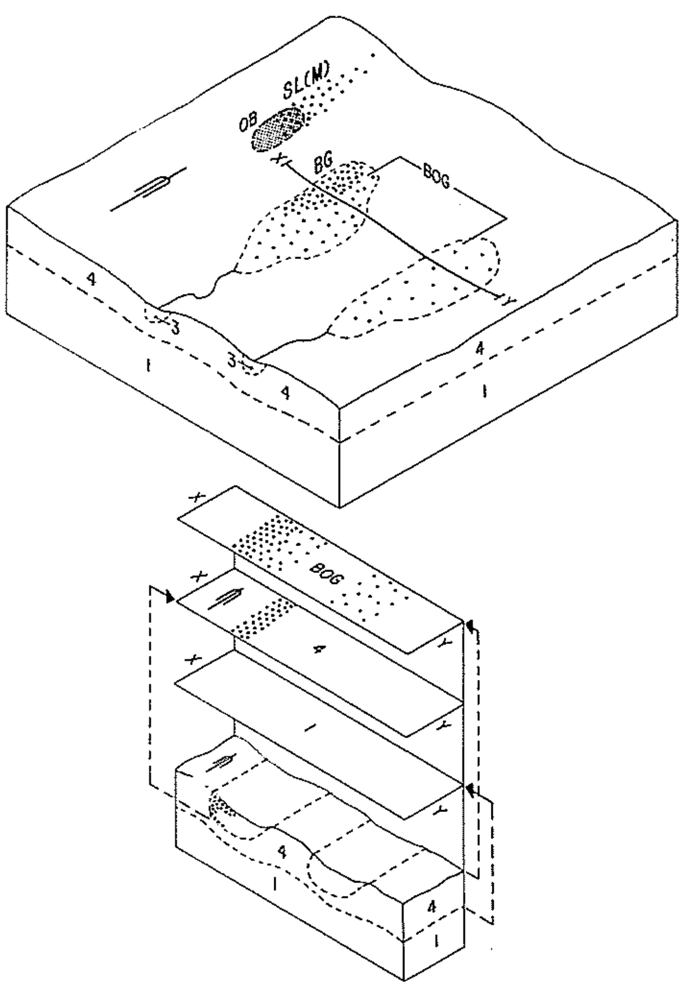

Fig.77. Model F1 (Shield). Idealized model for geochemical dispersion of mobile elements in bogs overlying till (see Fig.68 for legend).

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

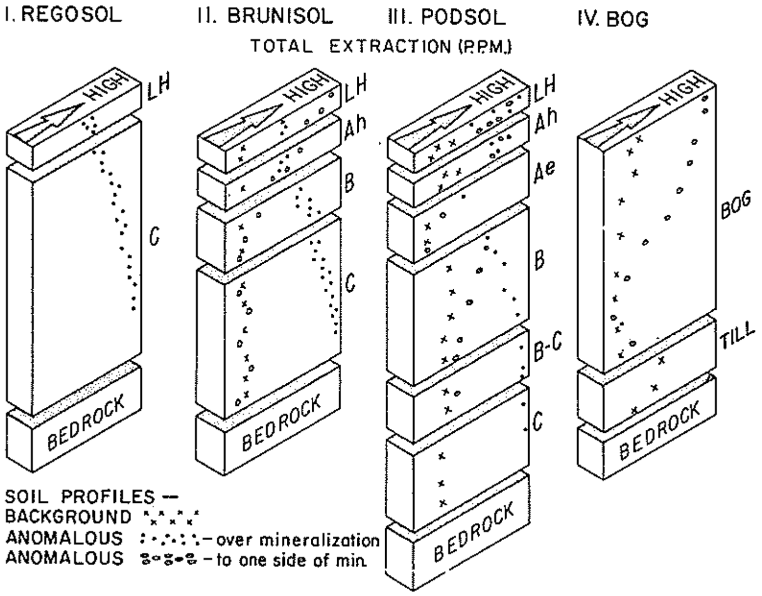

Fig.78. Model G1 (Shield). Idealized model for geochemical dispersion of mobile elements in different soil types overlying till (see Fig.68 for legend).

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).

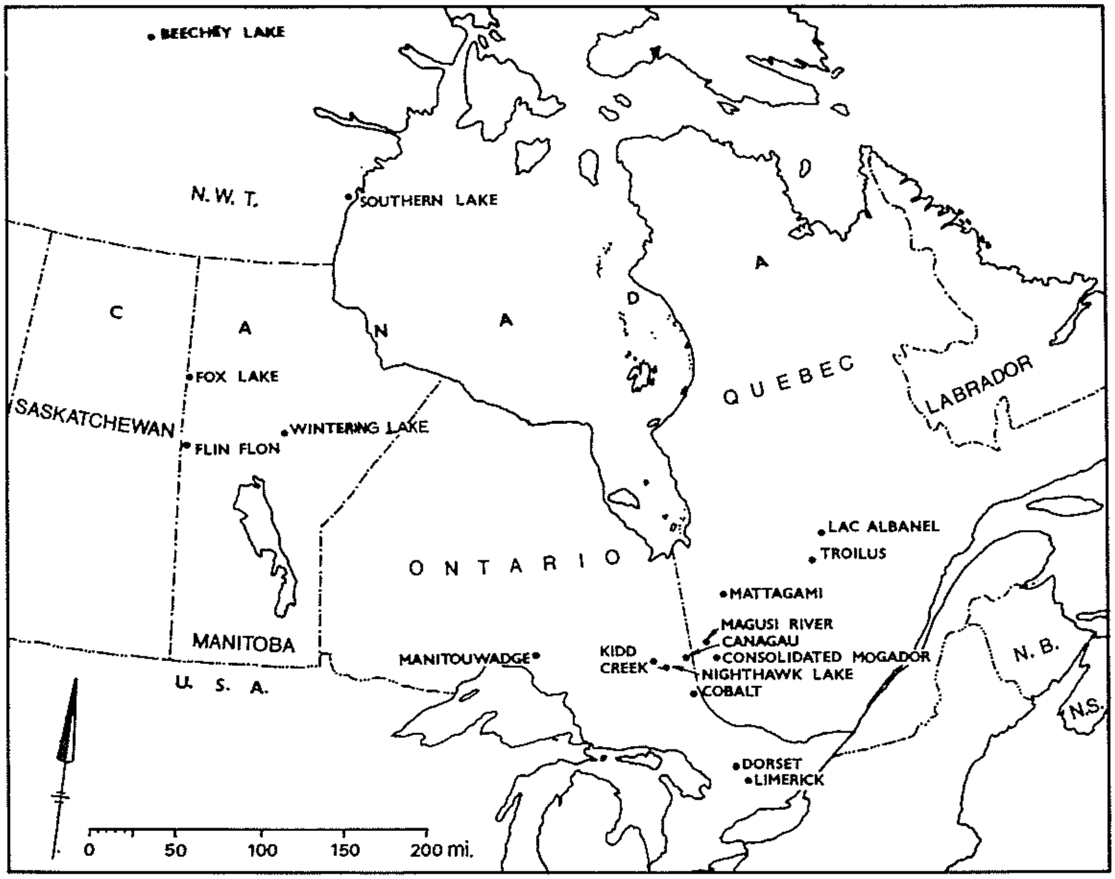

Fig.79. Location map of case histories contained in Section C.

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

*Present address: International Atomic Energy Agency, Ankara, Turkey.

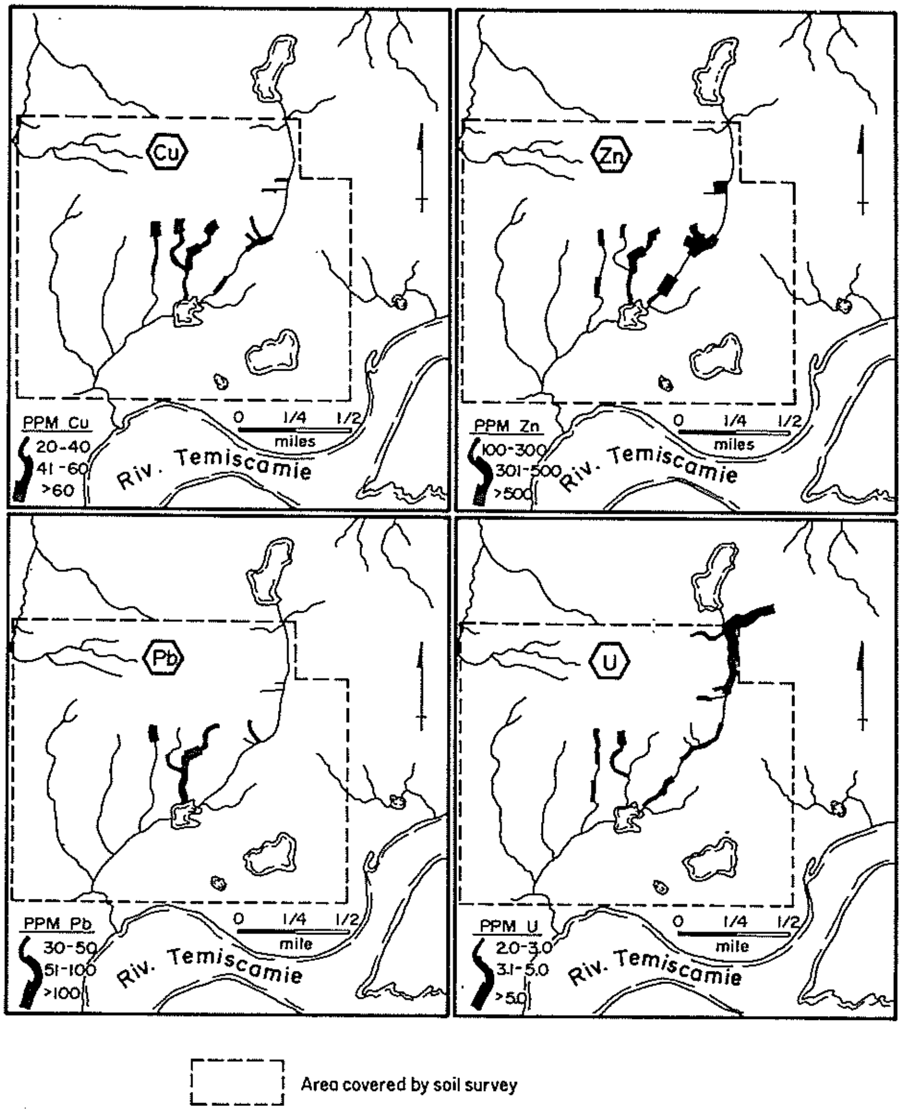

Fig.80. Copper, lead, zinc and uranium in stream sediments, Lac Albanel area, Quebec.

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

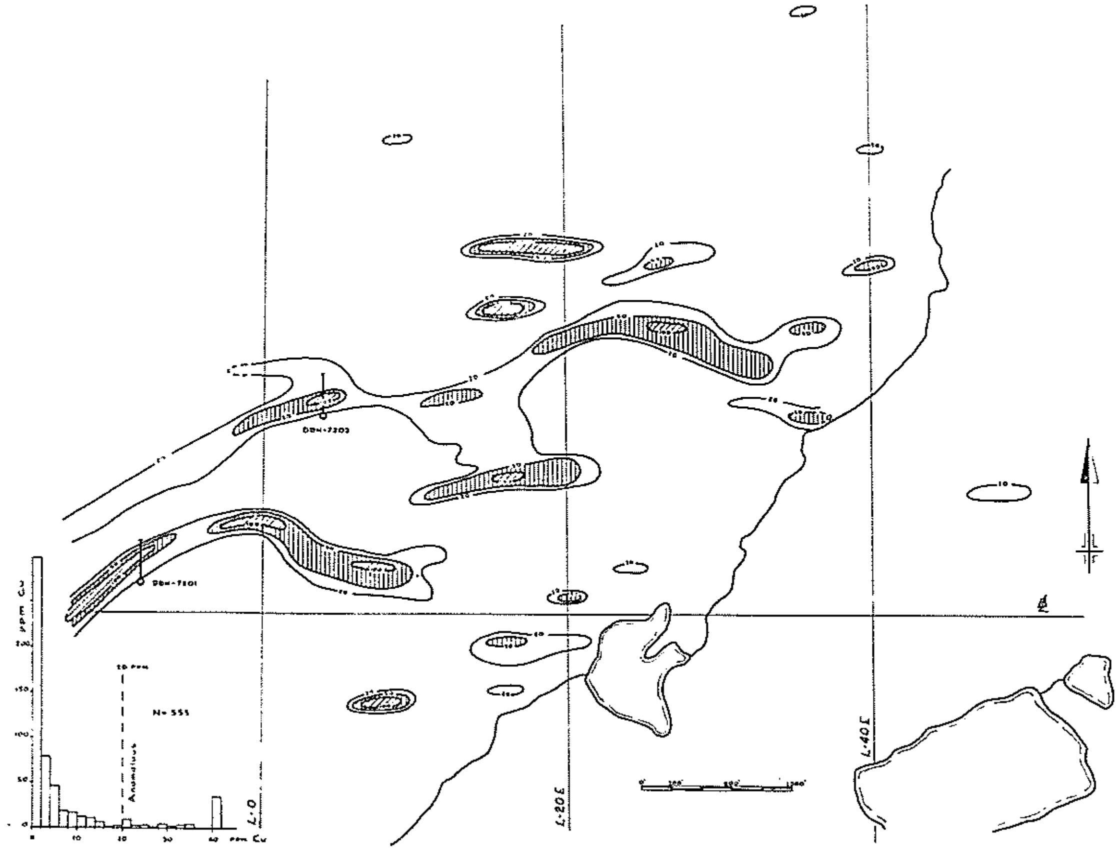

Fig.81. Copper content of surface soils, Lac Albanel property.

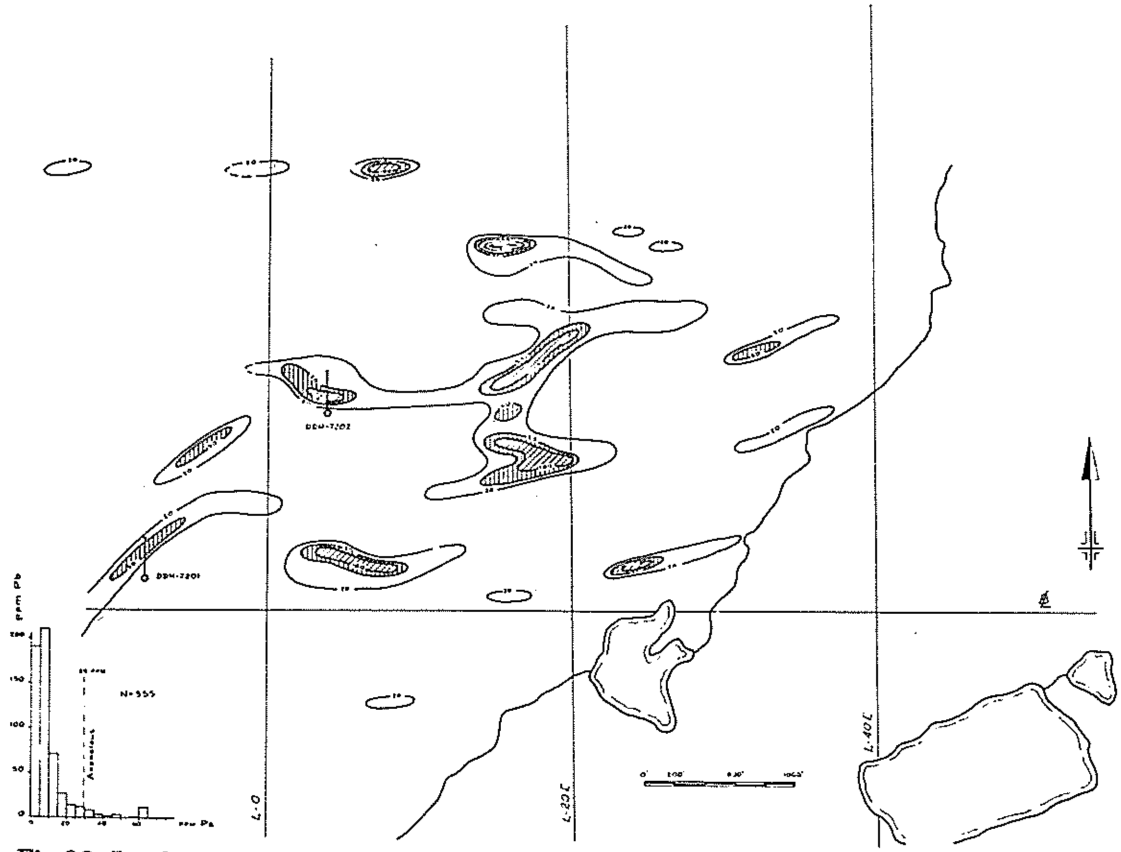

Fig.82. Lead content of surface soils, Lac Albanel property.

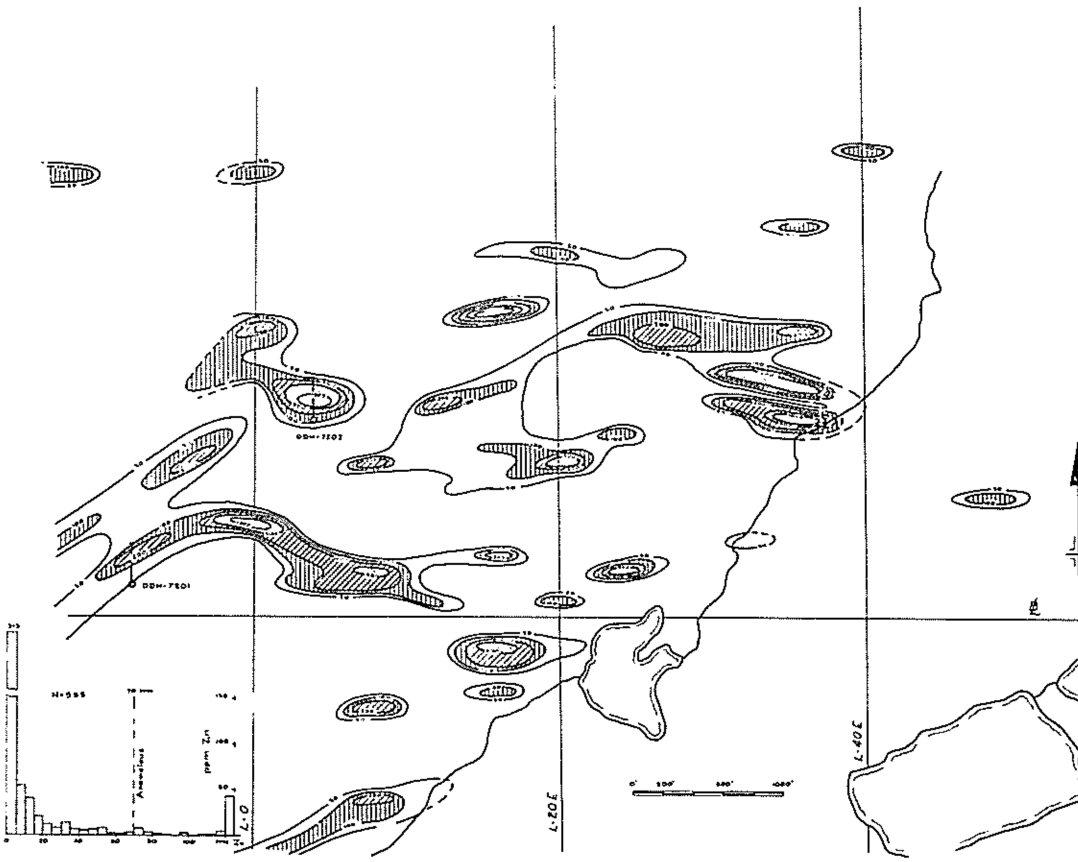

Fig.83. Zinc content of surface soils, Lac Albanel property.

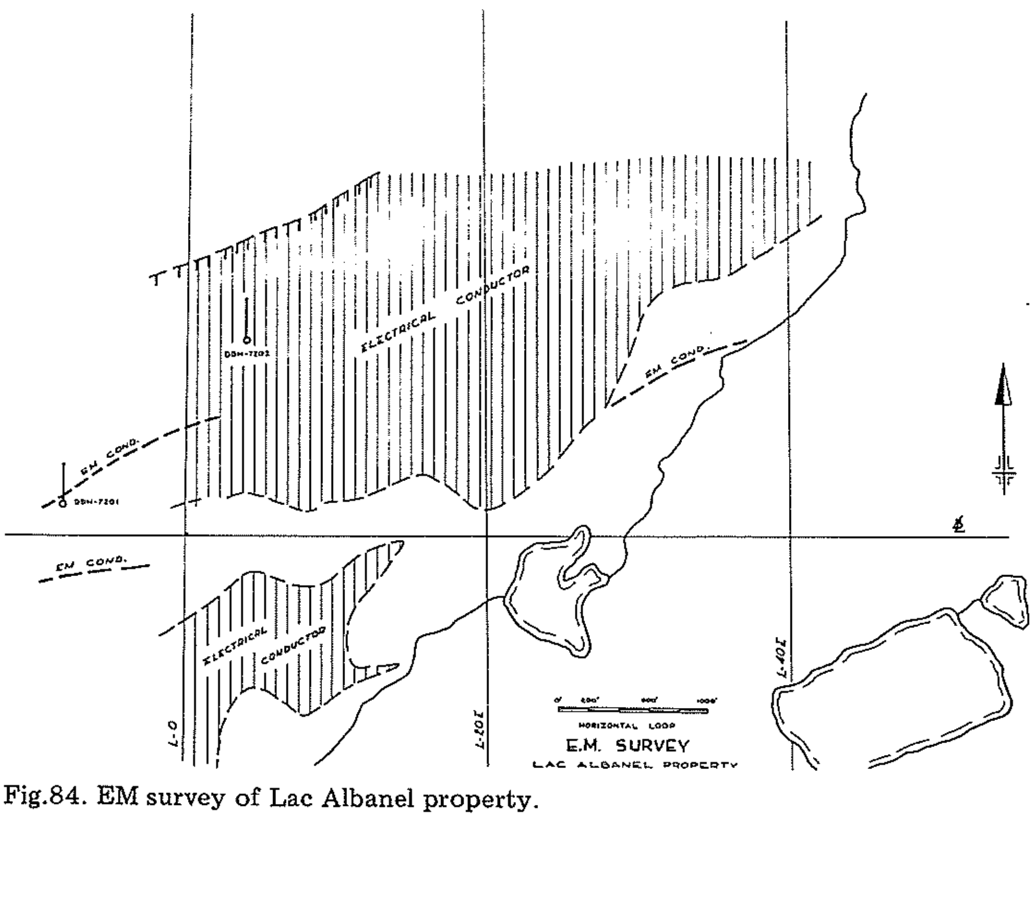

Fig.84. EM survey of Lac Albanel property.

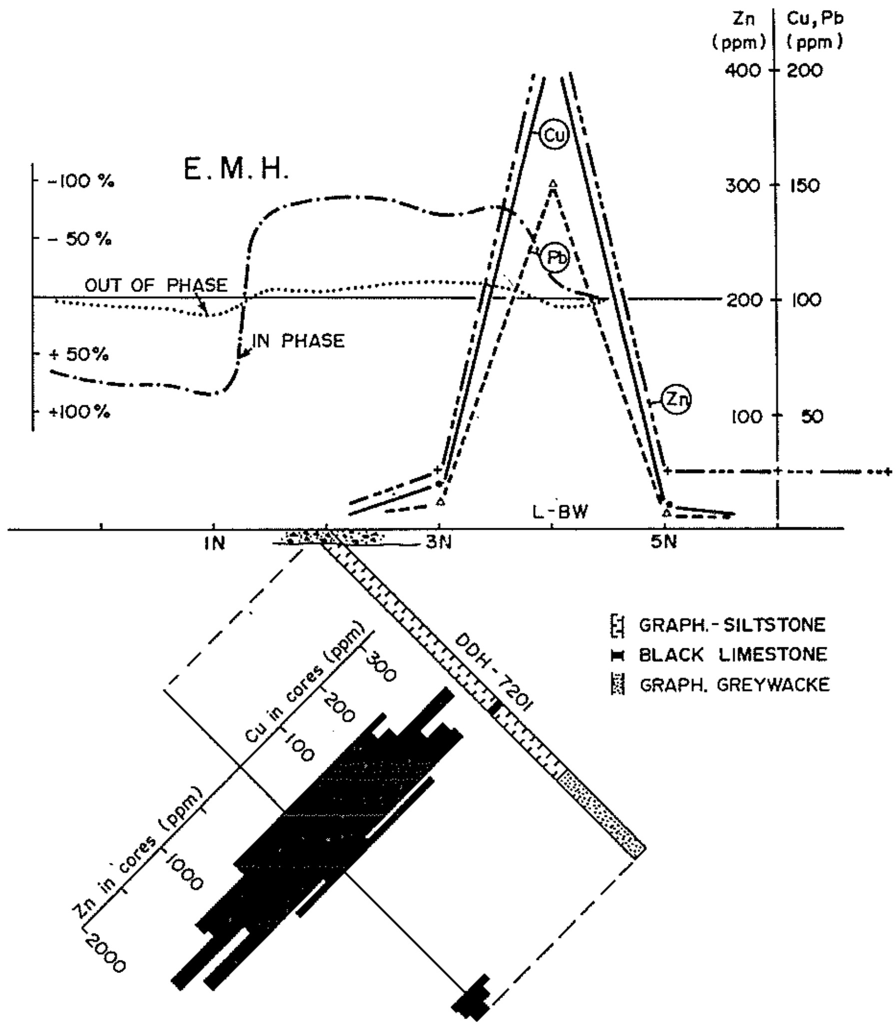

Fig.85. Copper content of surface soils and diamond drill hole 7201, Lac Albanel area.

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

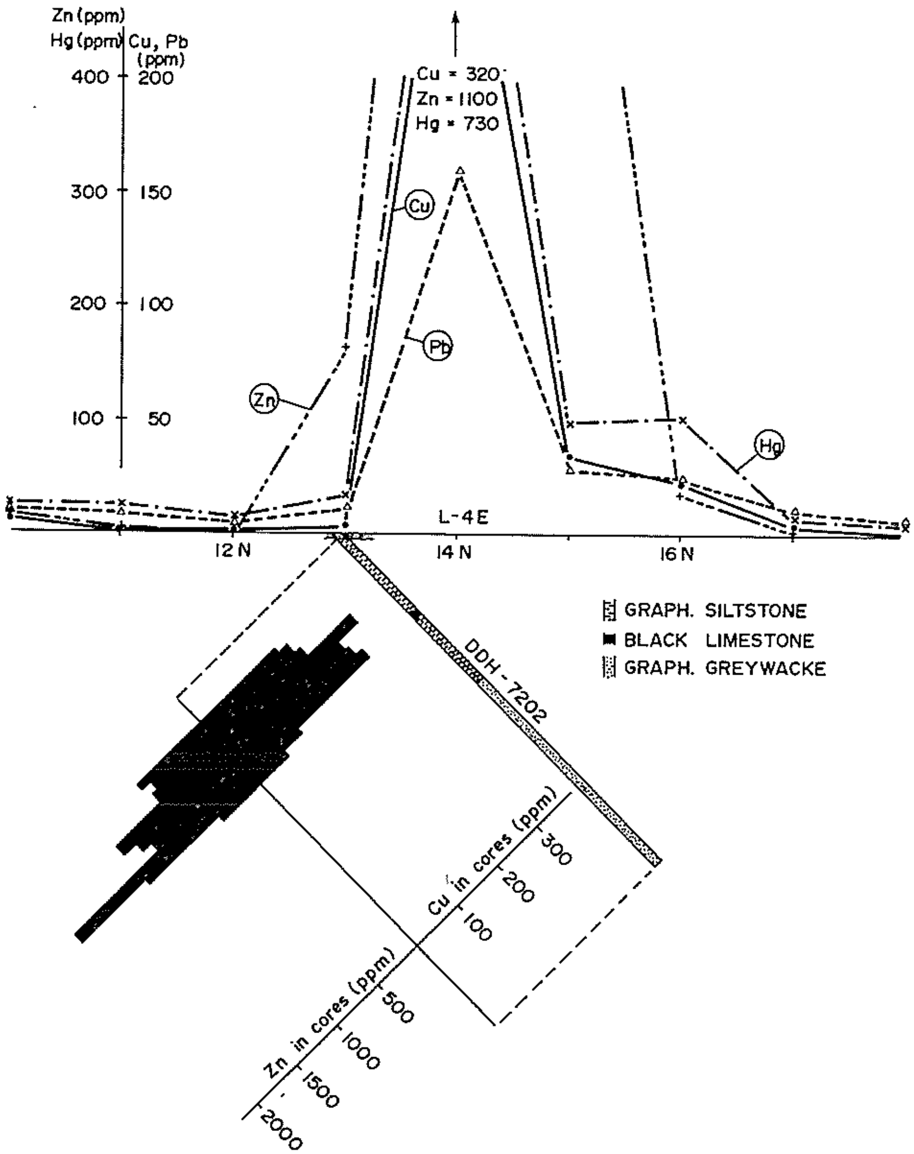

Fig.86. Copper content of surface soils and diamond drill hole 7202, Lac Albanel area.

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

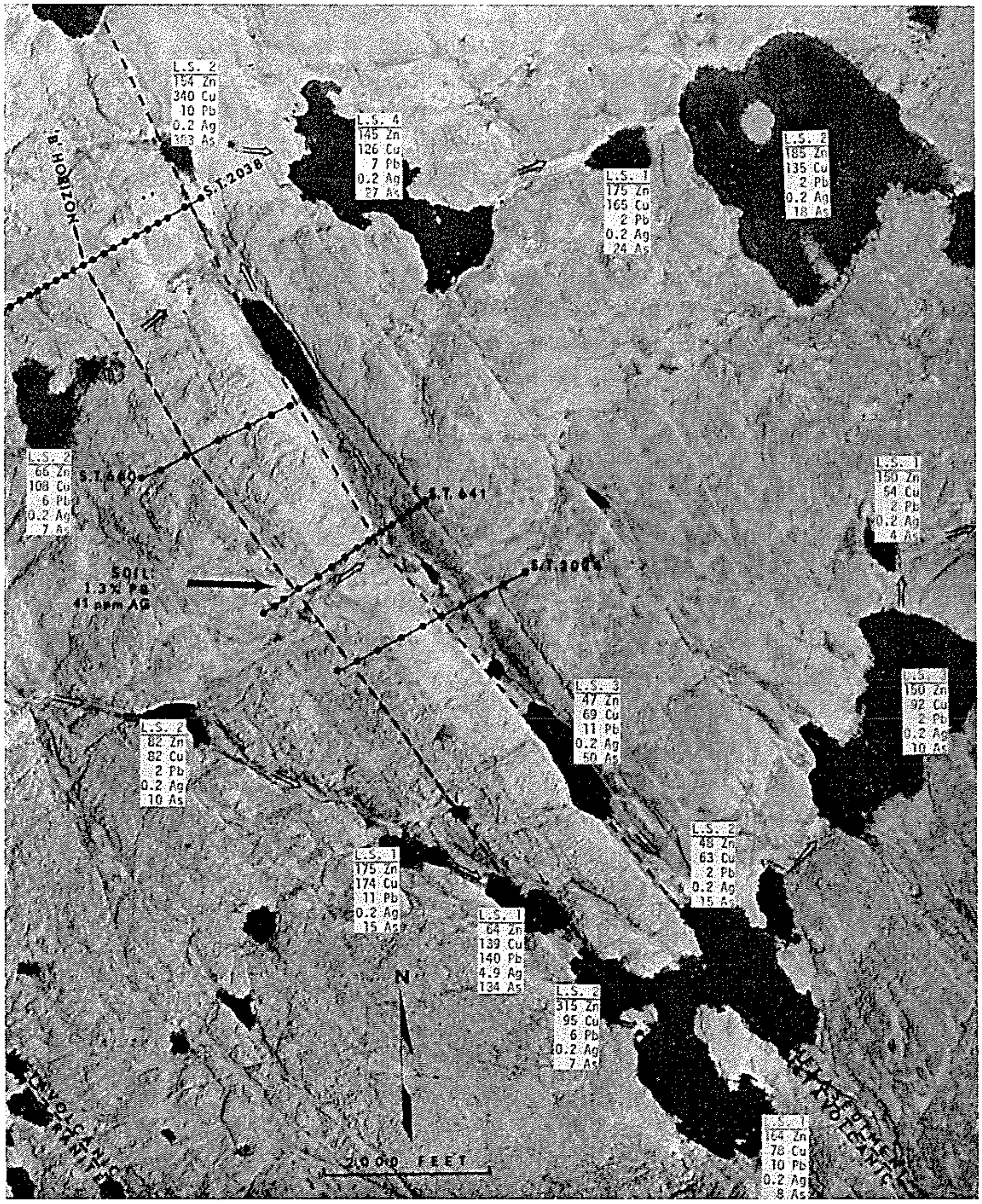

Fig.87. Geochemical data for Beechey Lake area, N.W.T. The numeral following lake sediment (L.S.) is the number of samples from that lake that were averaged to provide the analyses given below. Soil sampling traverses identified as S.T. Rock sampling traverses not shown. Drainage directions given by 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

TABLE XXIV

Zinc, copper, lead, silver and arsenic in soil samples from soil traverse 641 (see Fig.87)*

Soil sample	Zn (ppm)	Cu (ppm)	Pb (ppm)	Ag (ppm)	As (ppm)
641	37	25	15	0.2	44
642	67	44	10	0.2	309
643	31	31	20	0.2	239
644	14	10	15	0.7	92
645	26	20	10	0.2	72
646	79	297	83	3.4	317
647	112	206	271	3.1	92
648	47	116	2	0.2	7
650	136	856	1,370	23.0	145
651	26	56	206	4.7	13
653	141	163	189	0.2	28
654	42	450	12,600	41.0	890
656	126	189	259	3.1	7
657	93	158	644	11.0	22
658	75	38	25	1.0	12

* 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 north-east of Kirkland Lake and 48 km west of Noranda.

(2) The Ben Nevis area is situated in the central part of the Abitibi green-stone belt, an extensive belt of Early Precambrian (Archean) volcanic and sedimentary rocks with associated intrusions. This belt covers an area of 21,200 km^2 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,

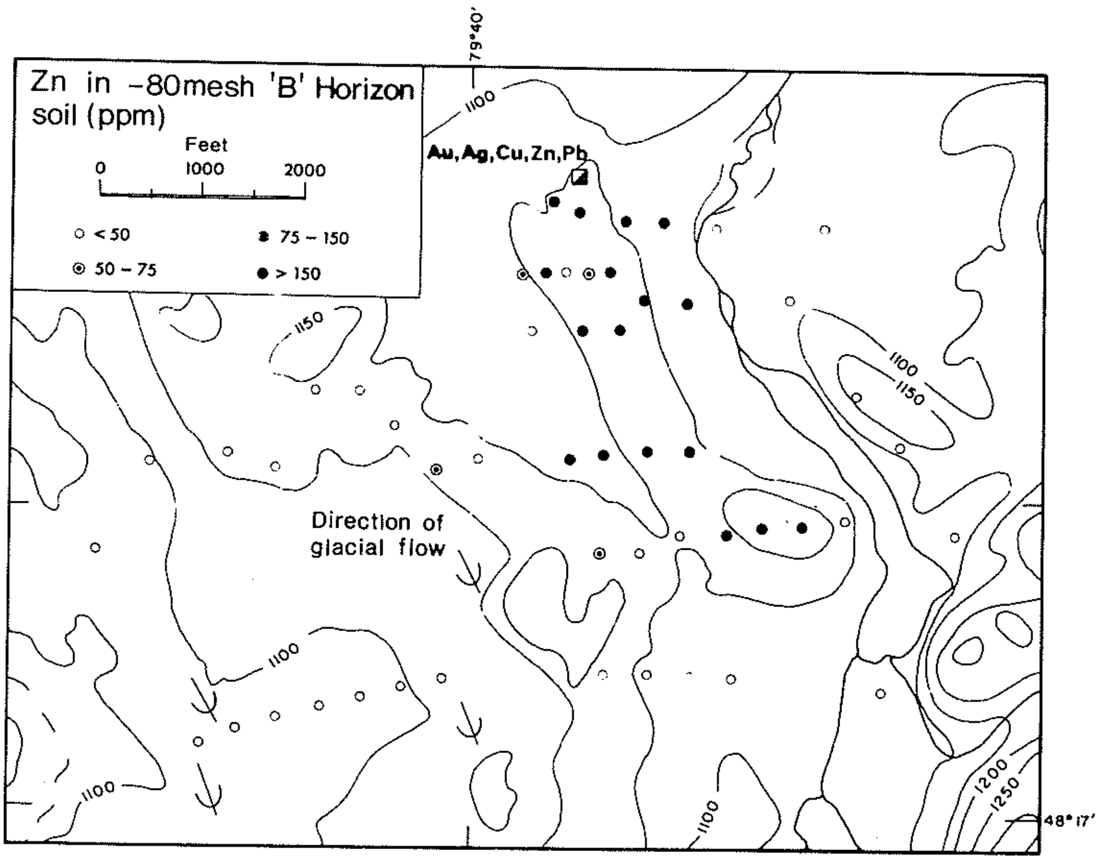

Fig.88. Zinc content in minus 80-mesh B horizon soil, Canagau area, Ontario.

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 HNO_3/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 HNO_3/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

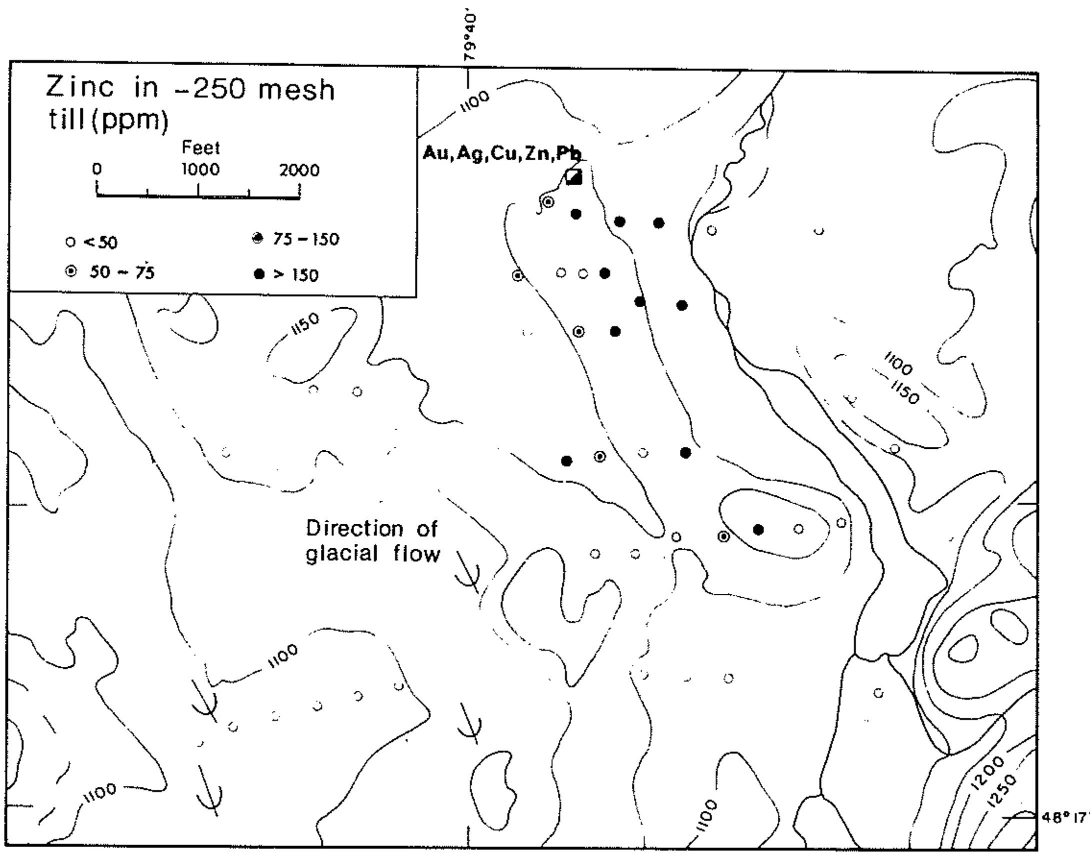

Fig.89. Zinc content in minus 250-mesh till, Canagau area.

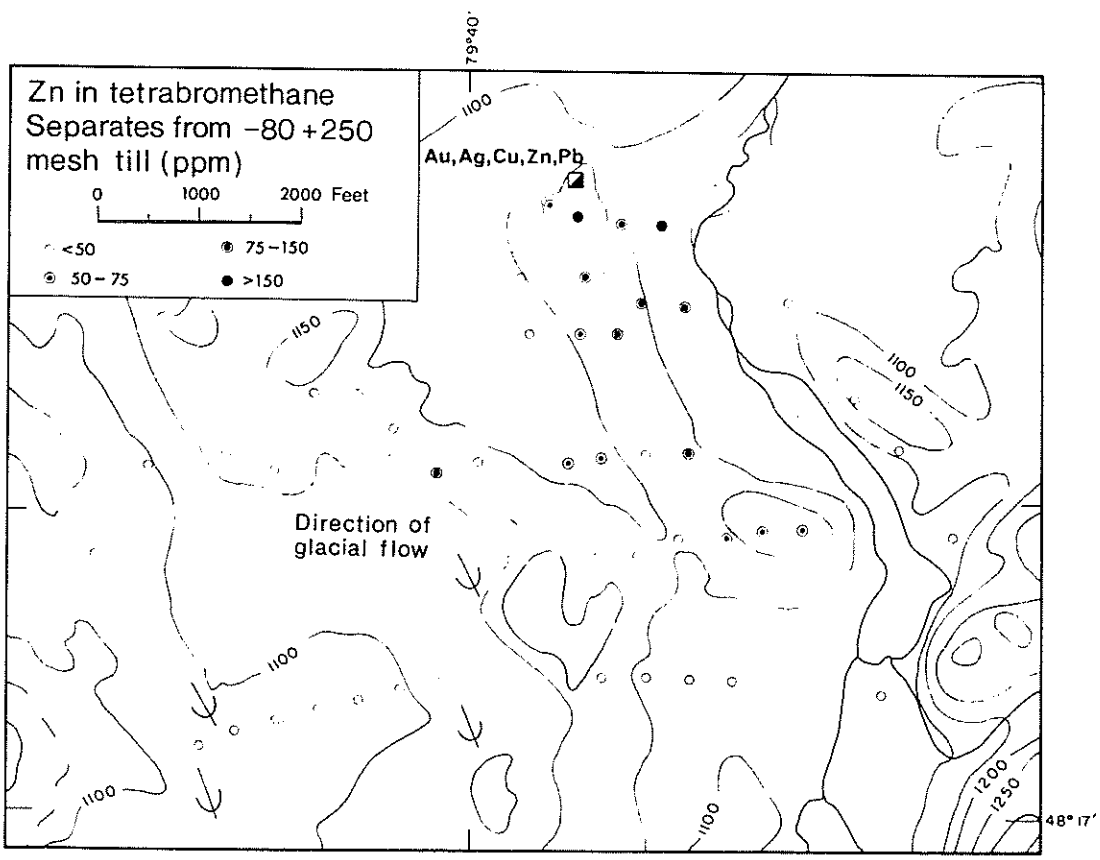

Fig.90. Zinc content in tetrabromethane separates of minus 80-mesh, plus 250-mesh till, Canagau area.

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 tetrabromethane 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).

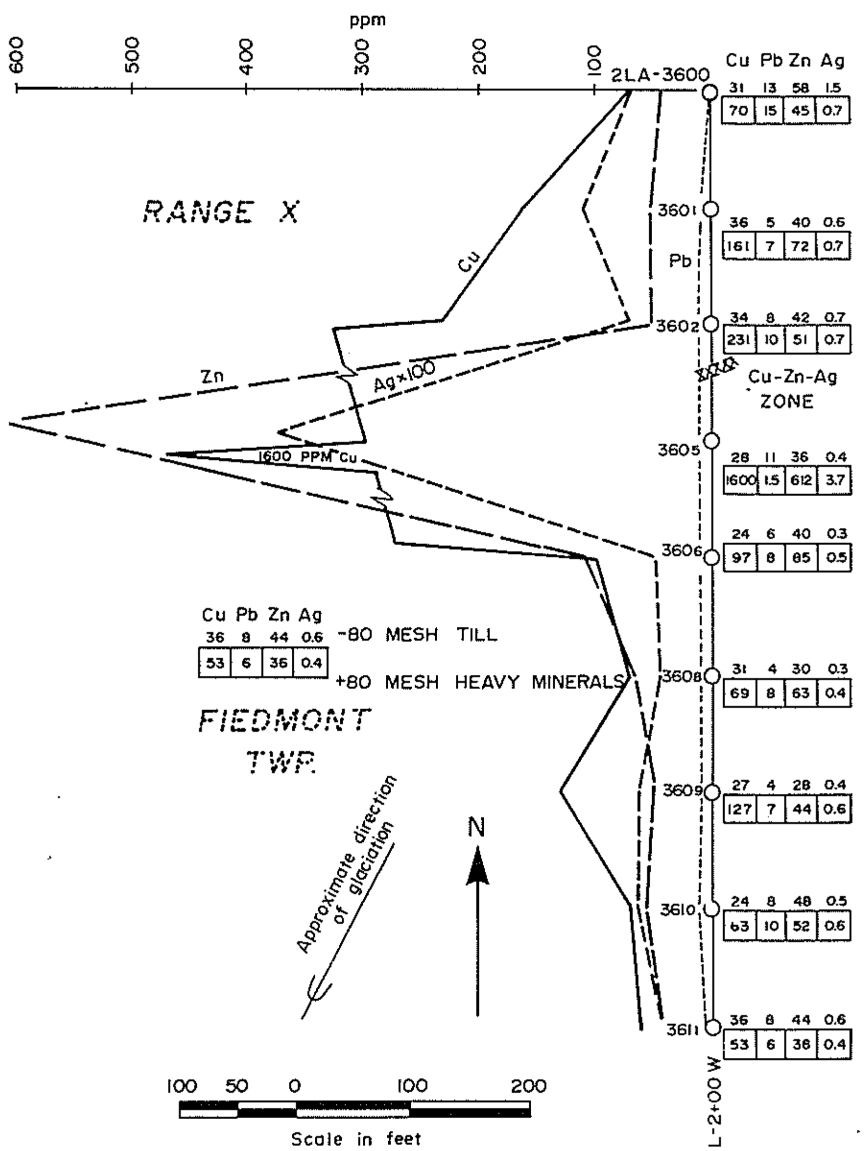

Fig.91. Cu—Pb—Zn—Ag in till, Consolidated Mogador deposit, Quebec.

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).

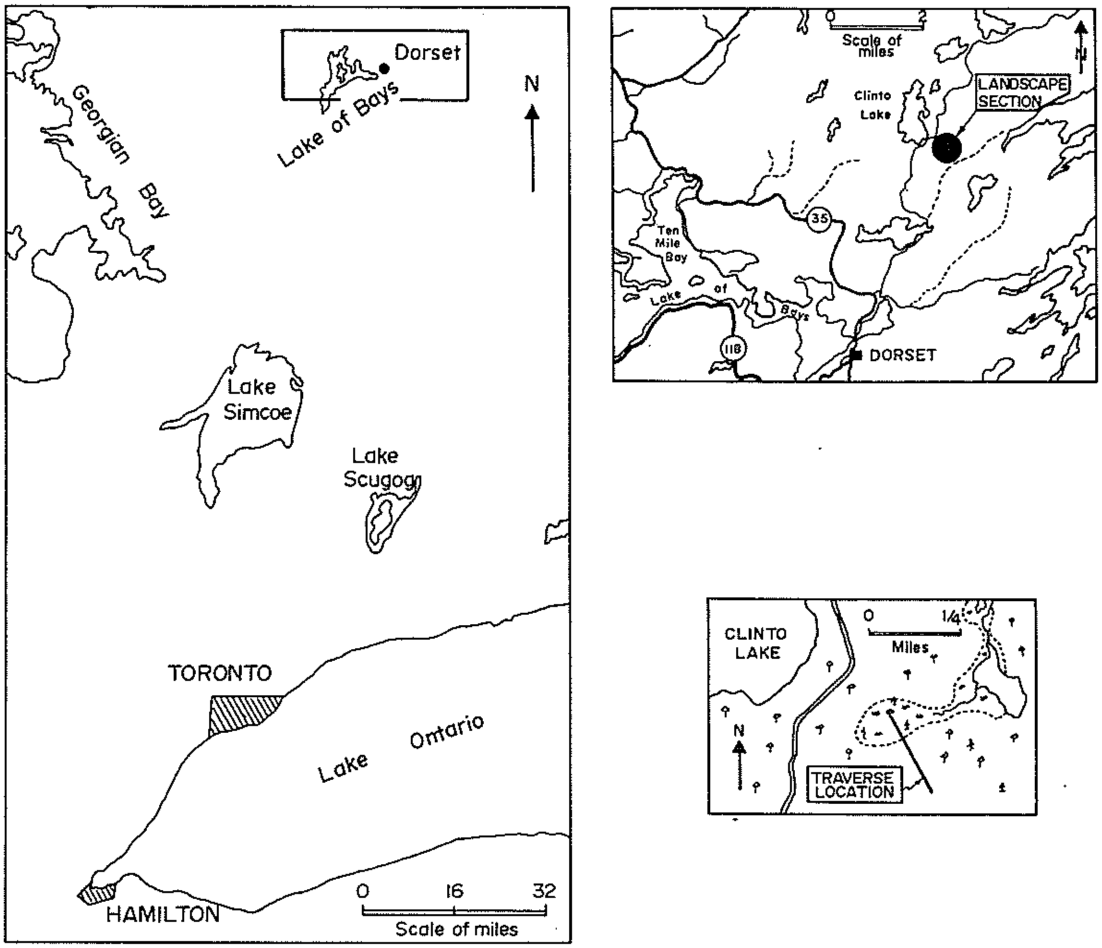

Fig.92. Location and setting of the sampling strip, Dorset area, Ontario.

(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 A_2 (or Ae) horizon is generally depleted in copper, lead and zinc; and (c) in the bogs the values generally decrease with depth.

Reference: Fortescue et al., 1973.

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,

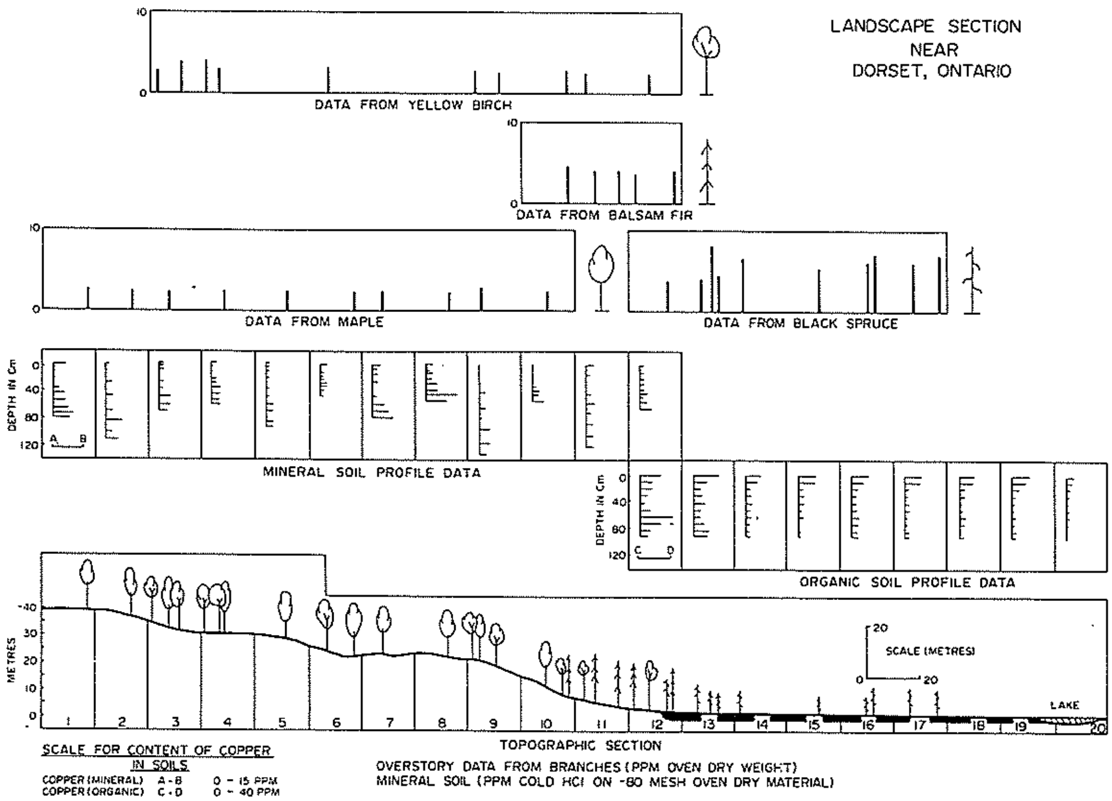

Fig.93. Distribution of copper in soil profiles, Dorset area.

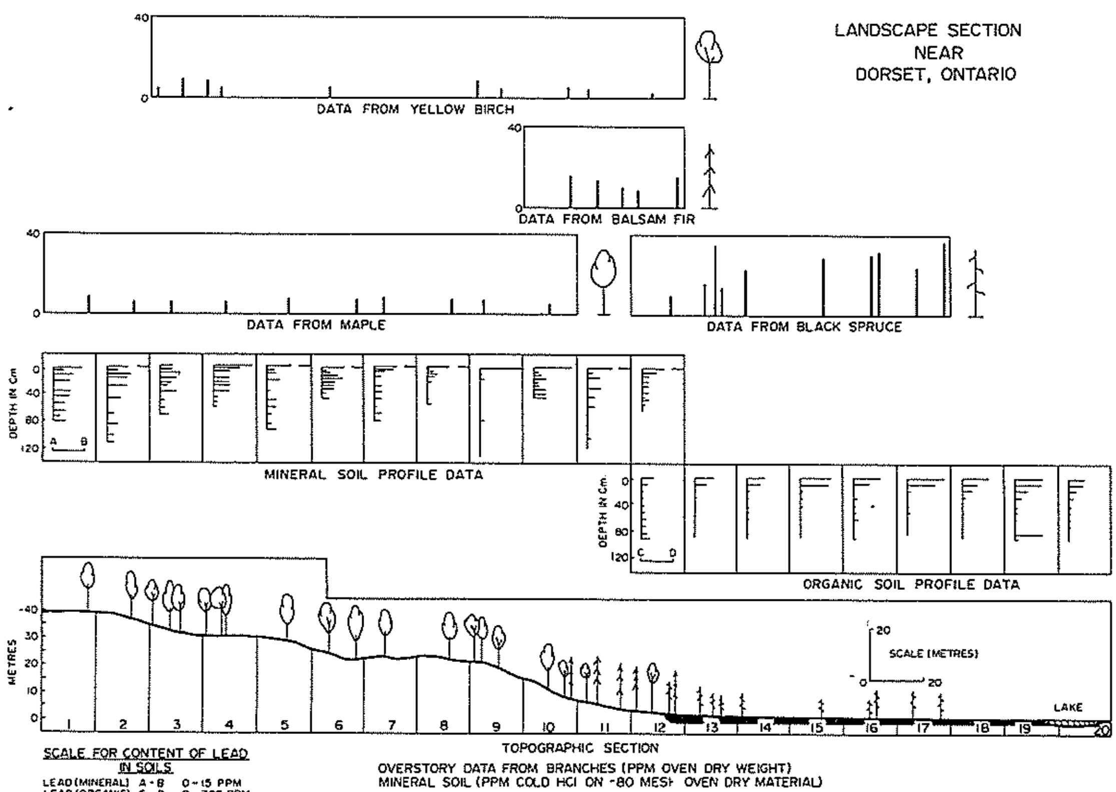

Fig.94. Distribution of lead in soil profiles, Dorset area.

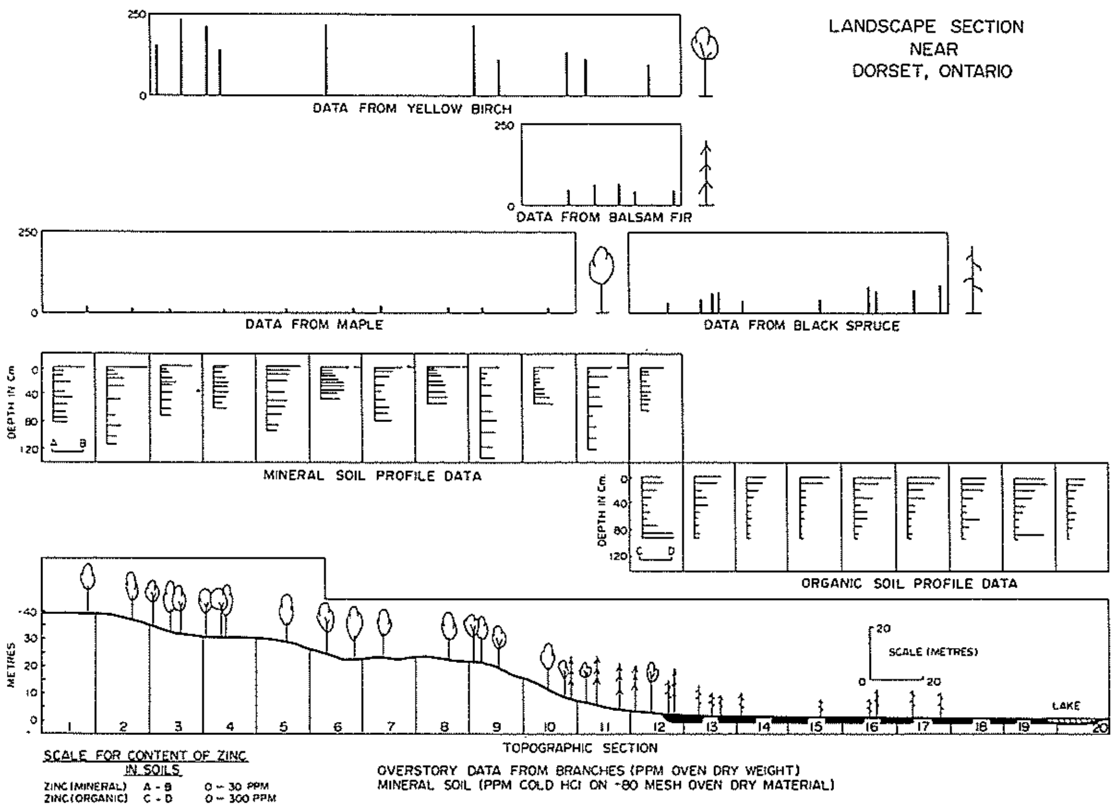

Fig.95. Distribution of zinc in soil profiles, Dorset area.

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

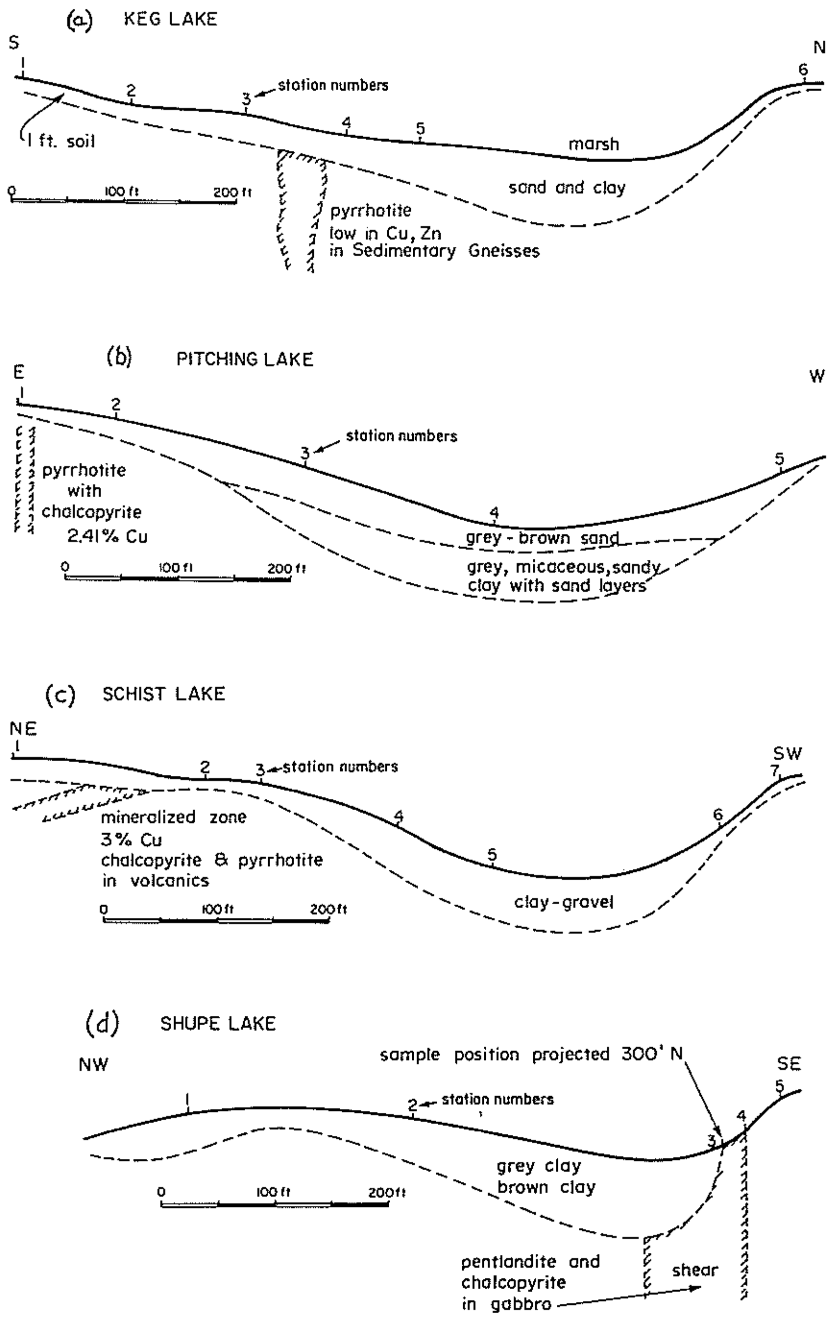

Fig.96. Location of soil profiles and details of overburden conditions, Flin Flon area, Manitoba.

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

	Soil horizon	Station number						
		1	2	3	4	5	6	7
Keg Lake								
Total Cu	A_1/A_2	12	5	20	9	19	7	
	A_3	7	19	20	7	7	—	
	A_3/B	5	19	18	14	8	6	
Total Zn	A_1/A_2	40	110	110	35	65	40	
	A_3	115	65	110	35	15	—	
	A_3/B	90	90	85	60	35	35	
Total Ag	A_1/A_2	7	1	356	9	8	1	
	A_3	6	7	164	1	1	—	
	A_3/B	1	15	85	4	1	1	
Pitching Lake								
Total Cu	A_1	25	14	—	11	23		
	A_3/B	106	10	19	10	42		
	C	38	19	19	13			
Total Zn	A_1	85	115	—	65	40		
	A_3/B	65	60	85	115	135		
	C	60	35	60	85	—		
Total Hg	A_1	32	15	—	1	110		
	A_3/B	27	14	4	2	68		
	C	3	1	1	1	—		
Schist Lake								
Total Cu	A_1	34	—	—	46	50	25	—
	A_2	50	—	25	55	34	—	21
	A_3	38	—	42	29	38	—	23
	A_3/B	42	23	38	—	—	—	—
Total Zn	A_1	115	—	—	115	110	65	—
	A_2	140	—	115	115	65	—	60
	A_3	85	—	135	85	60	—	60
	A_3/B	115	140	110	—	—	—	—
Total Hg	A_1	125	—	—	82	34	85	—
	A_2	138	—	36	40	18	—	3
	A_3	20	—	20	18	22	—	17
	A_3/B	21	42	83	—	—	—	—
Shupe Lake								
Total Cu	A_2	9	13	54	118	14		
	A_3	16	—	98	250	31		
	B	—	44	—	—	—		
Total Zn	A_2	40	43	53	37	37		
	A_3	37	—	56	101	74		
	B	—	65	—	—	—		
Total Hg	A_2	5	3	21	17	13		
	A_3	10	—	24	30	11		
	B	—	21	—	—	—		

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

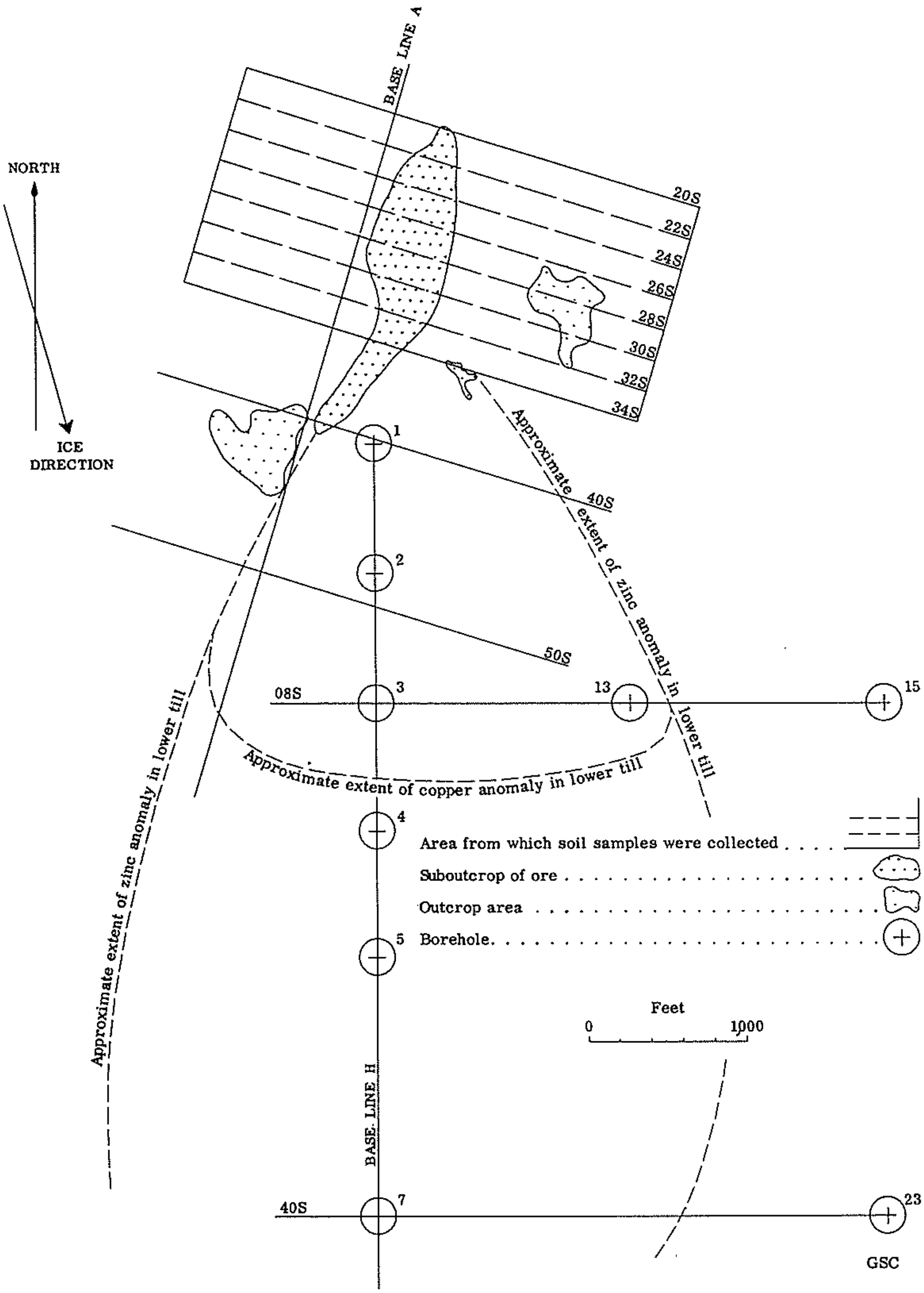

Fig.97. Location of soil and plant samples, boreholes from which surficial material was collected and the sub-outcrop area of the mineral deposit (after Fortescue and Hornbrook, 1969).

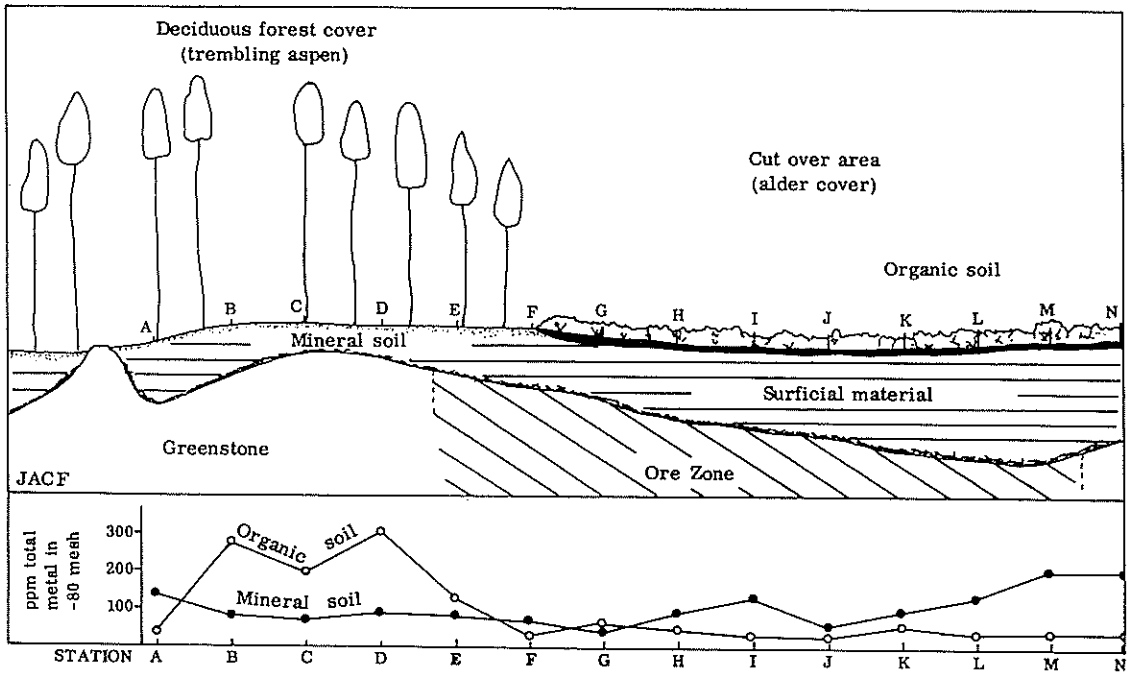

Fig.98. Landscape section showing bedrock geology, surficial geology, soil cover types, plant-cover types and zinc content in soil in Line 24S (after Fortescue and Hornbrook, 1969).

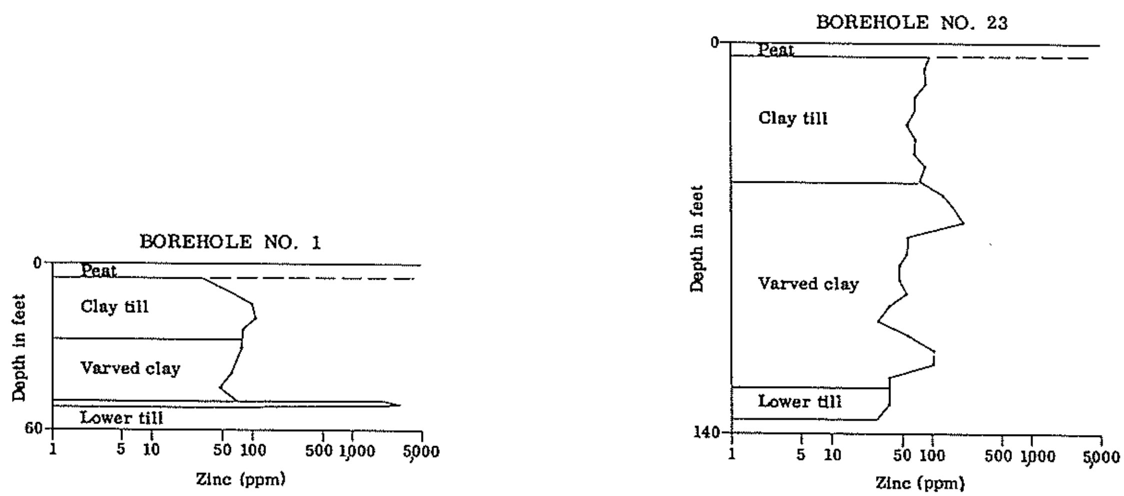

Fig.99. The distribution of zinc in surficial material over the Kidd Creek deposit (borehole No.1) and to one side (borehole No.23) (after Fortescue and Hornbrook, 1969).

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.

References: Fortescue and Hornbrook, 1969; Garrett, 1971; Gleeson and Cormier, 1971.

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.

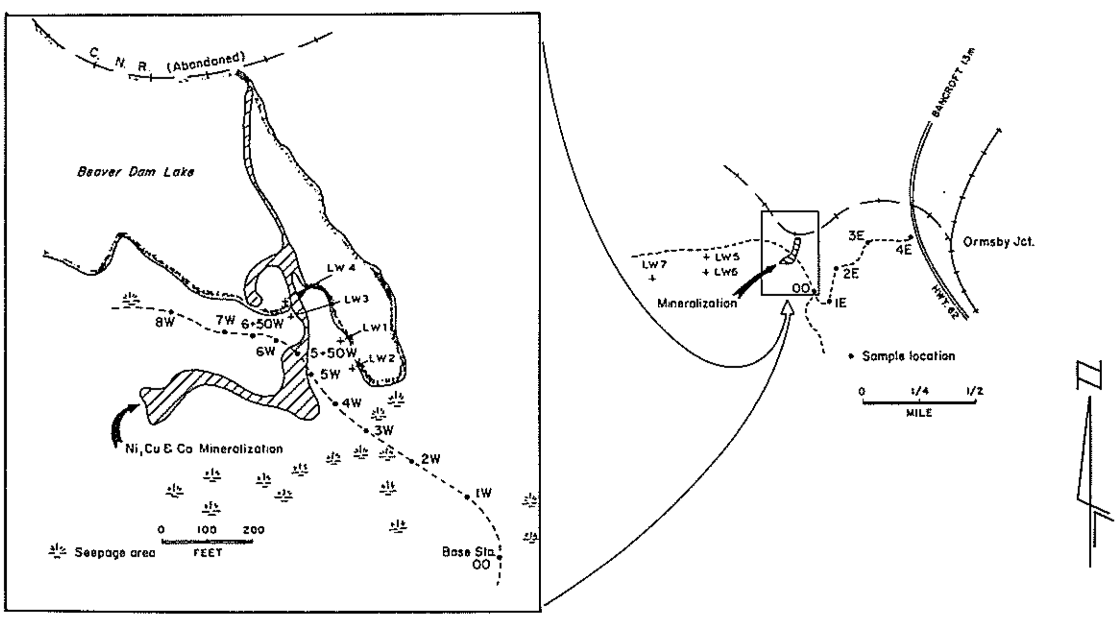

Fig.100. Sample collection locations, Limerick Ni--Cu prospect, Ontario.

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 A_3 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 A_0, 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

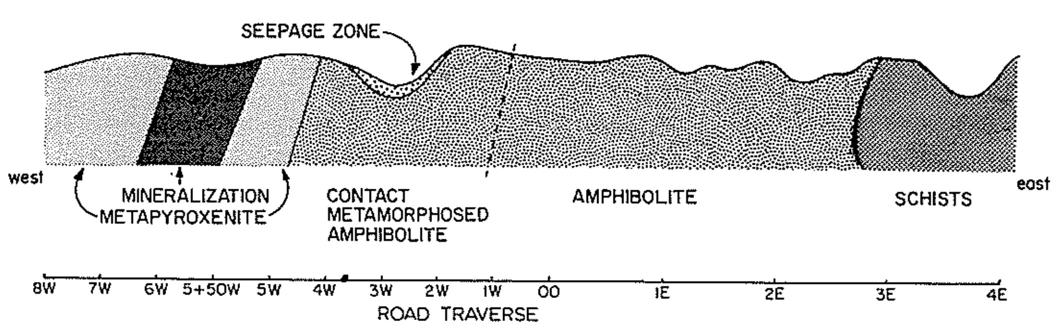

Fig.101. Geology and location of mineralization, Limerick prospect.

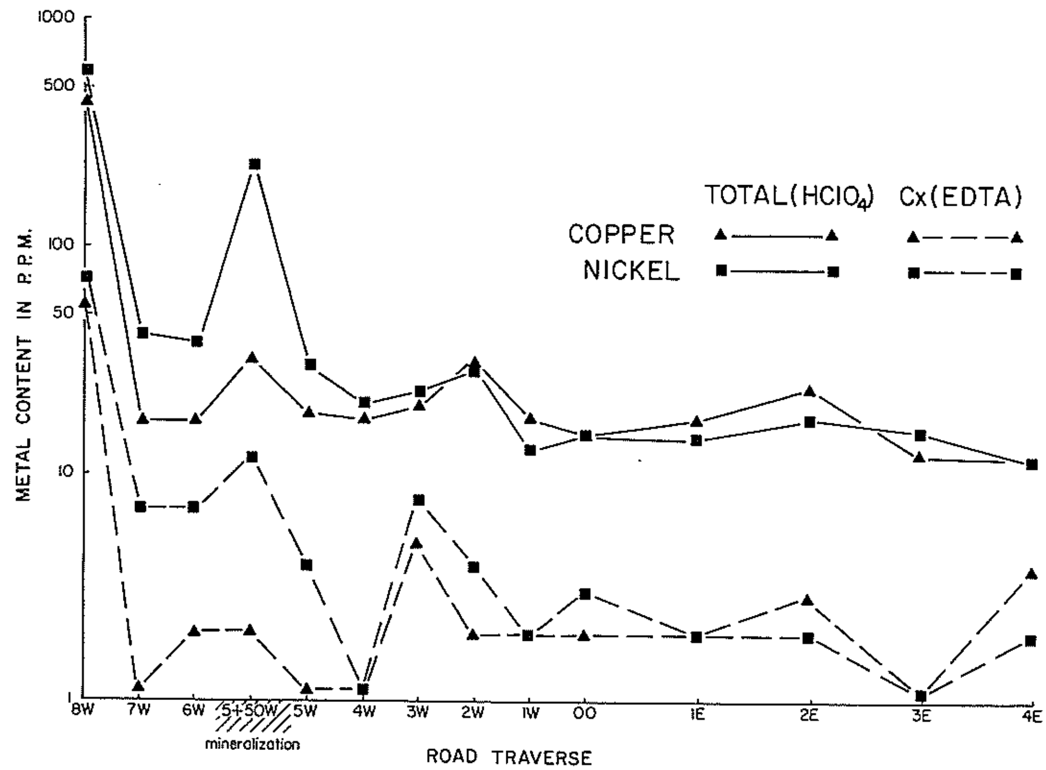

Fig.102. Distribution of copper and nickel (minus 80-mesh fraction), in A_0 horizon soils, Limerick prospect.

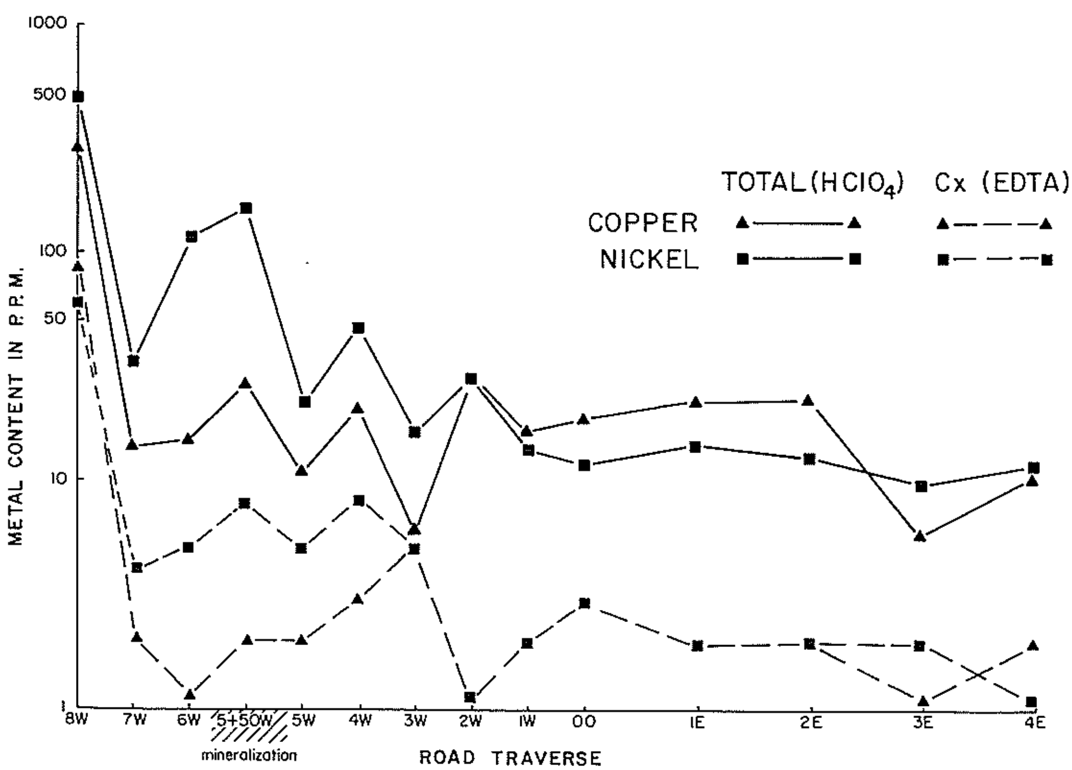

Fig.103. Distribution of copper and nickel (minus 80-mesh fraction) in A_1 horizon soils, Limerick prospect.

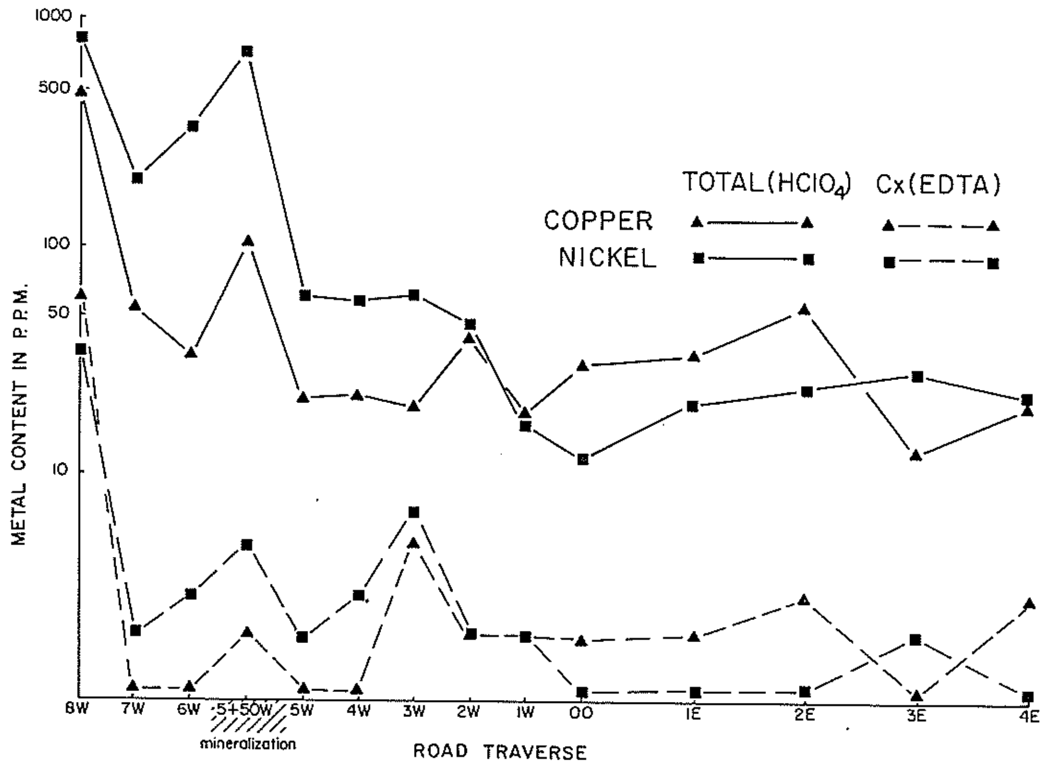

Fig.104. Distribution of copper and nickel (minus 80-mesh fraction) in B horizon soils, Limerick prospect.

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

Metal content in Water, Limerick area

Sample No.	Ni (ppb)	Cu (ppb)
Near mineralization	15	17
LW1	23	70
LW2	—	15
LW3	—	3
Removed from mineralization		
LW5	—	2
LW6	—	1
LW7	—	1

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

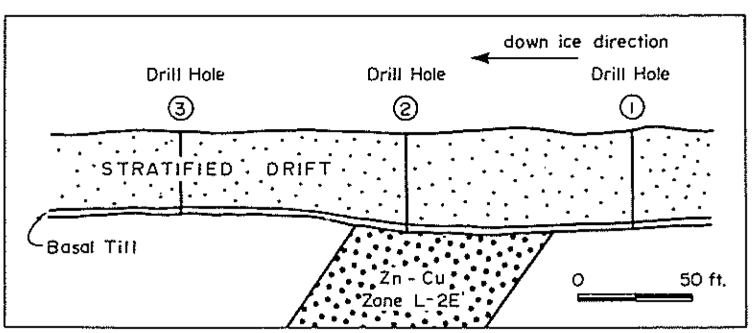

Fig.105. Location of overburden drill holes, Magusi River Deposit, Quebec.

TABLE XXVII

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

Drill hole		Cu (ppm)	Zn (ppm)	Ag (ppm)	Hg (ppm)
1	(1)	22	70	1.0	55
	(2)	58	124	1.2	50
	(3)	24	81	0.9	30
2	(1)	1,680	10,000	9.4	150
	(2)	1,500	8,100	8.7	135
	(3)	1,750	11,800	8.2	120
3	(1)	24	36	0.9	60
	(2)	250	750	2.0	75
	(3)	24	28	0.9	35

(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.

MANITOUWADGE Cu—Pb—Zn DEPOSIT, ONTARIO

E.H.W. Hornbrook *(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

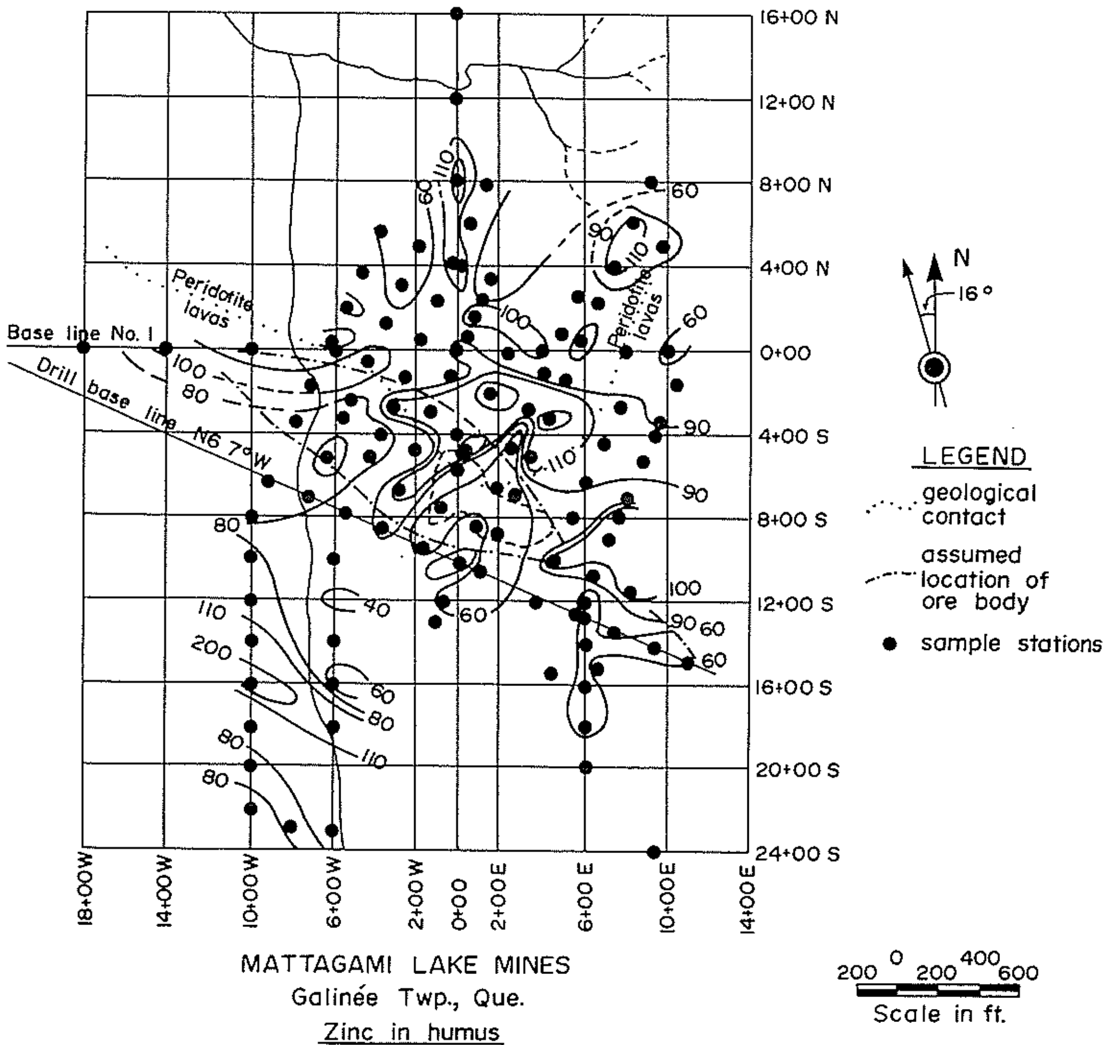

Fig.106. Zinc content in surface humus material over the Mattagami deposit, Quebec.

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.

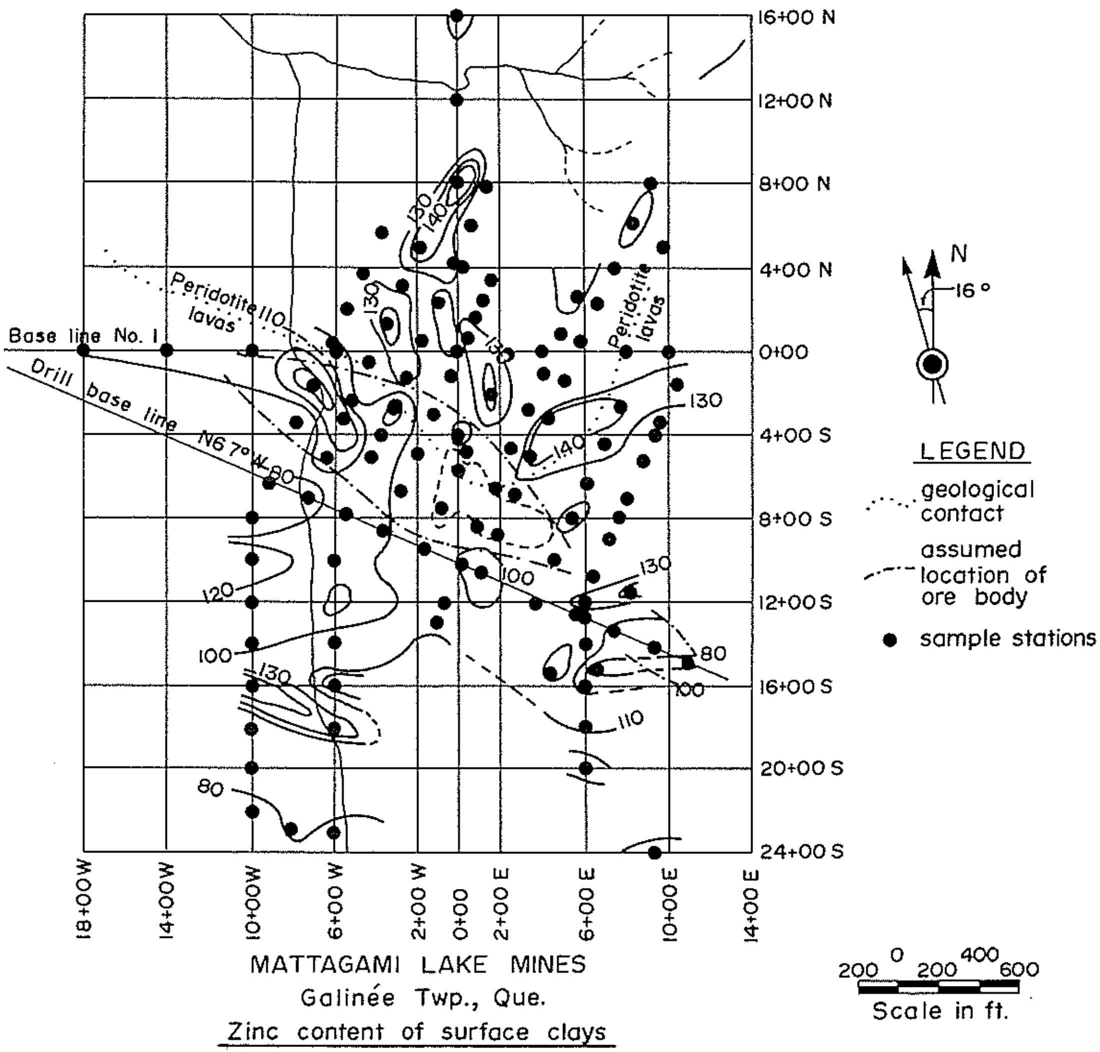

Fig.107. Zinc content in surface clays over the Mattagami deposit.

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 (1½—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

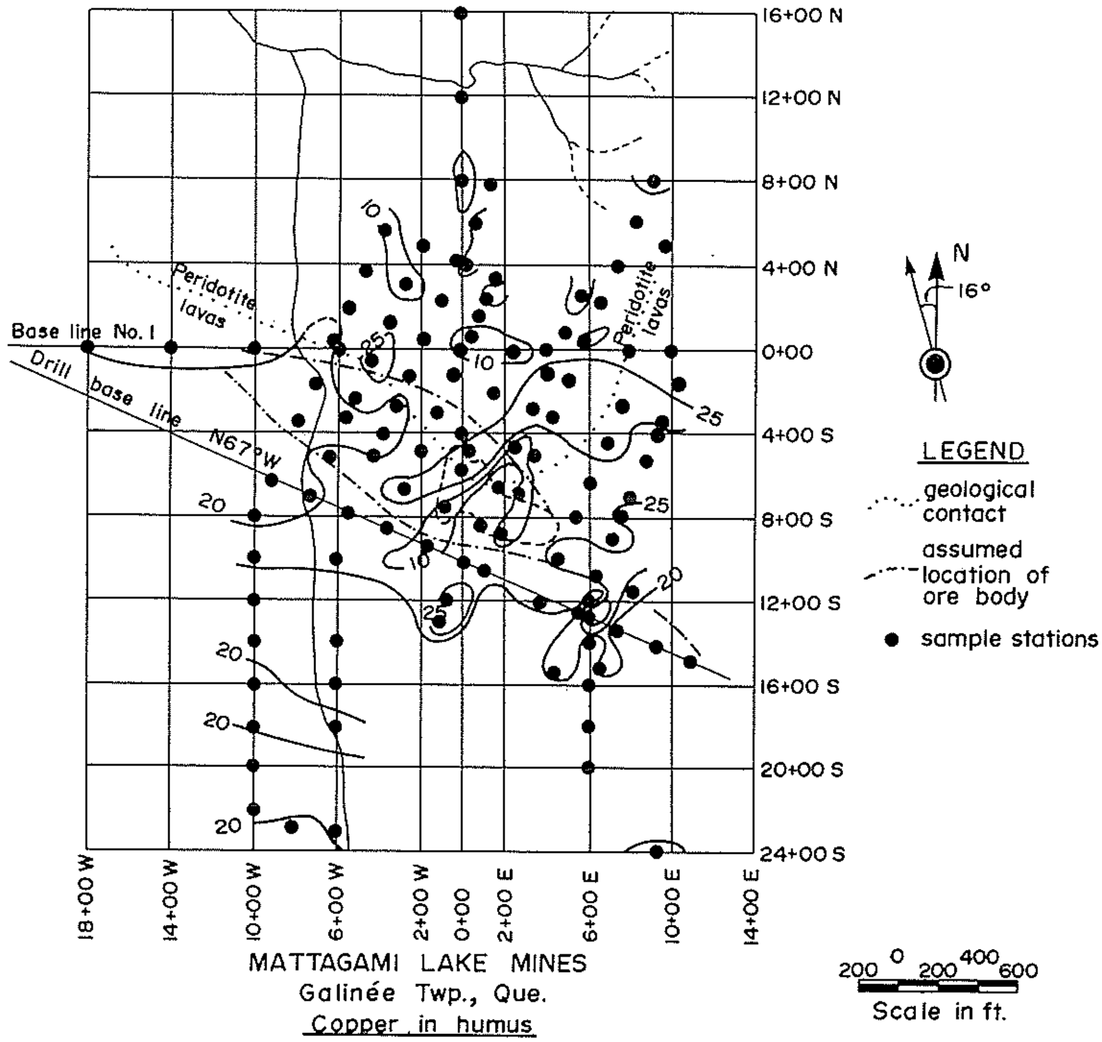

Fig.108. Copper content in surface humus material over the Mattagami deposit.

extraction with a hot solution of HNO_3. 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 A_0 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.

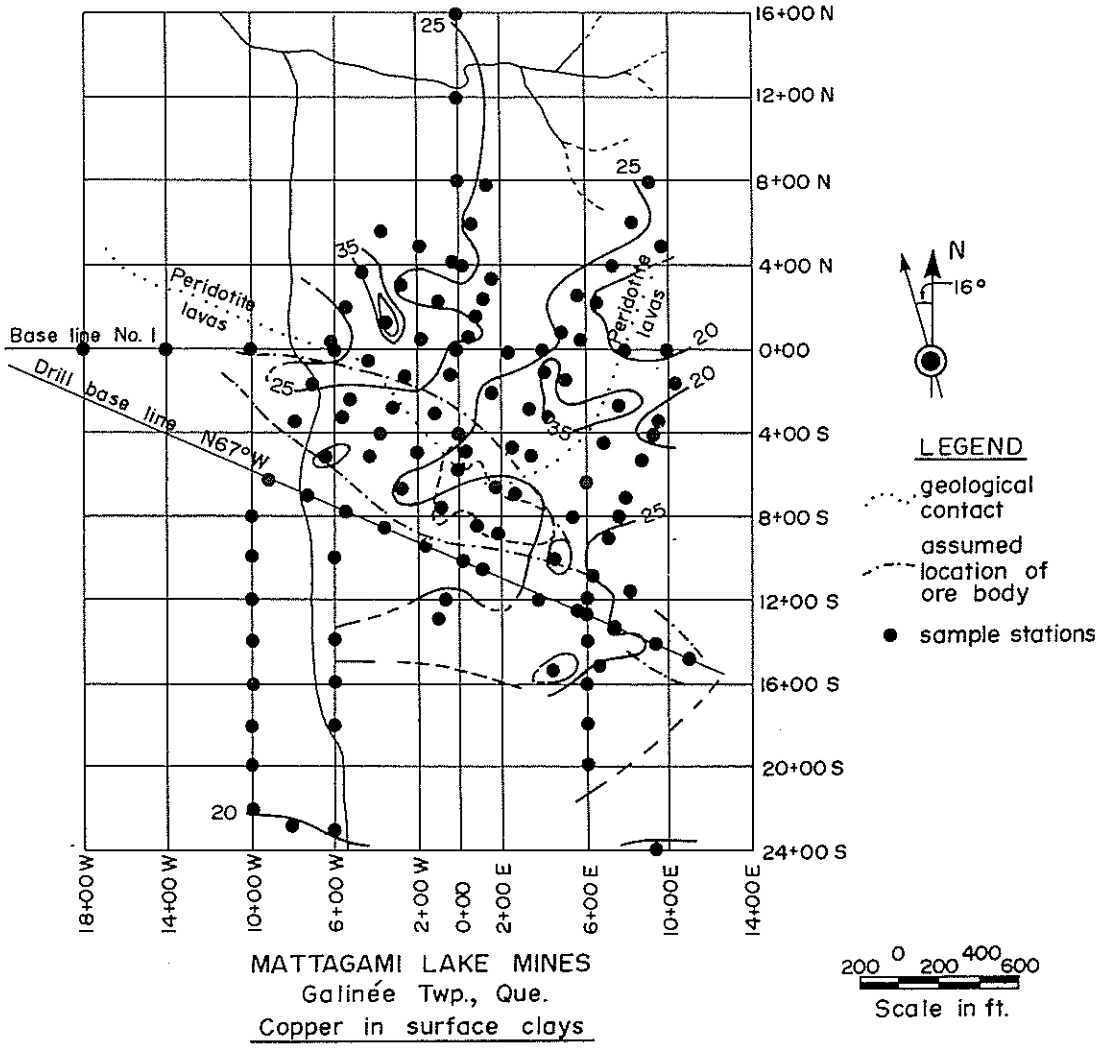

Fig.109. Copper content in surface clays over the Mattagami deposit.

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 schisted 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.

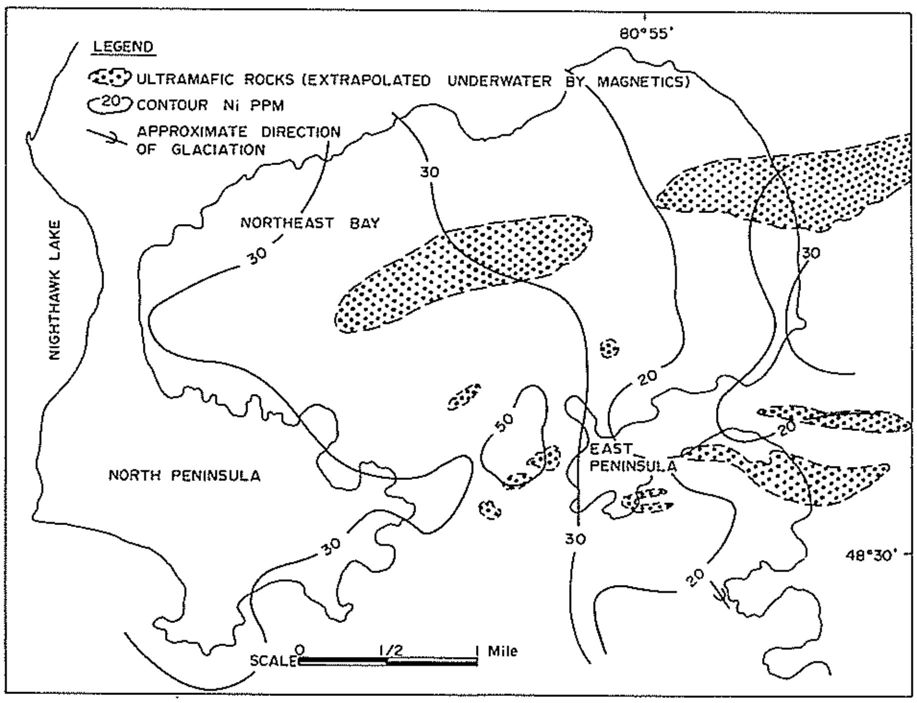

Fig.110. Nickel in minus 230-mesh fraction of lake sediments, Nighthawk Lake, Ontario.

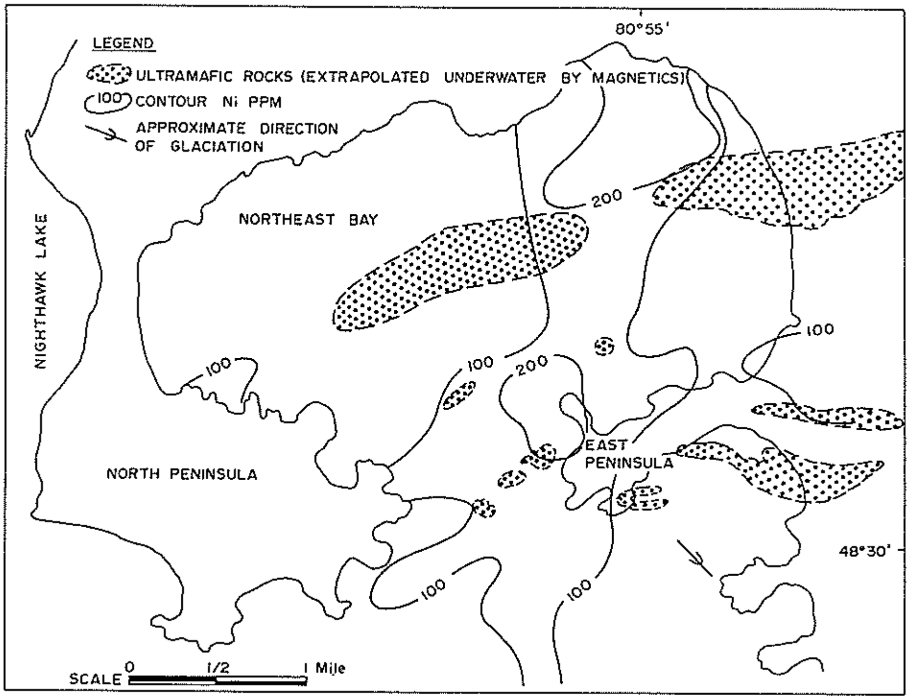

Fig.111. Nickel in minus 230-mesh fraction of till, Nighthawk Lake.

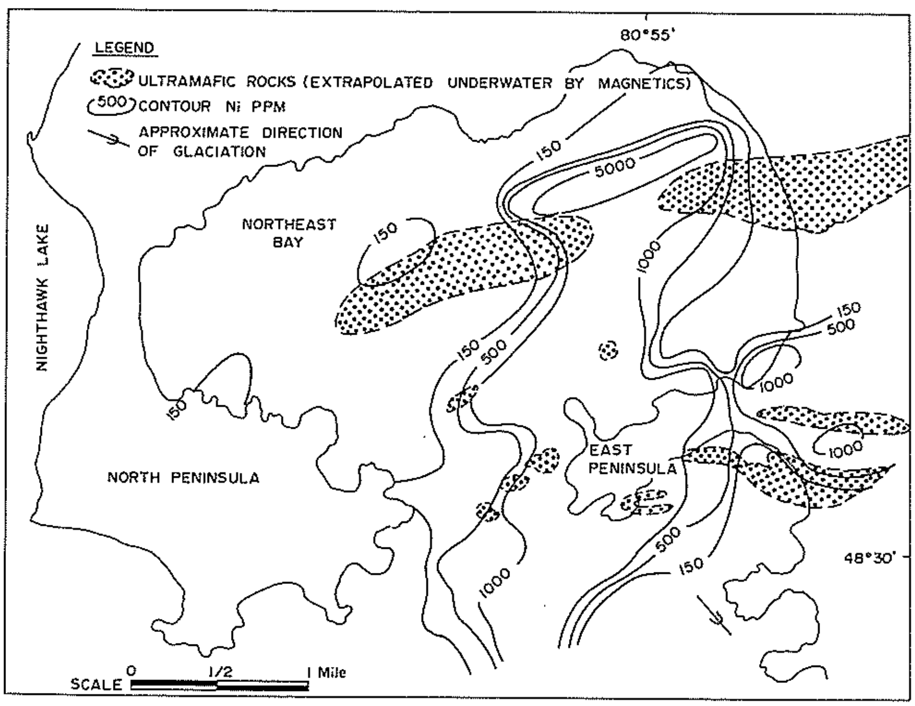

Fig.112. Nickel in minus 50-mesh, plus 230-mesh fraction of heavy-mineral concentrates from till, Nighthawk Lake.

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.

Reference: Gleeson and Hornbrook, 1975.

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 coverėd 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.

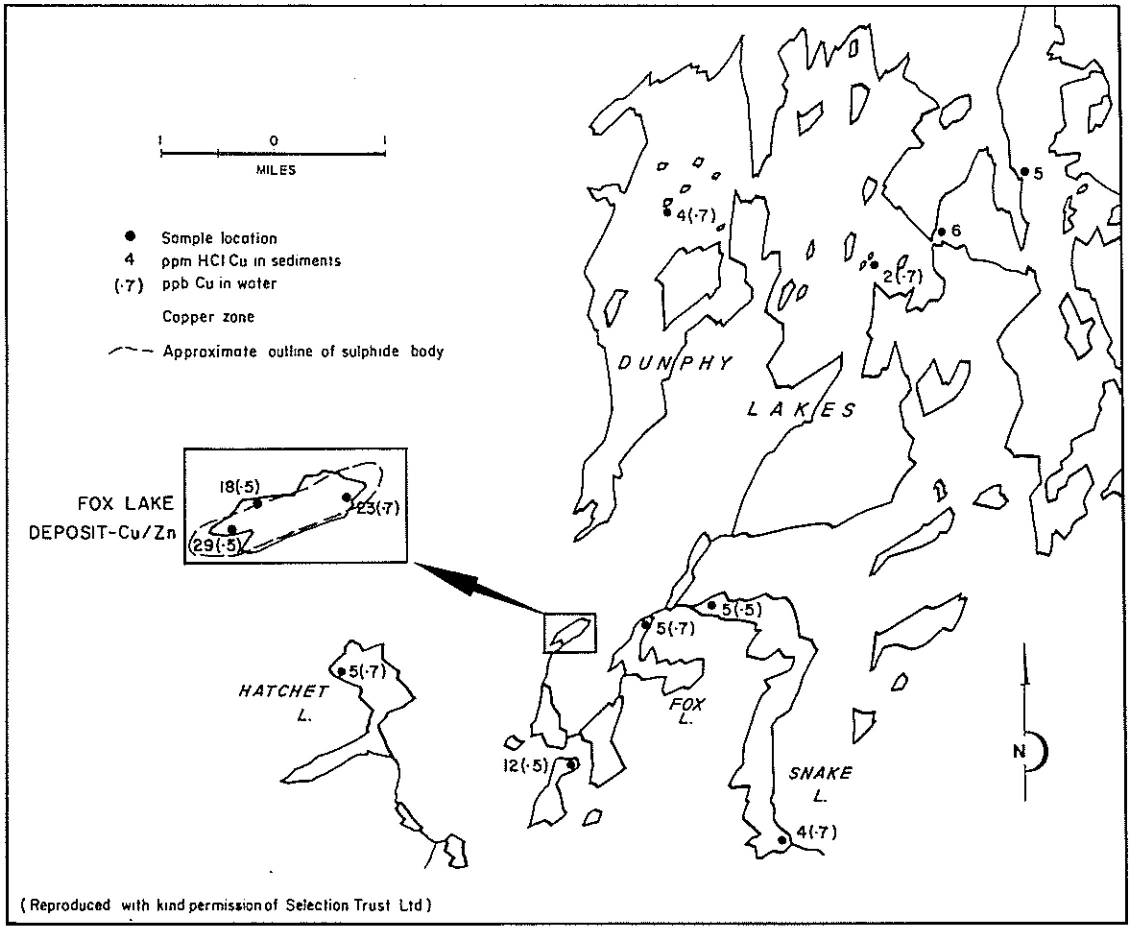

Fig.113. Distribution of copper in lake sediments and lake water, Fox Lake area, Manitoba.

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 $(Ni, Fe)S_2$, 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

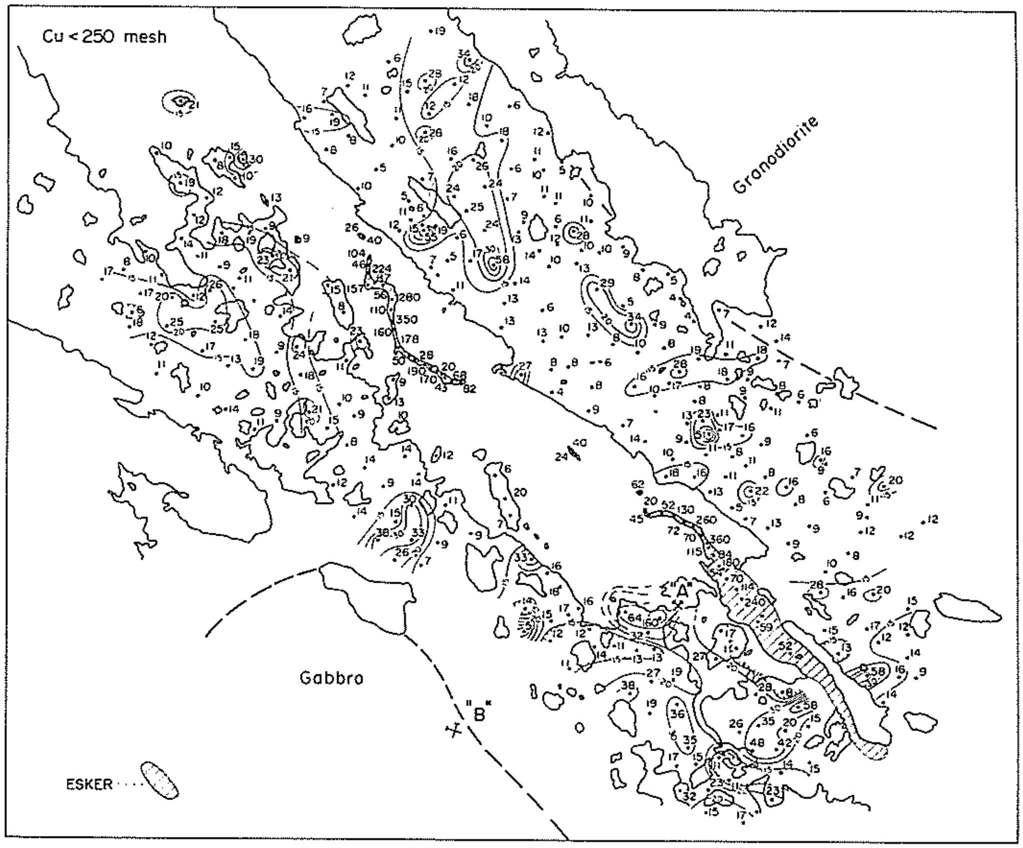

Fig.114. Copper in the minus 250-mesh fraction of till samples, Southern Lake, N.W.T.

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

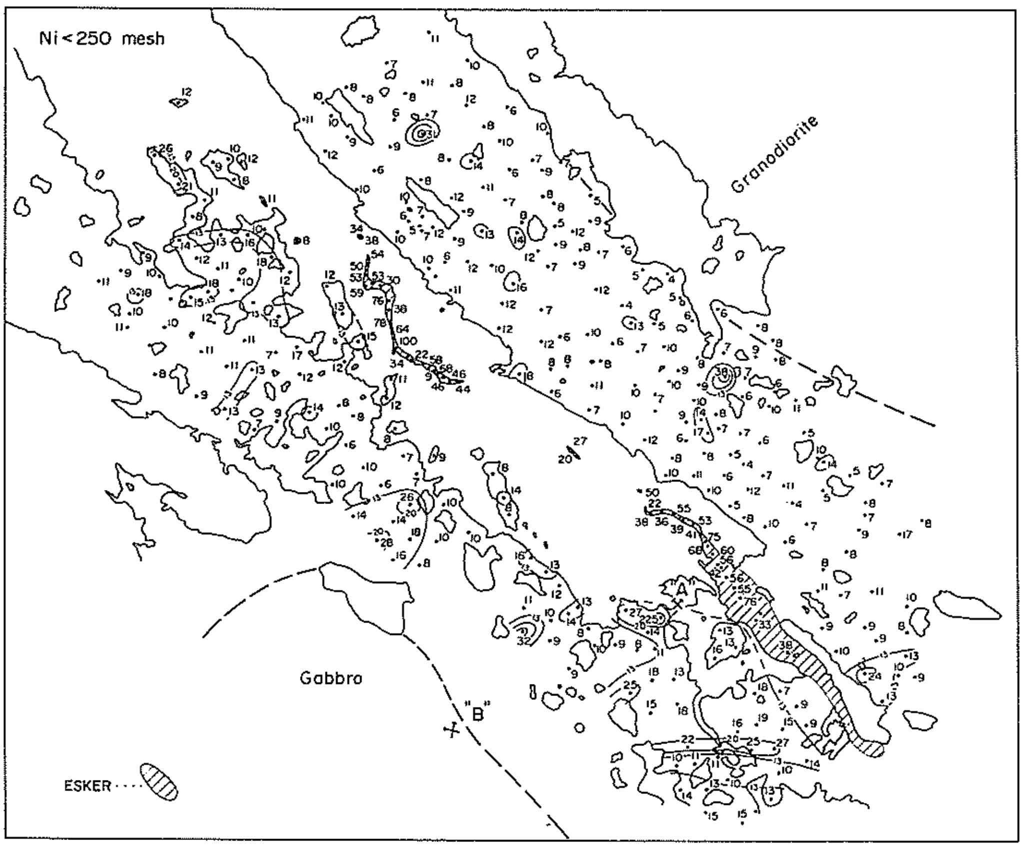

Fig.115. Nickel in the minus 250-mesh fraction of till samples, Southern Lake.

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

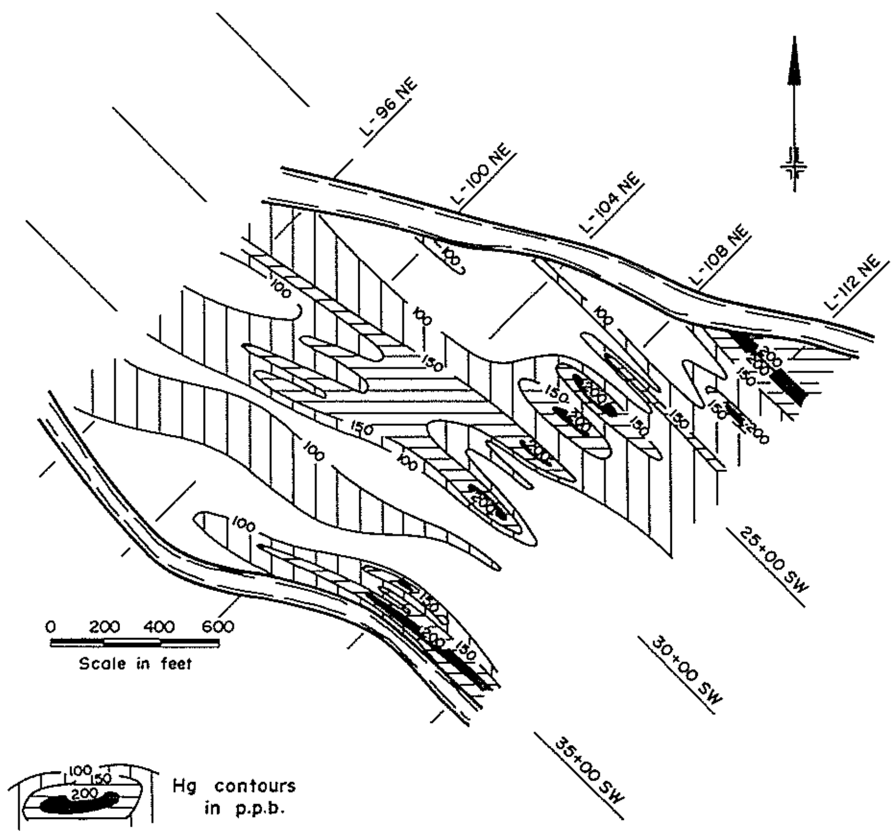

Fig.116. Mercury in A horizon soil samples, Troilus deposit, Quebec.

*Present address: Atomic Energy Agency, Ankara, Turkey.

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

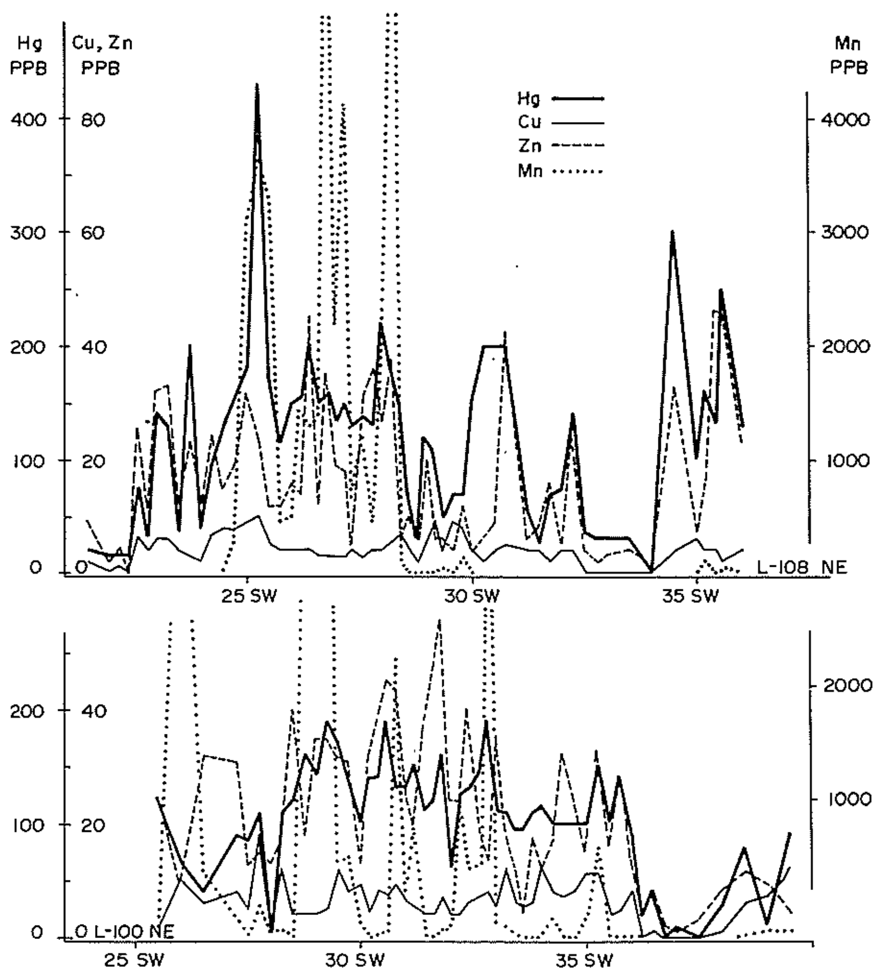

Fig.117. Mercury, copper, zinc and manganese in soils across the Troilus deposit.

(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.

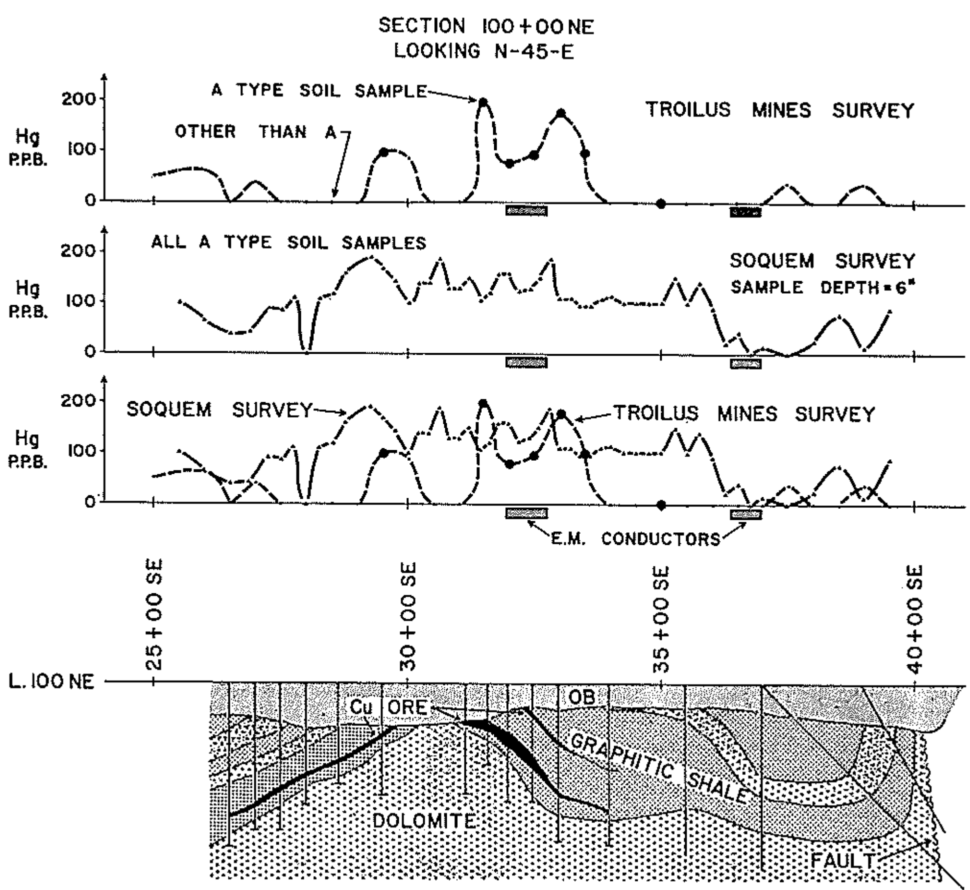

Fig.118. Mercury soil traverses, Troilus Mines Limited (after Gaucher and Gagnon, 1973).

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-pyrrhotite 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.

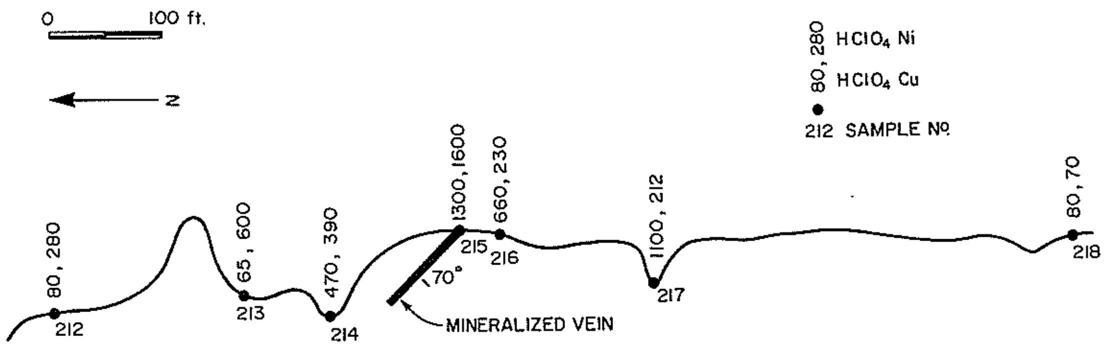

Fig.119. Distribution of copper and nickel in lake sediments, Wintering Lake area, Ontario.

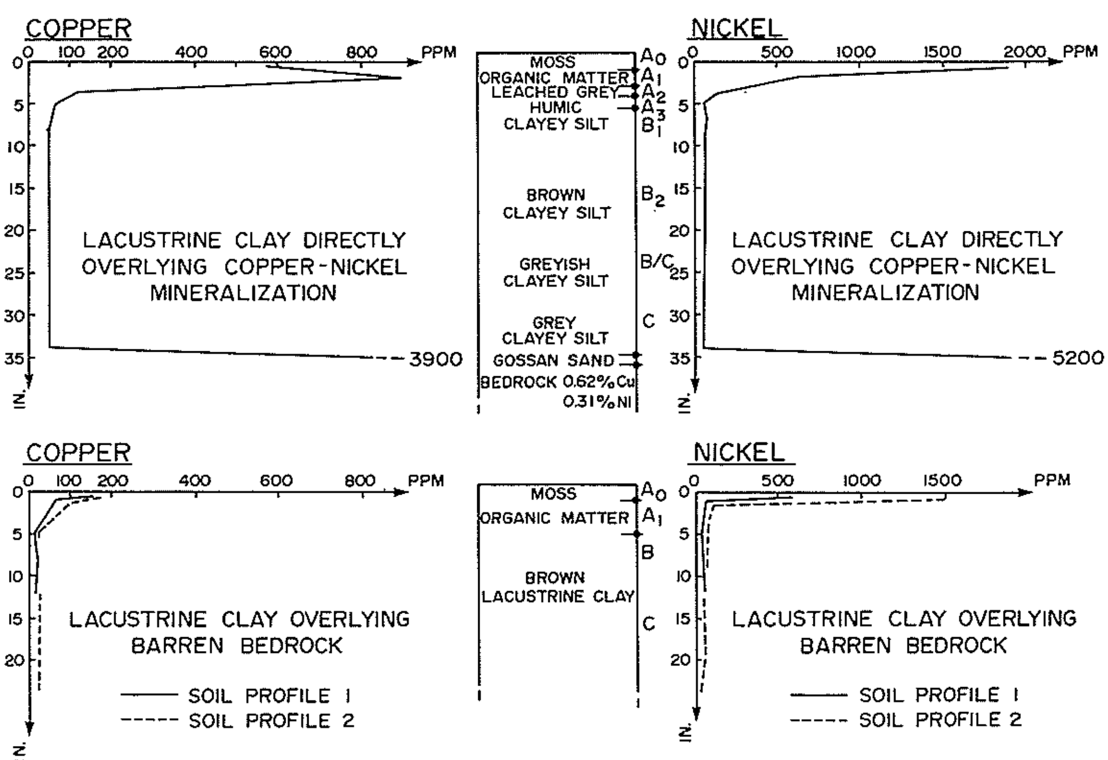

Fig.120. Distribution of copper and nickel in soil profiles, Wintering Lake area.

(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 hydromorphic 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.

Reference: Bradshaw et al., 1973.

APPENDIX*

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

(1) Lodgment and ablation till

Distribution, form. Till occurs virtually everywhere on the Shield; locally it may be thin or discontinuous over bedrock or buried to great depths beneath postglacial fluvial or lacustrine deposits. It is the most widespread of the glacial deposits. It forms flat plains, thin coverings on slopes, lineated plains with flutings or drumlin axes parallel to ice flow; it forms hummocky, irregular ridges that outline the front of the former glaciers during periods of stability.

Provenance. Consists of ground-up bedrock or reworked unconsolidated deposits overridden by the glacier. It usually bears components of the bedrock immediately under or slightly up-ice from the deposit. It also carries a minor but significant proportion of far-travelled detritus depending on mineralogical or chemical uniqueness of the component, roughness of glacial bed, rate of ice flow with respect to distance from source, physical properties of the detritus, and stability of detritus under postglacial weathering.

Readvance till is deposited by glacial tongues readvancing into ice-front lakes — usually during general ice retreat. Such till is often composed wholly of reworked lake-bottom

*Prepared by W. Shilts, Geological Survey of Canada, Ottawa, Ontario.

TABLE XXVIII

Summary of length and strength of anomalies over different deposits*

Name (reference) Sub-outcrop size of mineralization Economic metal	Overburden	Extraction and element	Sediments: max. dispersion length (miles)	Sediments: strongest contrast	Sediments: comments	Soils: anomaly size (length × width)	Soils: strongest contrast	Soils: comment
Massive sulphide-type mineralization								
Kidd Creek 2000′ × 100′ Cu, Zn, Ag	varved clay	tot Zn				0	0	deposit completely masked by varved clay
	till below clay	tot Zn tot Cu				>6000′ × 4000′ 3000′ × 2500′	40	strong smearing down-ice
Coppermine 47-zone (Allan et al., 1972) 1300′ × 100′ Cu	till	tot Cu	>0.3	3	anomaly runs into lake otherwise would probably be traceable further; lake also anomalous	1600′ × 8000′ 2000′ × 1600′	4 5	B horizon O/A horizon Strong indication of downslope creep, probably also hydromorphic movement
Coronation mine (Scott and Byers, 1965) 40′ wide where sampled Cu	till 5—16′ thick	tot Cu				100′ wide 50′ wide	100 2	A horizon; A_1, A_2, and B horizons also give anomaly but only 8—10 × background; on a second traverse with overburden 20′ thick anomaly is very weak
N. Coppercliff zone, Chibougamau (Ermengen, 1957) 100′ wide where sampled Cu	till 15′ thick	tot Cu tot Zn				100′ wide 100′ wide	10 10	some smearing down-ice seen in profile
Campbell, Merrill zone, Chibougamau (Ermengen, 1957) 60′ wide where sampled Cu	till shallow	tot Cu tot Zn				400′ wide 200′ wide	20 15	strong seepage anomaly in a swamp 900′ downslope

Eaton Bay, Chibougamau (Ermengen, 1957) 100' wide at traverse Cu	boulder till approximately 70' deep	tot Cu	300' wide	3	
Keg Lake, Flin Flon area 40' wide where sampled Low Cu, Zn	sand and clay 2' deep	tot Cu	nil	—	
		tot Zn	nil	—	
		tot Hg	100'	35	
Pitching Lake, Flin Flon area 15'wide where sampled 2.4% Cu	sand and clay	tot Cu	nil		
		tot Zn	nil		
		tot Hg	nil		
Schist Lake, Flin Flon area 50' wide where sampled 3% Cu	clay-gravel	tot Cu	nil		
		tot Zn	nil		
		tot Hg	nil		
Shupe Lake, Flin Flon area 90' wide where sampled Low Cu, Ni	clay and minor outcrop	tot Cu	50' wide	2	anomaly only on outcrop
		tot Zn	50' wide	2	
		tot Hg	nil	—	
Vein-type mineralization					
Agnico mines, Cobalt area Ag (Zn, Pb, Cu, As)	glacial till average 2—8'; A horizon results	tot Ag	200' wide	15	minor displacement of about 100' down-ice; one single anomalous peak; length not determined
		tot Zn	100' wide	2	
		tot Pb	100' wide	2	
		tot Cu	100' wide	3	
Agnico mines	glacial till average 5—20'; A horizon results	tot Ag	>300' wide	10	anomaly apparently smeared down-ice some distance; several anomaly peaks which are less definitive
		tot Zn	>300' wide	5	
		tot Pb	>300' wide	10	
		tot Cu	200' wide	6	
Hiho Silver mine, Cobalt area Ag (Zn, Pb, Cu, As)	glacial till 20'—70' thick; A horizon results	tot Ag	500' wide	4	anomaly diffuse and spread down-ice
		tot Zn	500' wide	3	
		tot Pb	500' wide	5	
		tot Cu	0		

TABLE XXVIII (*continued*)

Name (reference) Sub-outcrop size of mineralization Economic metal	Overburden	Extraction and element	Sediments: max. dispersion length (miles)	Sediments: strongest contrast	Sediments: comments	Soils: anomaly size (length × width)	Soils: strongest contrast	Soils: comment
Langis mine, Cobalt area Ag, (Zn, Pb, Cu, As), Cu	varved glacial clay >90′ thick	tot Ag				0		
		tot Zn				0		
		tot Pb				0		
		tot Cu				0		
Kekko, Chibougamau area (Ermengen, 1957) 12′ wide where sampled 3% Cu	till 2′—10′ thick	tot Cu				150′ wide	10	
		tot Zn				400′ wide	2	
High-grade zinc zone, Chibougamau area (Ermengen, 1957) Narrow Zn, (Cu)	till shallow	tot Zn				200′ wide	7	B horizon slightly wider in A_0
Portage Island, Chibougamau area (Ogden, 1954) 80′ wide where sampled 0.3% Cu	cross-bedded sand 4—10′ deep	tot Cu				200′ wide	1.5	
Lac Albanel Narrow veins	till	tot Cu	0.6	20			320	the outline of the mineralization is poorly known making details as to size, etc., difficult to estimate
		tot Pb	0.6	25			300	
		tot Zn	0.6	60			2,600	
		tot U	0.5	2.5			—	
		tot Ag					24	
		tot Hg					40	

Disseminated mineralization								
Setting Net Lake (Wolfe, 1974) >2 mi. × 1 mi. anomalous bedrock	glacial till flanked by varved clay	tot Mo tot Cu				3500′ × 1500′ 2000′ × 1200′	80 20	some hydromorphic movement of metals; varved clay apparently inhibits soil anomalies but geochemistry may still be effective
Shawinigan Ni—Cu (Felder, 1974) Scattered Ni, Cu	mainly thin glacial till	tot Ni tot Cu	1 1.3	4 8	dispersion distance generally short		15 10	scattered nature of mineralization makes size very hard to calculate; virtually no glacial smearing

* 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 the other 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, tetrabromethane, 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 serpentinized 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 supraglacial 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 analagous* 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 (phyllosilicate) 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 interstratified, 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, subareal 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, off-shore 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 hydromorphic 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.

Section D

ORIENTATION SAMPLING AND STANDARDIZATION OF DATA COLLECTION AND PRESENTATION

INTRODUCTION

Before undertaking a geochemical programme in an area it is essential, in order to gain the best results by the most economic means, to determine the optimum sampling media, sampling interval, method of analysis, etc. This is most reliably done by an orientation survey.

Orientation sampling is best described as a series of preliminary experiments aimed at determining the existence and characteristics of anomalies associated with mineralization. The information obtained from the sampling is used to: (1) define background and anomalous geochemical values, (2) define adequate prospecting methods utilizing the various available media and analytical techniques, and also (3) identify the criteria and factors that influence dispersion and have a bearing on the interpretation of the geochemical data.

A comprehensive orientation survey can be an exhausting investigation. In practice, the factors of time and cost are prime considerations which require an objective approach by the economic geologist. A knowledge of the basic principles of exploration geochemistry plus geochemical experience are extremely valuable in the development of this objective approach, and it is anticipated that the examples and descriptions in this volume will provide data which will have a bearing on this judgement, by indicating the potentially most promising media and analytical approaches to supply the required geochemical data to help solve the geological problems that can be defined.

Ideally, orientation sampling should be carried out in areas of known, but essentially virgin, mineralization, therefore eliminating the complicating effects of human activity and contamination. An important criterion is that the orientation study be conducted over mineralization of the type being sought in an area which can be considered geologically and/or geomorphologically characteristic of the project area to be prospected. The determination of metal values in non-mineralized terrain is also an important objective of the orientation survey. This requires that the sampling programmes be extended into areas having no known mineralization, but which are characterized as closely as possible by the same environmental conditions of geology, geomorphology, climate, vegetation and topography. The combined data from mineralized and unmineralized areas allow the more accurate identification of background levels and anomalous values related to mineralization.

The choice of the medium to be used for the orientation sampling and prospecting — soil, stream sediment, water, vegetation, rock, lake sediment, etc. — is a decision that requires a knowledge of the field area, the prospecting problem and previous geochemical work and experience. A careful preliminary judgement of the most suitable media can be gained from the understanding of the case histories and block diagrams contained in the previous sections of this volume. When the choice of media has been made, a sampling pattern is designed to test the extent and nature of the geochemical dispersion and enable the definition of the optimum physical parameters for sample collection. The empirical approach to lake and stream sediment sampling, rock sampling, soil sampling, vegetation sampling and water sampling is briefly, but satisfactorily described in Hawkes and Webb (1962).

Commonly, specific fractions or types of a sampled medium yield the most readily interpretable and most definitive geochemical patterns. For example, a biogeochemical survey may yield better data from leaves than twigs; a heavy-mineral fraction may give more meaningful patterns than the lighter fractions of a soil or sediment; the analysis of specific minerals like biotites may outline distinctive anomalies not apparent in whole rock analysis or the plus 80-mesh, minus 35-mesh fraction of a soil may give stronger anomalies than the minus 80-mesh or minus 270-mesh fraction of the same soil or sediment.

The examination of the usefulness of these different fractions and sample types is an important part of the orientation survey. It is apparent that, theoretically, there is an infinite number of possible choices, but experience plus knowledge of the mechanisms of geochemical migration and geological common sense and judgement should be applied in all instances to simplify the problem.

There also exists a positive need for standardization in the collecting and reporting of field data so that the orientation survey being conducted can be reliably compared with existing data, and valid conclusions drawn from such intercomparisons. For example, if two orientation surveys are conducted over similar landscapes and one described the total analysis of the heavy-mineral fraction which is plotted on a scale of 1:50,000, while another described the cold-extractable analysis of the minus 300-mesh material which is plotted on a scale of 1:63,360, then the two sets of information cannot be reliably compared. However, if both case studies contain the same information (e.g. both types) and are plotted at the same scale, then reliable comparisons can be made. After presentation of a set of data to a standard format, firstly it is possible to compare it with any other data already existing and presented in the same manner and determine if there are any important deviations from experience elsewhere, and secondly after several sets of such data are obtained, it should be possible to construct reliable idealized models. Without this standardization the recognition of any general principles will take, at best, a long time.

DATA COLLECTION

Meteorologists have for many years standardized the collection of weather information to such an extent that comparable information is collected systematically from all parts of the world every hour. As yet there is no standardized method for the collection of geochemical and morphological information from landscapes although such an approach was described some time ago (Fortescue, 1967b) for the collection of biogeochemical data. A tentative attempt at standardization of geochemical data is given below.

In fact the number of sample sites which need to be collected for a reliable orientation survey are frequently fairly low. However, it is desirable to collect a complete set of data from each sample location (i.e. each soil horizon, several mesh fractions, etc.) to at least a minimum standard, in order to document and evaluate the normal geochemical variables. In every case, as was emphasized earlier in this section, it is most important to collect sufficient background samples (i.e. samples well removed from the influence of mineralization) as well as anomalous material.

The criteria for a reasonably complete orientation, and recommendations for standardization of the data collected are given below. Any orientation survey may include more detailed work than is suggested here, but should include the following as a minimum. In addition, since this volume deals specifically with sediments and soils, recommendations for these media only are included, although rock and biogeochemical samples should normally also be included. Many of the case histories given here were, in fact, run as limited orientation surveys and can usefully be studied in this regard.

Stream sediments. As already described in Section A under "General Principles of Geochemical Migration" stream sediment anomalies are formed by both clastic and hydromorphic processes. In order to take particular advantage of clastic dispersion, it is important to collect sediments from the active channel. In addition, the active channel material is frequently the most homogeneous as a result of mechanical mixing.

Samples should be collected starting (if possible) above the deposit and continuing for several miles downstream and include all streams influenced by the mineralization as well as background streams. Sample analyses should include the five mesh sizes outlined in Table XXIX, plus the heavy-mineral fraction, and also the three analytical extractions suggested in Table XXX.

TABLE XXIX

Recommended mesh sizes

Fraction (mesh)			Opening (microns)
1:	(a)	−38, +80	−494, +210
	(b)	−80	−210
	(c)	−80, +160	−210, +112
	(d)	−160, +296	−112, +54
	(e)	−296	−54
2:	Heavy-mineral fraction		

TABLE XXX

Tentative minimum list of recommended analytical extractions

Class of attack	Suggested details
"Total"	hot $HClO_4$ or $HClO_4/HNO_3$ at reflux temperature for a minimum of 4 hours
"Hot extractable"	0.5*N* HCl boiling for 20 minutes
"Cold extractable"	0.25% EDTA shaken cold for 2 minutes

Lake sediments. The collection of lake samples is more difficult to standardize at this time because the controlling factors for their use in exploration are not yet fully documented. However, as a minimum, sampling should include collection of mineral matter from the margins of the lake in shallow water, and also from the deeper parts of the lake. If the mineralization occurs under the lake then a regular grid of samples from the lake bottom is recommended. Both anomalous and background lakes must be included.

Surface soils. B horizon soils should be collected from at least two traverses crossing the mineralization and continuing well into background. The sample spacing depends on the size of the mineralization, but at least four to five samples should be collected directly over it and then continuing well into background. As shown in Figs.20 and 78 as well as others of the idealized models there can be considerable variation in metal distribution between different soils. As a result of this it is important that the soil traverses cover all normal physiographic conditions and major soil types encountered, such as well-drained ground, steep slopes, seepage areas, and bogs.

Soil horizons. As shown in Figs.20 and 78 there is frequently considerable variation in the metal content in different soil horizons. Consequently, in addition to collection of B horizon soil samples it is important to test the variation of metal content with depth, not only between horizons but also with depth down any one horizon if it is particularly thick (as is normal for the C horizon). Samples should be collected from every recognizable soil horizon, or at 1-foot intervals down the profile, whichever is the lesser. It is not necessary to collect a soil profile at every sample site, but a representative number should be collected to cover a range of conditions both on and off the mineralization.

By far the most effective method of collecting soil profile samples is from a continuous trench dug to the correct depth. In this way not only can reliable samples be collected, but variations in the soil profiles can also be observed. However, this is not always practical and individual pits at each profile site may have to be used instead.

Sample treatment. Mesh size and analytical extractions must also be standardized if data are to be compared.

The success and efficiency of a geochemical programme is materially influenced by the analytical methods utilized. With the growth of geochemical knowledge many analytical techniques for different elements and mineral types have been developed. These not only include the broad spectrum of colorimetric, atomic absorption, X-ray, neutron activation, spectrographic and other techniques, but also methods designed to measure only part of the metal or mineral contained in a sample. These partial analytical techniques can be used to separate readily soluble from insoluble metal fractions; metal contained in sulphides from metals contained in silicates; metals contained in organic from metals contained in inorganic compounds; and make other separations which are geologically and geochemically desirable to obtain data for objective interpretation. Once again there is an infinite variety of combinations, but a geological and geochemical understanding of the objectives of the exploration and the prospecting problems will serve to indicate the most suitable analytical approach.

Three separate attacks have been recommended in Table XXX which represented the "extremes" or a "total", intermediate and weak extraction. All samples must be analysed using a total extraction. In addition, particularly sediments, but preferably also soils should be analysed by the other two classes of attack as well as any specialized extractions (such as sulphide selective) which may be desirable.

In order to be comparable with existing data all samples should be analysed for the now virtually universal minus 80-mesh fraction. However, sediments in particular should be analysed at least for the size fraction shown in Table XXIX, and for coarser fractions as well when dealing with resistant minerals such as cassiterite, scheelite, gold, etc. In addition, it is desirable to undertake size fraction analyses for soils as well. These mesh sizes have been selected such that starting with 80-mesh, each successive opening is approximately half of the previous one.

DATA PRESENTATION

It is also highly desirable to have a series of standard map scales, symbols, etc., for presentation of the data to facilitate comparison of case histories. However, recommendations of this type are outside the scope of this volume. As an initial step, however, authors are urged to use, as closely as possible, the standard map sizes and symbols, etc., recommended by the Geological Survey of Canada in their guide to authors.

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