GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY,
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PAPER 72-50

RECONNAISSANCE GEOCHEMISTRY USING LAKE SEDIMENTS OF A 36,000-SQUARE-MILE AREA OF THE NORTHWESTERN CANADIAN SHIELD

R. J. Allan, E. M. Cameron, C. C. Durham

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FOREWORD

This paper does not contain a detailed interpretation of the results from the Bear-Slave Operation. Its contents are meant to complement separately published maps and to familiarize the map user with the background to the operation, its planning and execution, and the uses of the results. As much interpretation as is wise at this stage is included in the marginal notes on the maps for each element. Only detailed follow-up will eventually lead to a complete interpretation of the regional trace element distribution maps.

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ABSTRACT

The Bear-Slave Operation is a regional, helicopter-supported, geochemical survey of some 36,000 square miles of the central parts of the Bear and Slave Structural Provinces of the Canadian Shield. The regional survey area extends from 64°30'N to 66°00'N and from 106°00'W to 118°00'W, covering nine 1:250,000 scale map-sheets. Nearshore, inorganic, silty, lake sediment and surface lake water were the sample media collected at a site density of one per ten square miles.

Sampling was carried out from June 25th to August 2nd. Three Bell G4A helicopters were used as transport for lake sampling. A DHC-3 Otter aircraft was used to set out gas caches. Helicopter traverses were crudely radial in pattern. All helicopters operated from the same base camp so that three consecutive camps were established.

Average flying time per sample site was less than 10 minutes. Approximately 1,500 square miles was sampled each day. Water samples were acidified and sediment samples dried in the field.

Sediment samples were sieved to minus 250 mesh (63μ) and sample preparation was completed in Ottawa by the end of September. Analyses by D.C. arc emission spectrometric, atomic absorption spectrophotometric, fluorimetric, and colorimetric methods are being undertaken in the laboratories of the Geological Survey, Geochemistry Section. The sediment samples are being analyzed for Cu, Ni, Pb, Zn, Ag, Co, Mn, U, Hg, Mo, Ti, Ba, Cr, Be, V, Sn, Zr, Y, La, Li, Mg, Fe, K, Ca, Sr, Sb and As. Water samples are being analyzed for Cu, Zn and Hg.

The data are being published as 1:250,000 scale maps on which the element concentration at each sample site and geochemical contours drawn by computer will be superimposed on a base showing geology, lakes and drainage, and sample site locations. The most significant elements will be published at this scale. The remaining data will be published as computer data listings and small scale contour maps along with a map showing sample locations and numbers. Preliminary results show that there are significant anomalies for several elements within the survey area. Follow-up procedures for such anomalies are outlined. Costs of the operation are itemized.

RÉSUMÉ

La Mission Ours-Esclave constitue un levé géochimique régional, effectué à l'aide d'hélicoptères, qui couvre 36,000 milles carrés dans les parties centrales des provinces structurales de l'Ours et des Esclaves du Bouclier canadien. La région où les levés ont été effectués est comprise entre les 64°N et les 106° et 118°W et occupe 9 cartes de la série au 1:250,000. Des échantillons de sédiments près des rivages, de sédiments inorganiques, de sédiments de vase, de sédiments lacustres et d'eau de surface des lacs ont été prélevés à raison d'un par dix milles carrés.

Les échantillons ont été prélevés au cours de la période du 25 juin au 2 août. Trois hélicoptères Bell G4A ont été utilisés pour transporter les échantillons provenant des lacs. Un avion DHC-3 Otter a servi à à constituer les stocks d'essence. Les envolées en hélicoptère ont été faites grosso modo de façon à rayonner à partir d'un centre. Tous les hélicoptères s'envolaient d'une même base de sorte que l'on a établi trois bases consécutives.

Une envolée moyenne vers un endroit d'échantillonnage a duré moins de 10 minutes. Environ 1500 milles carrés ont été échantillonnés chaque jour. Les échantillons d'eau ont été acidifiés et les échantillons de sédiments, séchés sur le terrain.

Les échantillons de sédiments ont été tamisés au treillis de 250 mailles (63) et l'on a terminé la préparation des échantillons à Ottawa vers la fin de septembre. Les laboratoires de la Commission géologique, Section de la géochimie, ont entrepris des analyses par des méthodes de spectrométrie d'émission (arc électrique à courant continu), de spectrophotométrie d'absorption, de fluorimétrie et de colorimétrie. Les échantillons de sédiments ont été analysés pour leur teneur en Cu, Ni, Pb, Zn, Ag, Co, Mn, U, Hg, Mo, Ti, Ba, Cr, Be, V, Sn, Zr, Y, La, Li, Mg, Fe, K, Ca, Sr, Sb, et As. Les échantillons d'eau ont été analysés pour leur teneur en Cu, Zn, et Hg.

Les résultats sont publiés sur ces cartes au 1:250,000. La concentrations des éléments à chaque endroit d'échantillonnage et les courbes relatives aux données géochimiques tracées par ordinateur seront portées sur un fond de carte montrant la géologie, les lacs, le drainage et les endroits d'échantillonnage. Les résultats concernant les éléments les plus importants seront publiés à cette échelle. Les autres résultats seront publiés sous forme d'imprimés d'ordinateur et de cartes en courbes, à petite échelle accompagnés d'une carte indiquant les endroits d'échantillonnage et leurs numéros. Les résultats préliminaires démontrent que dans la région il existe, pour plusieurs éléments, des anomalies importantes. Les auteurs proposent les mesures à prendre par la suite au sujet de ces anomalies et ils présentent le détail du coût de l'entreprise.

RECONNAISSANCE GEOCHEMISTRY USING LAKE SEDIMENTS OF A 36,000-SQUARE-MILE AREA OF THE NORTHWESTERN CANADIAN SHIELD (BEAR-SLAVE OPERATION, 1972)

INTRODUCTION

General

The Bear-Slave Operation is a reconnaissance geochemical survey of some 36,000 square miles of the Canadian Shield. Field sampling was conducted during the summer of 1972. The sample media collected were nearshore sediment and surface water from lakes. One sample was collected every ten square miles. Analyses of the samples for a variety of elements will result in the publication, during 1973, of computer-drawn geochemical contour maps of selected elements for the area surveyed. This paper is intended to describe all aspects of the operation from project proposal to map publication. It is intended to be a background reference on the logistics, organization, techniques and procedures used in the operation. As such it can be used in conjunction with the geochemical maps published separately so that the map user is familiar with the complete operation involved in the production of the maps. This report also includes information on the geology and metallogeny of the survey area, and indicates possible follow-up procedures for areas of higher trace element content.

The Bear-Slave Operation was conceived on the basis of studies carried out in the last few years by the Geological Survey, studies that involved both sampling of drainage materials and of bedrock.

Previous to the use of lake sediments, other drainage system media had been used in systematic geochemical surveys of relatively small areas of the Canadian Shield. Descriptions of the evolution of drainage sediments (Allan *et al.*, 1972) and drainage water surveys in the Shield (Boyle *et al.*, 1971) have been given elsewhere. In summary, water from springs, streams, rivers, lakes, muskegs and wells have been collected, along with sediments from streams, rivers and lakes. Only stream and lake sediments and waters have been collected systematically over significantly large areas. Chamberlain (1964) carried out a survey in the Bancroft area using uranium in stream waters. In the same area, Smith and Dyck (1969) made use of radon 222 in surface waters. Later, the radon method using stream and lake waters was applied regionally at Bancroft and Elliot Lake. In 1968, a regional comparison of uranium exploration methods using stream waters and sediments, and lake waters was carried out near Uranium City (Dyck *et al.*, 1971). In 1969, Allan and Hornbrook (1970) related copper content of lake waters in the Coppermine basalts to known mineralization. The next year, regional surveys for base metal exploration, using lake waters and sediments (Allan, 1971) and lake waters (Hornbrook, 1971) were carried out in the Coppermine and Kaminak Lake areas respectively. In 1971, a further survey took place in which for the first time, systematic rock and lake sediment samples were collected in the same areas, including two areas where Archean massive sulphide deposits occur (Allan, *et al.*, 1972).

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All of the above hydrogeochemical surveys resulted in the successful delineation of known mineralized areas, and outlined other areas that may be mineralized. The reason for this success is that waters leach great volumes of rock and drift and carry to the surface clues to the presence of hidden mineralization.

From lake water surveys, little extra information on regional trace metal distribution can be obtained by using sample densities greater than one per ten square miles (Boyle et al., 1971). Lake sediments were found to reflect this variation better than lake waters (Allan, 1971; Dyck, 1971; Allan et al., 1972) both at regional and detailed scales. In particular, analyses of lake sediments and bedrock from the 1972 survey showed that major and trace element contents of the former could be related to areas of mineralization and also to regional geological changes.

Because lakes occur near the end of the weathering, transportation and deposition sequence of the drainage cycle, which produces a wide dispersal of elements, sample media from them are particularly suitable for reconnaissance surveys. Accordingly, information on mineral potential that might require sampling of rocks and tills at a high areal density, may be obtained more economically by widely-spaced lake sediment surveys.

The above outline has been limited to surveys carried out by the Geological Survey. Lake waters have been used by industry for uranium exploration since the middle 1960's. Materials from lakes, including sediments, were used in the late 1960's in exploration in the Maritimes and later, British Columbia. In the late 1960's, and early 1970's the Saskatchewan Research Council investigated the use of lake water and sediments as exploration media for the Shield area of that province and in the early 1970's industry made limited use of lake sediments in various parts of the Shield.

Proposal and Objectives

The Bear-Slave Operation employed three helicopters to cover 36,000 square miles at a low sample site density. This was a major departure in scale of operations and density of sampling from previous operations. Systematic surveys using drainage system materials had been confined to much smaller areas of known mineral potential, such as Bancroft, Elliot Lake, Kaminak Lake, Coppermine and others. This was not the case for the Bear-Slave Operation and thus the objectives of the operation were different from previous surveys.

Why this survey should be undertaken, why it should be carried out in this particular area and the objectives of the operation were given in the original project proposal which, in part, follows:

"The Canadian Shield has proved itself in the south to be one of the world's richest mineral areas. Much of Canada's early development, present wealth and future potential can be directly related to known or suspected mineral occurrences in the Shield. That most mined occurrences are in the south can be readily seen from any mineral occurrence map of Canada. Yet, virtually the same rock types are found over the entire Shield. In particular, there are prime geological exploration targets in the Slave and Bear Provinces, for example in the Great Bear Lake silver belt, or the greenstone belts of the Slave Province. The Bear-Slave area is also ideal from a development viewpoint. Compared with other parts of the Shield north of 60°N, e.g. the District of Keewatin, it is the most readily accessible. At its southern tip is Yellowknife, the largest town in the N.W.T. and a major staging point for mineral exploration. There are some small operating mines in the area, e.g. Terra and Echo Bay silver mines; some small mines have closed down such as Tundra and Discovery gold mines; and some prospects of moderate size have been located at High Lake, at Hackett River and in the Coppermine region. However, in recent years exploration activity has declined. This may be partly due to exploration companies having insufficient information available to select areas on which to focus their activities. Most of the areas that are of most obvious geological interest have been explored by methods other than geochemistry, e.g. the Coppermine River basalts, the High Lake volcanics, the Muskox Lake basalts, etc. However, such areas constitute only perhaps 3 per cent of the Slave and Bear Provinces. A direct measurement of the relative abundance of trace elements in the environment obtained by lake sampling methods, will help to provide focus on areas of interest in which more detailed exploration may prove fruitful and also provide information that should facilitate resource assessment."

"The specific objectives of the survey are: (1) to outline areas of interest of 20 square miles or greater that have anomalous contents of one or more trace elements. This will be a direct aid to the future selection of areas for prospecting by industry, in that there will be focus on areas of interest so far unknown or only suspected to be mineralized; (2) to differentiate large areas of similar rock type, such as greenstone belts, or granitic areas, as to relative economic potential based on relative abundance of trace and major elements; (3) to provide geochemical information that may be of assistance in compilation of regional geological maps by differentiating rock units; and provide information that may be relevant to the geological and geochemical evolution of Shield areas; and (4) to assess the presently proposed logistics and operational procedures so that estimates can be made for contract surveys of this type for other parts of the Shield. The project should cover a sufficient area to enable an assessment to be made of the value of extending such surveys over wide areas of the Shield, and cover a large enough area so that unknown mineralized belts and zones are likely to be detected. This work is an essential step in developing geochemical methods for assessing the mineral potential of the entire Shield."

A further aspect of the results for such a large area is that the data will show the natural abundance and variation of potentially toxic metals in the natural and uncontaminated environment. This aspect should be of interest to environmental scientists and those concerned with public health. From similar surveys carried out farther south, data could be used in forestry and perhaps even in agricultural planning.

Survey Area

The area (lat. 64°30'N to 66°N; long. 106°W to 118°W) of the geochemical survey comprises the equivalent of nine 1:250,000 map-sheets. These are:

N.T.S. Number	Topographic Map Sheet Name	Geochemical Map Sheet
86 - F	Calder River	Sheet 1.
86 - G	Redrock Lake	
86 - B (north half)	Indin Lake	
86 - C (north half)	Hardisty Lake	
76 - E	Contwoyto Lake	Sheet 2.
86 - H	Point Lake	
76 - D (north half)	Lac De Gras	
86 - A (north half)	Winter Lake	
76 - G	Beechey Lake	Sheet 3.
76 - F	Nose Lake	
76 - B (north half)	Healey Lake	
76 - C (north half)	Aylmer Lake	

This area comprises approximately 36,000 square miles and was sampled systematically at a density of one site per 10 square miles. The area covered in the regional survey has been divided into three map-sheets for publication. Each sheet comprises the equivalent of three 1:250,000 map sheets. From west to east, the sheets are referred to as Sheet 1, Sheet 2 and Sheet 3.

In addition to the above regional sampling, a selected area of some 750 square miles of predominantly acid volcanic rocks was sampled at a density of one site per 2.5 square miles. This area is located between Regan and Muskox Lakes (lat. 65°00'N; long. 108°00'W).

General Description of the Terrain

Topography and Vegetation

In the extreme west of the survey area near Great Bear Lake, topography is fairly rugged with elevations up to 1,100 feet and relief of 200 to 300 feet. Rolling hills have a mixed coniferous cover of predominantly black and white spruce trees and tamarack. This type of topography with fairly dense forest cover is found from the west side of the survey area to approximately longitude 116°W. To the east of 116°W, the forest cover rapidly diminishes and is replaced by the low-lying, rolling tundra zone. Mosses and lichens predominate on the higher ground and shrubs and dwarf birch and willow trees in the lower, wetter depressions. Virtually all of Sheet 2, with the exception of the extreme west border where some trees are found, is in the tundra area. Elevation of lakes in this map-sheet are 1,200 to 1,400 feet and relief is in the order of one to two hundred feet. However, in traversing the area there is a much greater impression of flatness than in Sheet 1. Sheet 3 to the east, lies entirely in the zone of tundra vegetation referred to as the

Barren Lands. Lake elevations are in the order of 1,200 to 1,300 feet. Relief is low to moderate and is usually less than 200 feet. On traversing by helicopter, the impression is one of a very low-lying, rolling topography.

Outcrop

Outcrop in all three sheets is moderate to good and in some extreme cases the area consists almost entirely of rock and lakes. In general, granitic areas are low-lying but rugged and there is much outcrop and only thin soil cover; sedimentary areas in greenstone belts are relatively flat and outcrop is generally minimal; and volcanic areas, both basic and acidic, are associated with the major relief and outcrop areas of all three map-sheets. In volcanic areas there is usually a rugged appearance to the landscape, for example in the more intensely sampled acid volcanic belt near Regan Lake on Sheet 3.

Drainage

In the west and northwest of Sheet 1, drainage is predominantly into Great Bear Lake by rivers such as Wopmay, and Calder. In the south of Sheet 1 drainage is into Great Slave Lake by rivers such as the Acasta and Snare. The extreme south of Sheet 2 drains to Great Slave Lake via the Snare and Yellowknife rivers. The northern portion drains predominantly to the Arctic Ocean via the Coppermine River. In Sheet 3, most of the drainage is to the west into Back River, or directly north via rivers, such as the Mara, into the Arctic Ocean.

In general, other than such major river systems mentioned above, drainage is irregular. Many lakes have no obvious out-flow stream and the landscape is dotted with thousands of lakes that are part of no distinct drainage pattern. The major river drainage system, in places, appears to have been superimposed on the landscape with rivers often flowing across geological contacts and often at a lower level than most lakes.

Lakes

Lake size varies considerably and is commonly difficult to define because the "lake" may wind for many miles via several connections. Contwoyto Lake, the largest lake in the area, is over 70 miles long. The smallest lakes sampled were about 1,000 feet long. Many samples were collected in bays around Contwoyto Lake, and other large lakes.

In most of the lakes, nearshore sediment was easily visible. Also in many lakes, sediment could be obtained near islands or in shallow areas of the lake which often form reefs. Some lakes were extremely shallow over much of the bottom and were thus easily sampled. In general, lakes in areas of sedimentary and volcanic rocks contained more easily obtainable sediment than lakes in granitic areas. In the former, the lakes are often fairly shallow (not more than 6 feet deep for 30 to 40 yards from the shore) and islands and reefs are numerous. In the latter, the bottom often drops off steeply and sediment is usually located in bays. Most of the lakes have clear water; lakes filled with organic debris are rare and could be easily avoided at the sample site density employed. An interesting feature of most lakes is the presence of periglacial features in the bottom sediment, namely silty frost boils, stone rings and stone stripes. As on land, the degree of slope of the lake bottom determines which of these features occur. Sites of stripes and boils were excellent sample locations as they usually are underlain by a strongly gleyed bottom sediment with a dominantly silty texture. This can be viewed in two ways: (1) the sediment is a continuation of the surrounding land surface beneath the lake and thereby has a common origin; or (2) the lake sediment in shallow areas where it freezes annually is simply affected by the same periglacial processes, but has a multiple source, dominantly fluvial transport.

Climate

The whole survey area is characterized by short, cool summers and long, cold winters. Rotten ice was still to be found on most of Wopmay Lake at the Camp 1 site on June 17th, but had completely melted by June 19th. On Sheet 2 ice disappeared from the lake adjacent to Camp 2 on July 6th. Contwoyto Lake, was almost completely ice-covered on July 6th, and the ice did not completely leave it until very late in July. Only a few of the larger lakes in Sheet 3 were ice-covered on July 17th. During July sampling followed, almost daily, behind the melting ice.

Weather conditions directly affecting air operations were good. Often the sky was only partly overcast. Winds could be fairly high but caused few "down" days of helicopter usage. Cool weather was ideal for helicopter operations that necessitated landings to be made at ten-minute intervals.

Permafrost

Sheet 1 is 90 per cent underlain by discontinuous permafrost and 10 per cent by continuous permafrost. The opposite applies to Sheet 2. Sheet 3 to the east is entirely underlain by continuous permafrost. The boundary between these permafrost zones approximately follows the treeline.

Geology, Metallogeny and Some Geochemical Characteristics of the Slave and Bear Geological Provinces

McGlynn (1970), McGlynn and Henderson (1970), and McGlynn and Fraser (1972) have recently presented excellent descriptions of the geology, summarized below, of the Bear and Slave Provinces. The generalized geological map, Figure 1, is based on the compilation of Douglas (1968). The geological base for all the 1:250,000 geochemical maps prepared for this project is based on a recent, unpublished compilation by J.C. McGlynn. The mineral deposit occurrences shown on the 1:250,000 geochemical maps, are based on a recent compilation by R.I. Thorpe (pers. comm.).

Slave Province

This province, 75,000 square miles in extent, shares with the much larger Superior Province, the distinction of being the oldest portion of the Canadian Shield. Except for Proterozoic rocks along its margin, it is composed of rocks of Archean (>2.4 b.y.) age. Essentially, the province comprises a "matrix" of granitic and high-grade metamorphic rocks that encloses a number of north-trending belts of volcanic and sedimentary rocks of lower greenschist to amphibolite metamorphic grade. The term Yellowknife Supergroup has been applied to this volcanic-sedimentary succession.

The most common sequence found is mafic lavas at the base, succeeded by less abundant intermediate and acid volcanic and pyroclastic rocks. These basal volcanic units are generally found along the margin of the belt and vary from 1,000 - 40,000 feet in thickness. They may show either calc-alkaline or tholeiitic differentiation trends (Baragar, 1966). The main axial portion of the belts are filled by flysch facies greywacke-shale sediments which generally lie conformably on the volcanic units. The sedimentary rocks are volumetrically much more abundant (4:1) than the volcanic rocks, a feature which is the reverse of that for the equivalent belts of the Superior Province and which has an important bearing on the relative mineral potential of the two regions. An important point to bear in mind during the interpretation of the geochemical maps resulting from this project is that unrecognized volcanic rocks, of good mineral potential, may lie within sedimentary sequences. One such example, that was not recognized at the time of reconnaissance mapping, are the volcanic rocks associated with the stratabound massive sulphide deposit of Cominco Ltd. at Hackett River.

The flysch facies greywacke-shale sediments show the typical features of turbidite deposition. The composition of these sediments suggested to McGlynn and Henderson (1970) that their source included granitic rocks similar to those marginal to the belts (which, on average, are of granodioritic composition) along with silicic volcanic rocks. They feel that volcanic rocks marginal to the sedimentary rocks, made a relatively minor contribution to the sedimentary rocks. If this is indeed the case there should be little difference in the composition of lake sediments overlying areas of granitic or metasedimentary rocks. Chemically mature sediments, such as quartzites and limestones, are relatively rare in the Archean of the Slave Province. However, where they are present they may indicate periods of temporary tectonic stability and/or exhalative volcanic activity (Cameron and Baumann, 1972). Iron-formation of exhalative origin may accompany these sediments, although McGlynn and Fraser (1972) state that the Slave Province is deficient in iron-formation relative to the Superior Province. On the helicopter traverses many small iron-formation gossans were observed and within the Regan Lake volcanic belt there is an abundance of gossans, large and small, derived from iron-formation of carbonate and sulphide facies. The mature and exhalative sediments and gossans are preferentially located near the volcanic/sedimentary contact within the Regan Lake belt and elsewhere within the province. A number of gossans were observed near sedimentary-granitic contacts at the edges of the belts. These gossans may, in fact, be associated with unrecognized volcanic rocks as was the case at Hackett River.

The granitic rocks of the province may be divided into two broad types. The first are gneisses, migmatites, and granitic gneisses that appear to have been derived from the rocks of the Yellowknife Supergroup. The other type is batholithic rocks of massive to slightly gneissic appearance. The age relationship of the granitic rocks to the Yellowknife Supergroup is unclear in many parts of the province. Many of the granites are definitely younger, but there is substantial, although not conclusive, evidence (McGlynn and Henderson, 1970) to suggest that some of the granitic bodies are older than the volcanic-sedimentary rocks. Many studies throughout the Shield (e.g. Eade and Fahrig, 1971) have shown that the granitic rocks are, on average, of granodiorite composition.

In the northeastern part of Sheet 3 the Archean rocks are unconformably overlain by Aphebian sediments of the Goulburn Group. The basal unit, the Western River Formation, consists of argillites, white to buff quartzites, and red siltstones with some dolomite and conglomerate. The overlying Burnside River Formation is a thick succession of pink quartzites and quartz-pebble conglomerate. These strata are generally little deformed and unmetamorphosed. This testifies to the stable character of the underlying Slave craton since early Proterozoic time.

Along the eastern boundary of the Slave Province is a thick succession of white to pink sandstones called the Ellice Formation. They are thought to be of Helikian age (Tremblay, 1971).

The northern sector of the eastern margin of the Slave Province is prominently marked by the graben of the Bathurst Trench. The southern part of the boundary is placed along a granitization front and is therefore rather arbitrary. The rocks to the east of the boundary within the Churchill Province are granitoid gneisses; to the west they are nodular schists and gneisses. The rocks on both sides give somewhat similar ages (1950-2140 m.y.), which suggested to Tremblay (1971) that they are all Slave rocks and ages have been somewhat updated during the Hudsonian orogeny.

Relatively few ore deposits of currently economic size and grade have so far been located in the Slave Province. However, there is a fair amount of information on mineral prospects and this serves as clues to the type of deposits that may be discovered within the province. Thorpe (1972) has recently summarized the metallogeny of the Bear and Slave Provinces.

Massive sulphide deposits containing one or more of the following elements Zn, Cu, Pb, Ag. At the present time this type of deposit appears to have the greatest economic potential. It is likely to be found enclosed in Yellowknife Supergroup rocks and near acid volcanic rocks. It is beyond the scope of this report to discuss the many theories of origin for these deposits. As a working hypothesis that allows a basis for the interpretation of the lake sediment and water data, the authors accept the widely held view that the deposits are of volcanic-exhalative origin. They have formed subaqueously by the precipitation of metals brought up by fumarolic solutions that were released around centres of acid volcanism. The deposits are associated with acid, often fragmental, volcanic rocks and with sediments of exhalative origin, such as chert, iron-formation and limestones.

In the development of methods of lake sediment sampling for mineral exploration within the Slave Province that preceded this major operation the authors paid particular attention to the Archean massive sulphide type of deposit (Allan et al., 1972). It was suggested that such deposits may be outlined in lake sediments by a hierarchy of geochemical indicators. A typical hierarchy of indicators, in descending order of areal extend, follows:

1. Mineralized acid volcanic rocks indicated by lake sediments high in K and Si and low in such elements as Mg, Fe, Ti and Ni, but locally high in Cu, Zn and other ore elements.

2. Within (1), zones underlain by exhalative sediments, such as carbonates and iron-rich sediments. Since the exhalative carbonates may contain relatively large amounts of Mn (Allan, et al., 1972) and this element may be present in substantial amounts in the iron-rich sediments, Mn may be one of the most useful indicators of the exhalative facies.

3. Mg alteration zones around the volcanic vent. At the Hackett River and High Lake massive sulphide deposits of the Slave Province, there are Mg anomalies around the volcanic centres in both rock and lake sediment samples.

4. Anomalies for the metals forming the sulphides of the ore deposit or associated smaller showings or microdeposits (Fe, Cu, Zn, Pb, Ag, Hg).

Gold deposits. The Slave Province has, and continues to be, an important gold producing region, with Yellowknife and its environs being the major centre for mining activity. The gold commonly occurs in quartz veins and pods located along shear zones in volcanic rocks and sediments of the Yellowknife Supergroup. For the Yellowknife district Boyle (1961) has shown that H_2O, CO_2, S, and K were added to alteration zones around the gold-quartz lenses. As well as gold the lenses in volcanic rocks contain carbonates, pyrite, arsenopyrite, stibnite, chalcopyrite, sphalerite, pyrrhotite, sulphosalts, galena and scheelite. The accessory components of the gold-bearing lenses in sediments are: pyrite, sphalerite, galena and tourmaline. The content of As and Sb in these ores is particularly high relative to its crustal abundance. For instance, Boyle (1961, p. 153) reported up to 3.31% As for gold ore from the Giant mine. As and Sb are, therefore, likely to be an important indicator of gold mineralization in volcanic rocks. However, care should be taken in interpreting As anomalies since this element is much more abundant in certain Yellowknife Supergroup sediments than in other rocks (Allan et al., 1972). K anomalies in lake sediments may help to define the alteration zones around gold-quartz lenses. Au-As mineralization may also occur within metamorphosed iron-formation, such as at Point and Contwoyto Lakes (Thorpe, 1972).

Porphyry deposits. One of the intriguing questions concerning the economic geology of Canada is whether there are significant numbers of porphyry Cu/Mo deposits in the Shield. One body that may be of this type is located at Likely Lake, 12 miles north of Yellowknife. A quartz-feldspar porphyry contains pyrite, pyrrhotite, chalcopyrite, molybdenite and fluorite (Shegelski and Thorpe, 1972). A composite sample from this deposit averaged 0.24% MoS_2 over 105 feet (Jolliffe, 1938). Kirkham (1972) has pointed out the difficulties in exploring for porphyry deposits in the Shield caused by the metamorphism and folding that they are likely to have undergone. However, the extensive and disseminated nature of the mineralization within these bodies makes them an ideal target for reconnaissance geochemical exploration techniques. As well as anomalies for Cu and/or Mo, the lake sediment data may show patterns indicative of alteration zones around the deposits. For instance J.L. Jambor (pers. comm.) has found Fe and Zn enriched in zones extending out thousands of feet from porphyry deposits in the Babine Lake area of British Columbia. Porphyry deposits are more likely to be associated with late Archean or younger intrusive granites that contain higher contents of K than the bulk of Archean granitic rocks (Anhaeusser et al., 1969).

Other deposits. Thorpe (1972) discussed a number of other types of deposits found in the Slave Province. These are: native silver veins at the margin of Hope Bay volcanic belt; nickel arsenide veins at a number of localities; rare metal (Li, Be, Nb, Ta, Sn, Mo) pegmatite deposits; scheelite-bearing

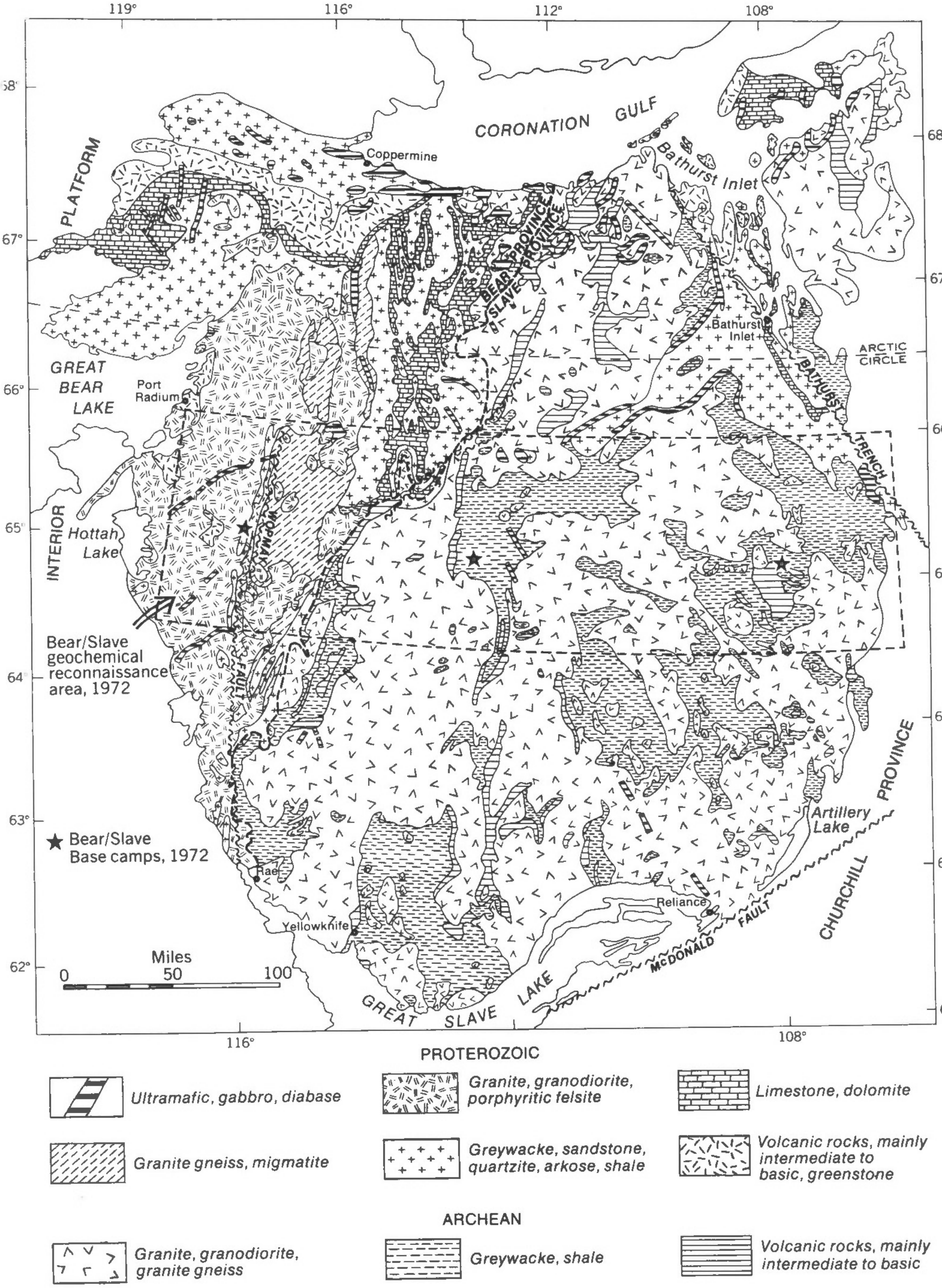


Figure 1. Geology of the Bear and Slave Geological Provinces.

veins in the Yellowknife-Beaulieu pegmatite district; and Au-Cu-W mineralization in sheared and silicified schists and gneisses of the Wilson Island Group southeast of Yellowknife. These different types of ores appear to be of only minor economic potential.

Bear Province

This province is entirely composed of rocks of Proterozoic age. Stockwell (1964) has subdivided it into four subprovinces. The area sampled for lake sediments and waters is entirely contained within one of these - the Wopmay Subprovince - and the following description will be confined to this area.

Aphebian sediments of the Snare and Epworth Groups that are relatively lightly metamorphosed lie along the eastern margin of the subprovince. These sediments are of mainly miogeosynclinal facies. The Epworth Group to the north (Fig. 1) has an aggregate thickness of about 15,000 feet. It is subdivided into five formations. The lowest, the Odjick, consists of quartzite and shale, with some conglomerate. Locally, andesitic lava occurs near the base. The overlying rocks are laminated to massive stromatolitic dolomites of the Rocknest Formation. The Recluse Formation comprises thin-bedded shales, siltstones and greywackes with thin beds of quartzite and dolomite. Limestones and shales of the Cowles Lake Formation and mudstones, siltstones and sandstones of the Takiyuak Formation do not occur within the area sampled.

The Snare Group contains a variable assemblage of quartzite, dolomite, shale (including black shale) and siltstone. As well as along the eastern margin of the province Snare sediments occur to the west. The most notable occurrence is in a north-south belt along Wopmay River where thick basic lavas overlie siltstone and shales and are, in turn, overlain by feldspathic sandstone and shales. The present Snare and Epworth Groups are separated by highly metamorphosed terrain but are thought to be, in part, equivalent; the Snare being the lateral equivalent of the Odjick Formation.

The Aphebian sediments were folded, metamorphosed and, in part, granitized and intruded by granitic rocks during the Hudsonian orogeny (1700-1900 m.y.). The earliest phase of folding along a north to northeasterly strike dominates; this was followed by folding along a southeasterly strike. Batholithic rocks of predominantly granodiorite or quartz monzonite composition grade into zones of migmatite and granitic gneiss which, in turn, pass into metamorphosed Snare and Epworth sediments. A broad area of this highly metamorphosed terrain lies to the east of Wopmay River. The metamorphosed Snare and Epworth sediments of this area are thought to be of eugeosynclinal character, in contrast to the miogeosynclinal Snare and Epworth exposed farther to the east along the Bear/Slave boundary (McGlynn and Fraser, 1972). The period of granite formation within the Bear Province was followed by faulting and by volcanism and molasse sedimentation that gave rise to the Cameron Bay and Echo Bay Groups. These units occur in various places to the west of the Wopmay fault and comprise a varicoloured assemblage of volcanic rocks - porphyritic andesite, dacite, trachyte, tuff, ignimbrite, breccia - with associated red arkoses, shales and conglomerate. These various rocks are intruded by comagmatic massive intrusions of granite to diorite composition that are of the high level type distinguished by sharp contacts and narrow metamorphic aureoles. These intrusives are known mainly from west of Wopmay River.

In summary, the easternmost part of the Wopmay Subprovince is composed of shelf sediments lying unconformably on Archean rocks. These pass westwards into rocks of miogeosynclinal and then eugeosynclinal character. The latter facies has undergone intensive metamorphism of the high temperature – low presure type and has been granitized. The Wopmay fault zone marks a sharp boundary between these rocks and a contrasting terrane to the west of high level granitic intrusions and possibly comagmatic volcanic rocks.

The boundary between the Bear and Slave Provinces (Fig. 1) is usually placed at the unconformity between the Archean and the Aphebian sediments or their metamorphic equivalents. However, following Stockwell (1964) the boundary, in some places within the sampled area, is defined as the western margin of a relatively undeformed and unmetamorphosed homoclinal sequence of Epworth sediments that rests on the Archean.

Mineralization. Although the production of minerals from the Wopmay Subprovince has been relatively low in monetary terms, mineralization within the area has attracted a good deal of attention from the prospector and economic geologist. The area to the west of the Wopmay fault zone is particularly favourable, since the geological character of the region is not dissimilar to that of the abundantly mineralized areas of the Cordillera. Most of the mineralization of economic interest occurs in this region.

Uranium occurrences are particularly notable and the Wopmay Subprovince may be considered to be a metallogenic province for uranium. The epigenetic uranium mineralization appears to be controlled on both a regional and a local scale by major faults of northeast and southeast strike (Ruzicka, 1971). At the Eldorado mine at Port Radium on Great Bear Lake pitchblende occurs along a prominent northeasterly fault zone. The minerals deposited with uranium during several stages of mineralization include: apatite, quartz, hematite, nickel and cobalt arsenides, pyrite, barite, siderite, sphalerite, tetrahedrite, bornite, chalcopyrite, galena, rhodochrosite, native silver, argentite and silver arsenides. There is conspicuous alteration of the wall-rocks with development of apatite, microcline, hematite, quartz, chlorite, white mica, pyrite, chalcopyrite and carbonates. The age of the mineralization, 1400 m.y. (Ruzicka, 1971), is much younger than the age of the high level granites noted above. The mineralization is approximately the same age as diabase dykes. U also occurs within extensive quartz stockwork zones. There are some 30 of these zones within the Wopmay Subprovince, although only a few are known to contain U. They may be more than 1,000 feet wide and 10 miles long (Jolliffe, (1952) and commonly strike northeasterly. The abandoned Rayrock Mine is an example of this type. The mineral assemblage is much simpler than for the Port Radium type of deposit. Only hematite, pyrite, and chalcopyrite accompany the pitchblende in the Rayrock deposit.

The rocks of the Wopmay Subprovince are relatively enriched in U. Eade and Fahrig (1971) record an average of 8.1 ppm for rocks from Hardisty Lake map-sheet, which is in the southwest of the area sampled in this study. This compares with an average of 1.7 ppm for the Fort Enterprise sheet to the east in the Slave Province. There should, therefore, be a marked difference in the level of U encountered in lake sediments from the Bear and Slave Provinces. In the Bear Province anomalies resulting from leaching of mobile U from deposits, showings and microdeposits should be superimposed on a generally higher regional level for U. The ore-related anomalies may be accompanied by anomalies for other metals, because of the multi-element nature of some of the uranium occurrences. On the basis of the discussion above and of spectrographic analyses for metals from three uranium occurrences within the Bear Province by Ruzicka (1971), it appears that Cu may be the metal that most consistently accompanies U, but there may also be anomalies for such elements as Pb, Zn, Ag, Ni, Co, As, and Y, amongst those we have analyzed for.

Silver was mined from the complex ores of the Eldorado Mine. Similar silver-bearing veins, which generally have a northeast strike, occur in this area and as far south as Hottah Lake. They have been mined at the Echo Bay Mine at Port Radium, at Terra Mine on the Camsell River, and from the Contact Lake, El Bonanza, Norex and Silver Bay deposits in the same general area. The U content of these complex ores is rather variable, being low for most of the deposits that have been mined for Ag. Copper is most commonly associated with Ag and was mined at the Echo Bay Mine at a grade of 2% (Thorpe, 1966). Thus for the related vein deposits of U and Ag, which have been the only ores mined on any significant scale within the Bear Province, Cu appears to be the most consistent indicator element. Arsenide minerals are found in many, but not all, of the U and Ag deposits and As may therefore prove to be another useful indicator element for geochemical surveys.

The possible occurrence within the Slave Province of "porphyry type" deposits of Cu and/or Mo has been discussed earlier. The Wopmay Subprovince of the Bear Province is, however, a much more favourable locale, in terms of lithology and tectonic history. The environment of high level granitic rocks intruded into comagmatic lavas and volcanogenic sediments is similar to Cordilleran regions that contain porphyry deposits. Also the Coppermine lavas to the north of the Wopmay Subprovince contain volumetrically enormous amounts of dispersed Cu (Cameron and Baragar, 1971) and Cu is an important constituent of the U and Ag ores discussed above. Minor chalcopyrite mineralization in feldspar porphyries at Bode Lake has been likened to a copper porphyry deposit by R. V. Kirkham (in Thorpe, 1972). During our 1971 pilot operation, the Bode Lake area was sampled. However on the basis of comparative results from other areas, it was not considered to be of interest. Otherwise, there are no known deposits thought to be of the porphyry type within the Bear Province. It is of interest that Hoffman (1972) has recently reported disseminated chalcopyrite within a pluton in the Bear Province. The Bear Province appears then to be a metallogenic province for Cu.

In addition to the deposits described above there are a number of other interesting mineral occurrences within the Bear Province that suggest potential ore situations. Copper occurs in the same group of 'giant' quartz veins that contain the pitchblende mineralization noted above. Bornite and chalcopyrite occur in such a 'giant' vein at Hunter Bay, north of Port Radium. Mo and U are found in paragneiss near De Vries Lake in association with magnetite. Thorpe (1972) has suggested that they may be metamorphosed fossil placers or iron-formation. Scheelite with chalcopyrite, pyrrhotite and pyrite occur in quartz veins in quartz feldspar porphyry near to Lever Lake. In addition to the complex silver-bearing veins at Terra Mine there is a stratiform copper horizon that is mined. It is contained in tuffaceous rocks of the Echo Bay Group and comprises mainly chalcopyrite and pyrite.

Most of the mineral occurrences discussed above, which fall within the area sampled for lake sediments, occur in the volcanic rock and high level granitic terrain to the west of the Wopmay fault. The mature sedimentary rocks of the Snare and Epworth Groups along the eastern flank of the Bear Province and the migmatized eugeosynclinal sequence lying between these rocks and the Wopmay fault contain few known mineral occurrences. This should not be taken as conclusive proof of a low mineral potential for this ground, because neither mature sedimentary sequences nor high grade metamorphic terrane have attracted much exploration activity within the Shield. Volcanogenic ores within the eugeosynclinal rocks and Pb/Zn deposits within the carbonate sediments are only two examples of the types of deposits that may be sought in the country to the east of the Wopmay fault. It is also possible that deposits, such as U, that are structurally controlled in the country to the west of the Wopmay fault may be found in extensions of these faults to the east of the Wopmay break.

Glacial Geology of the Bear-Slave Survey Area

The glacial geology of the Bear-Slave Operation survey area has not been examined in detail. Most of the information has been collected during helicopter supported reconnaissance geological surveys and the descriptions are very general, far more so than even the reconnaissance bedrock geology.

As the entire survey area lies well to the west of the Keewatin Ice Divide (Craig and Fyles, 1960), it was glaciated by ice moving roughly in an east to west direction. Most of the features of ice advance in the survey area are probably the result of the last advancing ice, the Wisconsin-Laurentide ice sheet. Marginal fluctuations of this ice sheet prior to ice retreat occurred outside the survey area and features associated with such fluctuations are not found within the survey area. As there is no known evidence of halts, the ice probably retreated across the survey area rapidly. Most of the area was deglaciated in a west to east direction. In the central to southwest part of Sheet 3 is an area which is described as a zone of major discontinuity in ice retreat (Craig, 1960; Craig and Fyles, 1960). Craig and Fyles (1960) attributed this discontinuity to the presence of fast-moving ice on the lower ground to the northeast and slow-moving ice on the higher plateau to the southwest. The zone contains few glacial features and is known to extend in a northwest direction from the south end of the Keewatin Ice Divide to the Arctic Ocean. Most of the survey area was deglaciated by an ice lobe southwest of this discontinuity. The northwest half of Sheet 3 was deglaciated by an ice lobe northeast of the discontinuity. From various C^{14} dates obtained from shells (Craig and Fyles, 1960; Blake, 1963), it is likely that the ice first began to clear the west end of the survey area around 10,000 B.P. and finally cleared the east end around 8,000 B.P. This assumes that the Great Bear Lake became free of ice about the same time as the coast near Coppermine (Craig and Fyles, 1960) and that the east end of the survey area became clear about the same time as the retreating ice deposited the major recessional moraine at MacAlpine Lake (Blake, 1963).

Features of Ice Flow

Features formed and caused by the forward advance of the Wisconsin-Laurentide ice sheet occur over the entire survey area. Striae, drumlins, drumlinoid ridges, crag-and-tail features and roche moutonnees are found. These features have been noted in different parts of the survey area (e.g. Folinsbee, 1949; Lord and Barnes, 1954; Craig, 1960; Blake, 1963; Fraser, 1968). Although it is extensive, ground moraine formed by the advancing ice is relatively thin. In many places rock outcrop is more common than till cover.

The features of ice advance show a southeast to northeast lineation in the eastern part of the survey area. To the west, the trend is almost east-west. Two prominent features in the area, Contwoyto Lake (Blake, 1963) and Point Lake (Craig, 1960) are elongated in the direction of ice movement in their vicinity.

Frost action has often heaved the underlying bedrock through the thin till cover (Lord and Barnes, 1954). Erratic boulders are widely distributed but apparently constitute a minor fraction of the till cover. Above the treeline in the tundra zone, felsenmeer is extensive (Blake, 1963). Because the till is thin and possibly local in origin (Folinsbee, 1949), and because of frost heaving of thinly covered bedrock (Lord and Barnes, 1954) it is our opinion that glacial movements have not significantly displaced geochemical anomalies, relative to the sampling density used.

Features of Ice Retreat

Eskers are the features of ice retreat that dominate all others. These extend for tens of miles, and are found in all parts of the survey area. Most of the area was deglaciated from west to east. The eskers generally run east to west. Some rise up to 150 feet above the surface of neighbouring lakes, and may be 500 feet wide or more. The eskers are usually anastomosing and form a dendritic drainage pattern, with tributary eskers some 20 feet high and 100 feet wide. They are often associated with kames and on rare occasions terminate at minor recessional moraines. The eskers are extremely sandy and normally lakes with nearby eskers were avoided as sample sites. The eskers south of the discontinuity in ice flow are larger and more numerous than to the north. Two distinct recessional moraines (Blake, 1963), running north to south, were formed to the northeast of Contwoyto Lake. They indicate a halt of the lobe of retreating ice to the northwest of the discontinuity in ice flow mentioned previously. The larger moraine is up to 100 feet high in places and was formed by southwest-moving ice, flowing away from the retreating ice divide. This small area to the northwest of Contwoyto Lake is the only one where ice movement was not predominantly due west.

Other but rare features of glacial retreat in the area are proglacial lakes. At Contwoyto Lake, beaches are about 100 feet above the present levels of the lake. No other known examples occur within the survey area. Great Bear Lake was itself a large proglacial lake and storm beaches (on the northeast shore) are found up to 470 feet above the present level of the lake.

Periglacial features

All of the survey area abounds in periglacial features. These are better developed in the tundra zone of continuous permafrost, above the treeline.

All of the features are active at the present and it is extremely likely that the frost heaving, churning and solifluction processes contribute significantly to weathering and geochemical dispersion and hence to the probability of success of geochemistry in the area. Above the treeline, felsenmeer is very common. Also to be seen are all varieties of periglacial phenomena, e.g., ice wedge polygons, tundra polygons, stone nets, stone rings, frost boils, solifluction lobes, vegetation and stone stripes, mud flows, tors, congelifractate, etc.

PRE-FIELD SEASON OPERATIONS

Logistics

For systematic reconnaissance geological surveys in the northern Shield, helicopters are the only feasible means of reaching sample sites (Lord, 1953; Wright, 1967). Calculations of field costs for the 36,000-square-mile survey were based on an expected average helicopter usage of 10 minutes per sample site, a time realized in the Coppermine survey (Allan, 1971). Considering the helicopter time required to complete the systematic sampling of such an area, the total cost was approximately 25 per cent greater than the total two-month contract minimum for 3 Bell G4A helicopters. It would have been possible within the contract cost needed to cover the area, to have four helicopters for a six-week period but this was considered a slight risk due to possible weather problems extending the season for more than six weeks. This later proved to be unfounded, for the three helicopters were on site for only 41 days and used for 650 flying hours, for both the regional coverage of 36,000 square miles and the detailed sampling of the Regan Lake acid volcanic belt. Twenty helicopter hours were used for the latter work.

The west to east centre line of the survey area lies 220 miles north of Yellowknife. Camp 1 on the west end was 215 miles north-northwest of Yellowknife, Camp 3 on the east end was 280 miles northeast of Yellowknife. Camp 2 was centrally located in the survey area, 215 miles north of Yellowknife.

A total of 30 hours was required to position the three helicopters from Yellowknife to Camp 1 and to deposition them from Camp 3. The regional sampling operation required approximately 600 hours (3,600 samples x 10 minutes). The 36,000-square-mile area was therefore covered at a density of one sample per 10 square miles using 210 hours per helicopter.

At 6 flying hours per day, the operation could theoretically be completed in 35 days. This, of course, anticipated that there would be (a) no down time due to weather problems; (b) no down time due to mechanical problems with any of the 3 helicopters; (c) no down time with the Otter aircraft which was used to put in gas caches; and (d) no unforeseen circumstances such as accidents, illnesses, etc. in the field party. Normally on helicopter operations in the north delays of several days due to weather conditions are common. Also, mechanical breakdown can easily result in a week of down time due to misplacement of spare part shipments. Therefore, it is wise in remote areas for field parties to allow about 30 per cent extra time for an operation. Thus, it was anticipated that the sampling operation would last about 48 days. Along with one week to cache, organize, and set up Camp 1 and 5 days to break Camp 3 and ship out the equipment from Yellowknife, a field season of some 60 days was expected. As it turned out the regional sampling operation took 37 days. Two additional days were spent on the detailed (one site per 2.5 square mile) sampling program.

The total field operation took 49 days. This was exceptional and was unusual in that there was no down time either due to weather, mechanical breakdown, or any unforeseen circumstance. Another very important feature was that the sampling crews had been carefully selected and interviewed in Ottawa. The result was that the entire student field crew was exceptional in maturity and interest in the operation. Of course, in such operations, compatibility between all members is essential. This was one, if not the major, reason for the short field operation

As the operation was expected to last up to 60 days, a charter was obtained for a single-engine DHC-3 Otter to support the camp and helicopters. The Otter was to be used to take in fresh food to the camp, take out samples to Yellowknife, and put out gas caches for all three helicopters. It was calculated that these operations would result in an average of 4 hours daily use of the Otter. This, in fact, was the case. The use of the Otter over the total 49-day field period was almost exactly equal to the minimum contract payments required for this period. All other field costs, such as food and salaries, had been based on a 60-day field season. Because of the short field season, the expected costs of the total operation were reduced. It should be emphasized that such a perfect field season would be unlikely to occur in normal years should the same type of operation be attempted again.

Equipment

Longhouse tents were used for the cook tent, the office tent, and the water sample acidification and pH tent. A large ridge tent was used for storage. All 18 members of the field party had individual Mount Logan tents. The fact that each man had his own tent contributed significantly to overall morale. Two CH-25 radios kept the camp in touch with Yellowknife and with the fixed-wing aircraft and helicopters. One aspect of the radio operation was that we were in contact with all the helicopters for most of the time. Only in very rare cases was contact lost, usually due to sun spot activity.

Caching

All the large items of field equipment for Camps 2 and 3 such as dining tables, benches, refrigerators and cooking stoves, along with the aviation gasoline, naphtha and propane tanks were cached during the winter using a Bristol freighter. Caching for Camp 1 was carried out in February by winter road from Yellowknife to Malfait Lake (64°30'N, 118°00'W). From there, the cache was moved in early March, 1972 by single-engine Otter to Wopmay Lake. Approximately 5,000 gallons of 80/87 aviation gasoline was cached at each campsite. The gasoline estimate was based on the helicopter and Otter hours to be flown from each camp. Our estimate for G4A helicopter gas consumption was 16 gallons per hour. However, during the operation, the helicopters used on the average about 12 to 13 gallons an hour. All the helicopters had recently been overhauled and this low figure cannot be safely used in future estimates, but it resulted in a surplus of 2,000 gallons out of a total of 17,500 gallons. If a summer field party runs out of gas and it has to be brought into camps during the summer by a float-equipped Twin Otter, gas costs can be very high.

FIELD SEASON OPERATIONS

Gasoline Caching

From Camp 1, for approximately 10,000 square miles, the sampling was below the treeline. This presented no obvious difficulties as numerous spots for gas caching by the Otter could be easily located. It was then not necessary to clear any helicopter pads and caching could easily be related to suitably efficient sample traverses. East of the treeline, gas caches could be placed almost exactly where required.

The caching operation was to begin as soon as the ice on Wopmay Lake permitted establishment of Camp 1. The starting date was June 17 and this was in fact the first day that we could have landed safely on Wopmay Lake. While an advance 4-man crew set up Camp 1, the Otter began to set out gas caches for the helicopters. This was virtually completed for the Camp 1 area by June 23rd, the date the helicopters arrived.

The caches were laid out on approximately a circle of radius 40 miles around the base camp and were at approximately 20-mile-intervals around this circle. For Camp 1 traverses each cache consisted of 100 gallons. This was to allow the helicopters to gas up twice and have 20 gallons left for emergencies. Later on in the program only 80 gallons were set out at each cache as it became evident that the helicopters were using less gas than estimated. In total, for the entire 36,000-square-mile area, 86 caches were put out. The empty and any full drums left at all 86 locations were later collected by the Otter and returned to the respective base camps. All of these drums plus certain larger pieces of field equipment are scheduled to be brought out to Yellowknife by Bristol Freighter during the 1972-73 winter.

The Otter was found to be the ideal machine to support such a three-helicopter operation. A smaller plane would have been unsatisfactory. Likewise a larger, more expensive plane, e.g. a Twin Otter, would have completed the caching too quickly and considerable funds been lost in maintaining the contract minimums for such a plane. As it was, the hours flown by the Otter in support of the entire operation were only slightly in excess of the minimum to be paid to have the aircraft on charter.

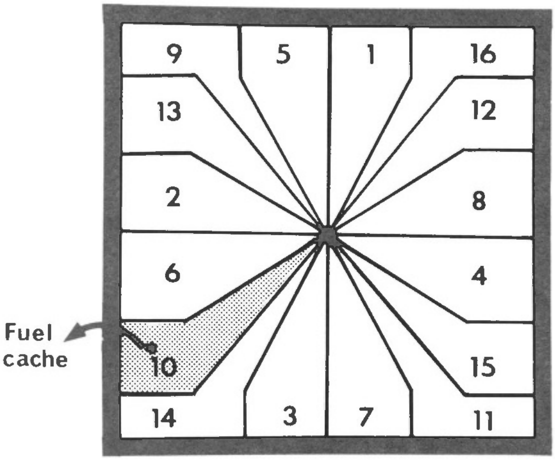


Figure 2. Helicopter Traverse Pattern.

Helicopter Traverses and Sample Times

The overall plan for the helicopter traverses had been worked out in Ottawa. In geological operations, where for example a perfect radial pattern (Wright, 1967) can be employed, ground near base camps is "sampled" more than ground farther out. A more irregular flying pattern must be used in geochemical sampling to allow more evenly-spaced sampling. An idealized system is shown in Figure 2.

Table 1.

Number of Samples Collected Daily and Average Rates per Site for July 1972 Bear-Slave Operation

DATE		HELICOPTER								
		YWY			NYM			HEL		
		SITES	HRS.	RATE MINS.	SITES	HRS.	RATE MINS.	SITES	HRS.	RATE MINS.
	July 1	48	7.30	9.4	51	6.40	7.8	61	7.25	7.3
	2	51	8.25	9.9	56	8.05	8.7	59	8.50	8.9
Camp Move 1	3, 4, 5									
to 2	6	42	7.30	10.7	54	7.10	7.9	33	4.45	8.6
	7	52	6.05	7.0	26	3.45	8.7	36	5.00	8.3
	8	28	4.30	9.6	30	4.10	8.3	34	4.35	8.1
	9	51	6.20	7.5	45	7.20	9.8	49	7.20	9.0
	10	-	-	-	67	7.45	6.9	-	-	-
	11	58	7.05	7.3	49	6.50	8.4	53	6.15	7.1
	12	47	7.20	9.4	46	7.40	10.0	48	7.25	9.3
	13	52	6.40	7.7	53	7.10	8.1	51	7.30	8.8
	14	32	4.30	8.4	52	6.35	7.6	55	7.50	8.5
	15	48	7.35	9.5	49	7.30	9.2	58	8.25	8.7
	17	29	5.55	12.2	21	3.10	9.0	20	2.20	7.0
Camp Move 2	18, 19									
to 3	20	44	6.40	9.1	52	6.35	8.8	52	6.30	7.5
	21	44	6.50	9.3	-	-	-	43	7.55	11.0
	22	48	7.20	9.2	55	9.00	9.8	58	8.10	8.5
	23	26	3.10	7.3	29	3.50	7.9	23	3.00	7.8
	24	38 (30D)[1]	7.30	11.8	40 (31D)	7.45	11.6	38 (30D)	7.25	11.7
	25	44	7.20	10.0	40	7.20	11.0	43	6.45	9.4
	26	49	6.35	9.3	56	8.10	8.7	48	7.05	8.8
	27	49	7.55	9.7	48	7.15	9.1	55	8.45	9.5
Detail[2]	28	65	5.35	5.2	64	5.40	5.3	54	6.00	6.7
Detail	29	59	5.25	5.5	-	-	-	-	-	-
	30	55	7.40	8.4	54	7.50	8.7	56	7.10	7.7
	31	50	7.20	8.8	45	6.10	8.2	48	6.30	8.1

[1] 30D = Thirty duplicate samples were collected on July 24. This is the reason for the elevated sample rates.

[2] Samples were collected at a site density of one per 2.5 square miles.

Each helicopter was expected to collect samples from 50 to 55 sites per day. With three helicopters it was usual (Table 1) to sample areas of 1,500 square miles in one day. The areas were sampled in the order shown in Figure 2, e.g., on the first day areas 1, 2 and 3 were sampled by separate helicopters. The helicopter sampling crew were encouraged to sample on the way out and to complete the farthest out sites in case bad weather occurred later. At all three camps the edges of the maps were completed at as early a stage as possible. Any sites missed at the inner end of the traverse could be collected later with a minimum of over-flying time.

The helicopter pilots found the above basic traversing systems satisfactory and no problems with gas cache accessibility or low fuel levels occurred. This pattern was only slightly modified as weather and mechanical problems seldom resulted in partially completed traverses. The areas to be sampled daily did, of course, vary in size and the traverses for each day could not be precisely planned until all helicopters had returned at the end of the day and the areas sampled plotted on the base maps. Accordingly, the base maps were kept up to date daily and the entire field crew could see the progress of the operation.

The helicopter flight path within the assigned area to be sampled was the responsibility of the sampling crew and the pilots. The crew received a 1:250,000 map, with an area, containing usually 50 to 55 samples, blocked out as numbered in Figure 2, e.g. area 10. The gas cache for this area was marked on the map. The crew could normally collect samples from an average of 15 sites in 2.5 hours flying time. This is the full-tank flying time of the G4A excluding 20 minutes reserve gasoline. They would select a path out from the camp that would reach the fuel cache after 2.5 hours, collecting samples on the way. This sometimes involved a little over-flying over sites already sampled. After refuelling another traverse was made to the edge of the map-sheet. In this case there was no over-flying and the sample rate increased as the crews got into the routine. After a second refuelling, a traverse would be run back to the camp. These planned flight paths were often changed somewhat during the day because of changes in prevailing wind direction or rate of sampling. This operation gave a fair degree of responsibility to the two-man sample crew and the pilot which resulted in the development of a team-like spirit and a sense of competition between the crews. This in turn increased the efficiency of the operation.

Lake Sediment and Water Sampling from Helicopters

The sediment and water sampling was carried out from each helicopter by a two-man sampling crew. The detailed routine sampling procedure was left up to the crew, and each crew employed a slightly different division of duties. One crew for instance, took daily turns at sediment sampling. Another crew alternated sediment sampling after each refuelling. However, the general division of duties was as follows: Three people can be comfortably accommodated in the G4A helicopter. Looking forward in the helicopter, the pilot is on the left, sampler one is in the middle and sampler two on the right. The door on the right was normally removed from the helicopter, depending on the weather. The pilot was given the 1:250,000 map, with the area to be sampled outlined and he and sampler one drew out a flight plan with two fuel caching stops.

The pilot kept the map between himself and sampler one and the pilot was responsible for navigation at all times. However, sampler one also read the map so as to check site locations. The exact sample site and the sample number was written on the map by the pilot and agreed upon by sampler one. Between locations sampler one would fill out a computer card with information he had noted at the previous location. The items listed on the computer card follow. Figure 3 is an example field use computer card for drainage sediments and waters. Sampler two meanwhile marked the number of the next sample site on the sediment sample bag, the 500 ml. bottle for general water analyses and the 175 ml. bottle for Hg analysis. Sampler two then started to look for the next sample site location which was by now being approached.

Geochemical Water/Sediment Field Card Information Key

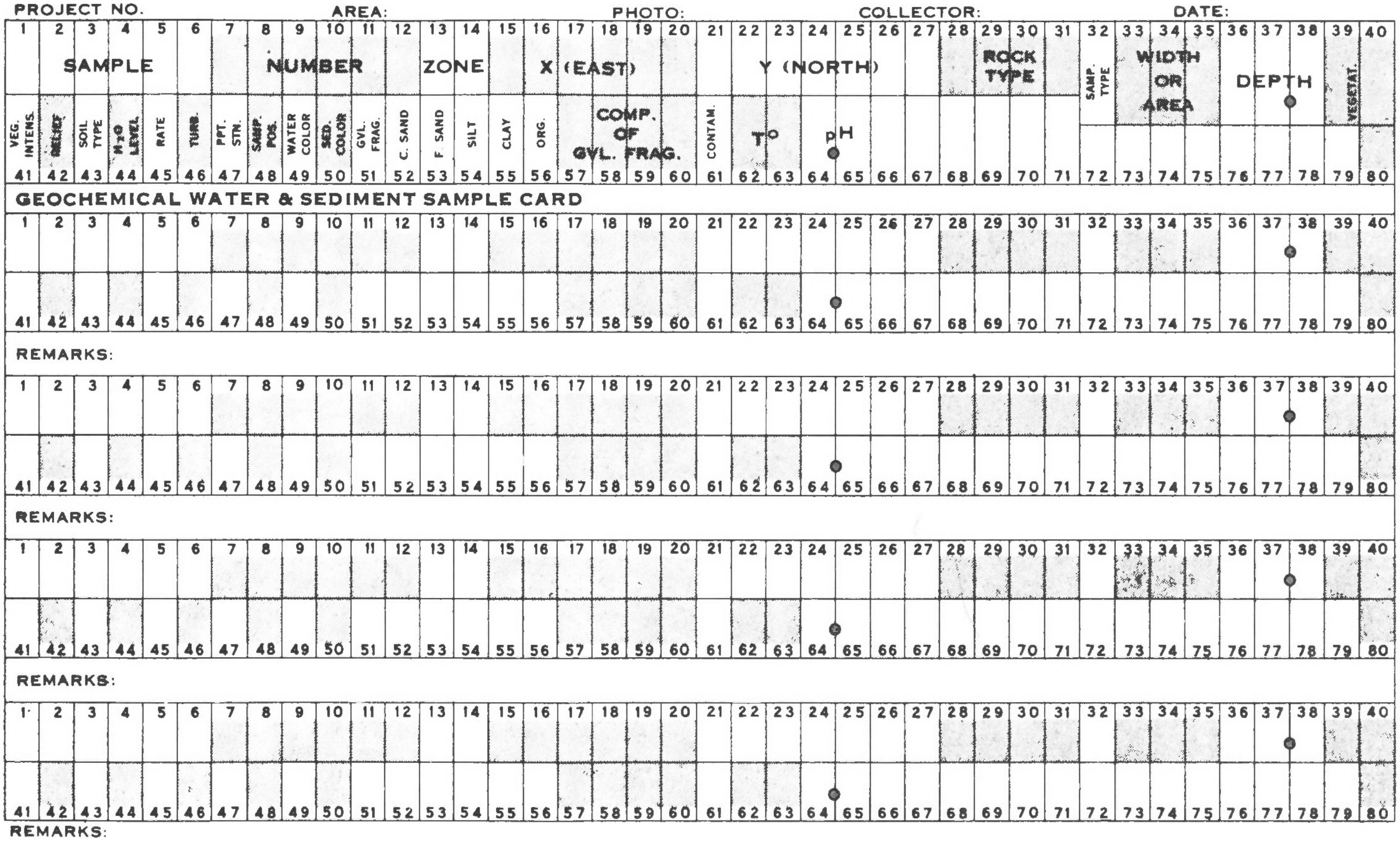
Box Range	Information - Description
1-12	Sample Number consists of NTS map number, year and 4 digit (consecutive) number, i.e., 086N14710136 Only the last digits have to be entered at the site, the NTS and year may be entered when convenient.
13-27	Zone and coordinates will be the UTM system. This may also be filled out when convenient.
28-31	Rock type to be entered when convenient using the geological map and the mnemonic code of Geodat.
32-33	Weather conditions should be entered at least once each day or as conditions change, but must be entered for each sample eventually.
34-36	Lake surface conditions is an indication of the wind strength and its effect on the lake.
37-40	Vegetation is for the predominant group only, around the lake. Note that the grass and moss category is primarily for tundra type conditions and not for bogs and swamps which are described under lake type.
41-43	Relief of Hi, Med., Low indicate: (a) shear, steep elevations (b) gently rolling hills (c) flat lying tundra plain
44-47	Lake type describes the general sampling area of the lake bottom.
48-50	Water colour, Note any other colour under remarks if not listed.
51-52	Water suspension - the measure of the amount of suspended matter in the undisturbed water. Always fill in one box.

Box Range	Information – Description
53-57	Sediment colour - noted while sample is wet. Any colours not contained in boxes should be noted under remarks.
58-61	The composition of the sediment for each of the headings in this section has a scale of 0-9 and all the sections should add up to 10.
62-63	Sample depth.
64-66	Sample area or width.
67-68	Temperature in degrees Centigrade of surface water at sample site.
69-72	Contamination in the lake of the immediate area around any part of the shoreline should be noted; workings include pits, trenches, dumps, adits, or drill holes. Gossans are of vital interest and should be noted on the sample location map also.
73-77	Indicate if water and/or sediment was collected and from which medium.
78	At least once a day replicate samples should be taken and the number 1 inserted in this column.
79-80	For pH measurement.

However, on the way to this lake, an excellent sample may become visible in a neighbouring lake. This latter site could be seen on the map by sampler two to still fit the required 1- per 10-square-mile sample density. He could then if he wished indicate to the pilot that this was the sample site. If this did not occur and the original selected lake was reached, the pilot would gain altitude and begin to circle the lake. As soon as sampler two selected a site, he indicated its location to the pilot, who would land exactly on it. Only sampler two selected sites. Sampler one was ordered never to interfere even if he saw what he thought was a better location. Obviously, only one man of the three could have final authority on site location. Of course, this alternated depending on who was sampler two at the time.

The tool used to sample the lake sediment was a very light 6-foot-long post-hole soil auger constructed of magnesium-zirconium drill rods. It was fitted on the helicopter pannier by two easily released catches. The augers were connected to the pannier by a length of rope so that it was impossible for the sampler to accidentally raise the auger into the main rotor blades. Also on the panniers, were aluminum boxes for separate storage of the sediment and water samples.

On landing above the sample site, sampler two would get out onto the helicopter float. All three pilots were skilled at holding the helicopter steady on the water surface. This proved to be a very important aspect of



PROJECT NO. AREA: PHOTO: COLLECTOR: DATE:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
SAMPLE						NUMBER					ZONE			X (EAST)						Y (NORTH)							ROCK TYPE				SAMP. TYPE	WIDTH OR AREA			DEPTH			VEGETAT.	
VEG. INTENS.	RELIEF	SOIL TYPE	H_2O LEVEL	RATE	TURB.	PPT. STN.	SAMP. POS.	WATER COLOR	SED. COLOR	GVL. FRAG.	C. SAND	F. SAND	SILT	CLAY	ORG.	COMP. OF GVL. FRAG.				CONTAM.	T°		pH																
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

GEOCHEMICAL WATER & SEDIMENT SAMPLE CARD

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

REMARKS:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

REMARKS:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

REMARKS:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

REMARKS:

Figure 3. Geochemical Survey sediment and water field card.

Table 2.

Total Helicopter Flying Hours Used and
Running Average Sample Rate, July, 1972
Bear-Slave Operation

REGIONAL (1 per 10 square miles)				
DATE	SITES	HOURS[1]	RUNNING AVERAGE RATE MINUTES	
July 1	747[2]	127.20	10.2	
2	926	152.40	9.9	Camp Move
6	1146	195.45	10.2	
7	1260	210.34	10.0	
8	1352	223.50	9.9	
9	1497	244.50	9.8	
10	1564	252.35	9.7	
11	1724	272.45	9.5	
12	1865	295.10	9.5	
13	2021	316.30	9.4	
14	2160	335.25	9.3	
15	2315	358.55	9.3	Camp Move
17	2385	370.20	9.3	
20	2536	404.35	9.6	
21	2623	419.20	9.6	
22	2784	443.50	9.6	
23	2862	453.50	9.5	
24	2978	476.30	9.6	
24D	3069	476.30	9.3	
25	3105	497.55	9.6	
26	3258	519.45	9.6	
27	3410	543.40	9.6	
30	3575	566.20	9.5	
31	3718	586.20	9.5	
MORE DETAILED (1 per 2.5 Square Miles)				
July 28	183	Total Sites = 242 Total Hrs used = 22.40 Rate = 5.6 minutes/site		
29	59			

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[1] Included in the hourly totals is the original positioning time from Yellowknife, all time used on hoisting in camp and all overflying.

[2] 747 samples were collected in June. This used 127.20 hours.

Table 3.

Field Personnel - Bear-Slave Operation

Personnel	Assignment	Remarks
R.J. Allan	Geochemist	Operation Chief
E.M. Cameron	Geochemist	Deputy Chief, Head, Geochemistry Section
C.C. Durham	Geochemical Technician	Deputy Chief
M. Forgie	Helicopter Pilot (Viking Helicopters) and Engineer	Sampling Crew 1
R. Benson	Geology Graduate	
B. Cumming	Geology Student	
G. Ball	Helicopter Pilot (Viking Helicopters)	Sampling Crew 2
G. Lund	Geology Graduate	
C. Pride	Geology Student	
M. Pigeon	Helicopter Pilot (Viking Helicopters)	Sampling Crew 3
R. Colley	Geology Graduate	
G. Thomas	Geology Student	
D. Mann	Geology Student	Water Sample Field Treatment, Gas Caching by Otter, Relief Helicopter Sampling
W. Woronuk	Geology Student	
M. Hartwell	Otter Pilot (Gateway Aviation)	Gas Caching Camp Supply
F. Benoit	Cook	
S. Pollock	Helicopter Mechanic	Viking Helicopters
D. Johns	Helicopter Mechanic	Viking Helicopters

the sampling operation. The sampler would release the auger from the pannier and lower it into the lake. The samples normally came from the lake near the shore, near islands, or above reefs, at water depths of 3 to 8 feet. By hand signals, the sampler would indicate to the pilot where to move the helicopter, then when to hold it steady, so as to be directly over the sample site. Sites were often subaqueous silty frost boils. Meanwhile, as soon as sampler two was on the float, sampler one would move over in the helicopter to the open door, lean out and collect the two water samples from beneath the lake surface. These were stored inside the helicopter. The sediment sampler, by this time, had retrieved the sediment. This was placed in the sample bag and stored in the helicopter. The auger was reclipped, by which time the helicopter was ready to lift off. On lift off the computer card and numbering process began again. The combination of collecting the sediments and selecting the sample locations was an extremely exhausting job over an 8-hour flying day. The computer card writer-water sampler had a less exhausting time. By changing over each day or run, the crews were able to maintain a rapid continuous sampling rate over the field season. It is important to note here that the samples always came from depths in the lake of 3 to 8 feet. These depths were recorded on the geochemical computer cards. Because an extension soil auger was used as the sampling device, samples could not be collected in depths other than in this range. This has also been the case in previous studies (Allan, 1971; Allan et al., 1972). This may be of considerable significance when regional comparisons of concentrations are made. It is well known that concentrations of trace elements in lake sediments vary both around and across lake bottoms. This is usually related to content of organic matter which in turn is related to depth in the lake. Often samples from deep parts of lakes are almost totally organic with a weight loss on ignition of up to 90 per cent. Obviously such samples cannot be compared directly with inorganic lake shore sediments. By using a sampling tool which restricted all the samplers to similar lake bottom environments, the samples collected were reasonably uniform in composition. Alternatively, if devices had been used that allow the samplers to collect samples from various environments in all parts and depths of lakes, it is likely that there will be inherent variations in trace element concentrations simply due to position in the lake and related organic content. To interpret this latter data requires extra analyses and statistical manipulation of the data.

Field Treatment of Samples

All sediment samples were brought back to the base camps by helicopter. Water samples collected after the second refuelling were also brought back to camp. The water samples on the run out to the cache and on the middle run were left at the cache to be picked up by the Otter when the empty fuel drums were collected. This was because carrying the water would have put the helicopters over the legal flying weight.

At the camp, the sediments were laid out on tarpaulins on the ground to dry. After one day, the samples, which were still damp, were dry enough to pack for shipment. The sediments were sent off as soon as possible to Ottawa for sample preparation and analyses. Water bottles were set out in the Longhouse acid tent. The small 175 ml. bottles were treated with 1 ml. of a 1% $KMnO_4$ and 5 ml. of concentrated H_2SO_4 in preparation for

Hg analysis in Ottawa. The large 500 ml bottles were acidified with 1 ml of concentrated HNO_3. Bottles and sediments were then packed separately for shipment to Ottawa.

Before acidification of the 500 ml water samples pH and Eh measurements were made using a meter developed by Q. Bristow and G. Gaumont. Two meters, one pH, one Eh were used simultaneously to speed production. For Sheet 1, pH and Eh were measured on all the samples but on Sheets 2 and 3 only one sample in ten was selected for measurement on the basis of an even areal and geological distribution. Values for pH were montonously in the 6.5 and 7.5 range. Many were essentially neutral. Values of Eh are, of course, unreliable if not done at the actual sample site, but all measured results were positive.

POST-FIELD SEASON OPERATIONS

Sample Preparation

Sample treatments carried out in the field have been described. The samples were shipped to Ottawa and on arrival, the water samples were ready for analysis. Sediment samples required pretreatment and were laid out to dry. The drying process took up to a week in certain cases. When dry, the sediments were ready for sieving. One half of the original sample was kept unsieved after disaggregation using a rubber mallet. The other half was sieved to minus 250 mesh on stainless steel sieves.

This procedure produces one plastic vial of minus 250 mesh (at least 3g); and two sample bags--that marked A has one-half or less of the original sample, that marked B has the residue from the sieving operation. All "A" samples were stored separately from all "B" samples. The vials of minus 250 mesh sediments were used for analysis.

The sample site numbers shown on the base maps are 1 to 1393; 2001 to 3375; 4001 to 5335; and 6000 to 6013. This gives the total number of sites as 4,117. However, 13 site numbers (Nos. 261, 2,078, 4053, 4,336, 4,388, 4,389, 4,448, 4,561, 4,562, 4,563, 4,564, 4,914, 5,235) were not used due to sites being skipped by the sample crews. Thus during the operation 4,102 sites were sampled.

Of the 4,102 sediments collected, 4,099 will be analyzed. Three (Nos. 5,046, 5,047, 5,049) were lost during shipment to Ottawa when the sample bags burst. Of the 4,099 sediments analyzed, only 27 did not contain sufficient minus 250 mesh material for analysis. These 27 (Nos. 227, 253, 268, 314, 465, 2,039, 2,404, 2,410, 2,508, 2,614, 4,152, 4,223, 4,347, 4,363, 4,377, 4,432, 4,447, 4,497, 5,548, 4,626, 4,753, 4,799, 5,071, 5,080, 5,081) were sieved to minus 100 mesh. The minus 100 mesh fraction was ball milled before analysis. On the base maps, sample sites where the minus 250 mesh sediment sample was used are shown as dots. Where the minus 100 mesh sediment was used, the dot is underlined.

The water sample had the same number as the sediment sample at a site. Water samples were then not collected at the 13 sites mentioned above for sediments. Of the 4,102 water samples collected, 6 (Nos. 255, 757, 4,419, 4,353, 4,372, 4,655) were lost during shipment to Ottawa due to leakage from the bottles.

Analytical Methods

The sediments, sieved to minus 250 mesh are being analyzed by a variety of techniques depending on the element. Some of the methods have only recently been put into operation routinely by the Geological Survey.

The techniques used to determine specific elements in the samples were: (1) atomic absorption spectrophotometry; (2) fluorimetry; (3) colorimetry; and (4) emission spectrophotometry. The details of the methods used for specific elements are presented below. The methods used on the atomic absorption have been adapted by J. J. Lynch and others. The Hg methods used on all samples were developed by I. R. Jonasson. The measurement of organic matter content published for all minus 250 mesh fractions analyzed is a colorimetric determination carried out on the diluted HNO_3 leach solution prepared for the atomic absorption analyses and was developed by J. J. Lynch, I. R. Jonasson and R. G. Garrett. The method used on the direct reading spectrometer was developed at the Geological Survey by M. Timperley.

(1) Atomic Absorption Spectrophotometry. This technique was used to determine: (a) Zn, Ag, Mn and Li in the sediments;
(b) Hg in the waters and sediments;
(c) Zn and Cu in the waters.

(a) Zn, Ag, Mn, and Li in sediments

For the above elements, 400 mg of minus 250 mesh sediment were weighed out. To this was added 6 ml of 4N HNO_3 and 2 drops of concentrated HCl. The sample was shaken and placed in a water bath at 90°C for 1.5 hours. The sample was then diluted to 20 ml with metal-free water, with intermittent agitation and allowed to settle. The leach was analyzed on a Perkin Elmer 303 atomic absorption spectrophotometer. A Deuterium background correction was used in the Ag analysis. Ag was read at 328.1 mμ; Zn at 213.9 mμ; Li at 670.8 mμ; and Mn 403.1 mμ.

(b) Hg in water and sediments

Hg in the waters was determined in the 175 ml bottles treated in the field with H_2SO_4 and $KMnO_4$. 5 ml of 5% oxalic acid were added to the bottles in Ottawa. The bottles were shaken until clear and Hg determined in a 100 ml aliquot on a Techtron A.A. 5 atomic absorption spectrophotometer, by a cold vapor method. To the 100 ml aliquot was added 100 ml of 2.5% $SnSO_4$. The sample was aerated and the metallic Hg vapour released determined at 253.7 mμ. For the sediments, 500 mg of less than 250 mesh material was leached with 20 ml conc. HNO_3, 1 ml conc. HCl, and 80 ml H_2O, at 95°C for 1.5 hours in a water bath. The sample was cooled and a 100 ml aliquot was analyzed for Hg as described above for the waters. In water the detection limit is 0.004 ppb Hg.

(c) Zn and Cu in Waters

These elements were determined in the 500 ml water samples to which 1 ml of conc. HNO_3 had been added in the field. The waters were analyzed directly using a HGA-70 heated graphite atomiser connected to a Perkin Elmer 303 atomic absorption spectrophotometer with automatic chart readout. This method was developed by G. Gauthier and J. J. Lynch.

For Zn, a 25μl aliquot of water was inserted into the graphite tube, dried at 100°C for 40 secs., charred at 490°C for 15 secs., and atomised at 1950°C for 10 secs. Zn was read at 214 mμ.

For Cu, a 50 μl aliquot was used and the settings are: 80 secs. at 100°C for drying; 30 secs. at 1100°C for charring; and 10 secs. at 2450°C for atomising. Cu was read at 325 mμ. Detection limits are 0.3 ppb Cu, 0.2 ppb Zn.

(2) Fluorimetry. This technique was used to determine U in the sediments (Smith and Lynch, 1969). Sample solutions prepared for the Zn, Ag, Mn and Li determinations were used. A 0.2 ml aliquot of the hot nitric acid leach was placed on a Pt dish and evaporated to dryness. The residue was burned for 1 minute above a Bunsen flame. To this was added 3g of a K_2CO_3-Na_2CO_3-NaF flux. The sample was then fused for 10 minutes at 650°C, cooled in a dessicator, and the U concentration read on a Jarrell-Ash fluorimeter.

(3) Colorimetry. This technique was used to determine As and Sb in the sediments. A weighed sample of minus 250 mesh material was heated with 6M HCl at 90° for 1.5 hours. The test solution was centrifuged and an aliquot was then removed for the As determination, where the As is reduced to the trivalent state with KI and $SnCl_2$ and evolved as AsH_3 by the action of nascent hydrogen generated by the addition of granulated Zn metal to the test solution. The arsine and hydrogen was bubbled through a solution of silver diethyldithiocarbamate. The colour intensity was determined at 520μ using a Bauch and Lomb Spectronic 20 colorimeter and the As calculated from a calibration curve. Another aliquot of the test solution was removed for the determination of Sb. The Sb was oxidized to Sb^5 with sodium nitrite and after dilution reacted with brilliant green. The Sb - brilliant green complex was extracted into toluene. The resulting blue colour was visually compared with standards.

(4) Emission Spectrophotometry. The method of analysis used on the direct reading spectrometer is more fully discussed elsewhere (Timperley et al., 1973). A short description follows. A 100 mg sediment sample less than 250 mesh is mixed with buffer (1 part Na_2CO_3, 7 parts graphite) with Pd and In as internal standards. The mixture is packed in 3/16" diameter preformed electrodes. These are burned in a DC Arc of 5 amps. for 10 secs. and 15 amps. for 50 secs. in an oxygen-argon atmosphere, in a specially designed chamber. An ARL 29000 Quantometer interfaced to a mini-computer is used to record the light emission from the DC Arc for the elements listed in Table 4. By suitable programming, each capacitor used to store the voltage produced by light of a particular wavelength striking a phototube is read at any time during the burning of a sample thus ensuring maximum line to background ratios. "Volatile" metals such as Cu, Pb, Ag, are measured during the initial stages of the burn while "involatile" metals such as Be and Zr, are measured near the end of the burn. Calibration and computation of sample concentrations as well as spectrometer functions are controlled by the computer. Calibration curves within concentration ranges are linear and natural silicates were used for calibration. Control standards (a composite sample of lake sediment from the 1971 pilot study was made up) were burned every tenth sample to check instrument drift. Mean concentrations and standard deviations for this control standard are given in Table 4.

Table 4.

Analytical methods used in analyses of the less than 250 mesh lake sediments from the Bear-Slave Operation

(a) Element	Method	Detection Limit in ppm
Zn	Atomic Absorption	2
Ag	"	0.5
Mn	"	10
Li	"	2
U	Fluorimetry	0.2
Hg	Flameless Atomic Absorption	5 (ppb)
As	Colorimetry	0.5 to 1.0
Sb	"	0.1 to 0.5

Data supplied by Mr. J.J. Lynch.

(b) Element	Method	Mean	S.D.	Coeff. Var.
		ppm		
Pb	Direct Reading Emission	37.6	4.7	12
Sn	Spectrometry	1.96	1.4	71
V	"	63.9	8.5	13
Mo	"	1.48	0.4	29
Cr	"	52.9	7.5	14
Cu	"	53.5	7.4	13
Co	"	14.8	3.3	22
Ni	"	36.8	4.4	12
Be	"	1.88	0.8	45
La	"	50.2	10.5	21
Y	"	23.0	5.3	23
Zr	"	281	62	22
Sr	"	261	29	11
Ba	"	540	55	10
Ti	"	3271	356	10
		%		
Ca	"	1.1	0.1	11
Mg	"	1.2	0.2	17
Fe	"	3.1	0.2	9
K	"	1.9	0.2	10

Means and standard deviations are for analysis of a composite sample of lake sediment made up from sediments collected during the 1971 pilot operation. The figures given above are for 254 analyses of the same composite sample run over a period of one month at regular intervals among the normal samples. Data supplied by Dr. M. Timperley.

Table 5.

Laboratory Personnel – Bear-Slave Operation

LABORATORY PERSONNEL	ASSIGNMENT	REMARKS
J.J. Lynch	Chemist	Overall supervisor
R. Horton	Spectrographer	Direct reader supervisor
P. Lavergne	Technician	Sample preparation supervisor
G. Gauthier	Analyst	Water analyses by A.A.
A. McLaurin A. Lemieux R. Crook	Analyst Student Analyst Analyst	Sediment analyses by A.A.
W. Nelson W. Alexander	Analyst Analyst	Sediment analyses by direct reader
J. Pelchat	Analyst	Uranium analyses
L. Trip	Analyst	Mercury analyses
A. Martineau	Technician	Sample preparation

A technique for background correction was devised based on movement of the primary entrance slit. This enables background corrections for most metals to be derived from the standard sample, and results in more accurate estimations of background contributions.

MAP PREPARATION

Base Map Compilation

Base maps were prepared from 1:250,000 topographic sheets by the Cartographic Section of the Geological Survey. The base maps used in the field had drainage, U.T.M. grid, geology, treeline and continuous-discontinuous permafrost line. The geology is from a compilation of J.C. McGlynn, Geological Survey of Canada. For publication the map base consists of geology, treeline and drainage.

Geochemical Contour Map Production

The geochemical contour maps are drawn by computer. In the field the sample points were accurately plotted each evening on 1:250,000 maps by the sample crews. These sites were transferred in Ottawa onto plastic sheet master base maps. The points were then digitized. Contours for each element are drawn over the complete range of element concentrations, which occurred. Due to the many rock types covered in the survey, there has been no attempt to define "background" and "anomalous" concentrations as this could prove to be very misleading.

All concentrations are printed on the map adjacent to the specific sample site.

The method used to produce the contour maps was the General Purpose Contouring Program (GPCP), a proprietary program of California Products, Inc. (Calcomp). The raw data were transformed into logarithms prior to computation. Most of the trace element data approximates a log-normal distribution. The contours plotted are the logarithmic levels but labelled in terms of the antilog. The Calcomp program grids the specified random data by a procedure which analytically constructs a smooth surface passing through every data point but the method is neither a weighted mean of nearby points nor a least squares fit of the data. The grid values are generated by weighting the intersections of the gradient plane at the data points with the vertical line (Z axis vertical) at the grid point. Extrapolation of gradient planes a great distance from the data points may cause spurious trends. Taking derivatives of $\Sigma_j^k = 1\ Wj(\vec{N}.\vec{Q}._j)^2$ with respect to x, y, z, gives three equations in three unknowns for the normal vector. The program subdivides each cell, refining the grid, to produce nearly smooth contours and interpolates within the sub-grid to define the contour. It should be noted here, that several elements were contoured by hand and the output of the above program was found to be virtually identical with hand contoured maps.

The published maps are produced by superimposing geochemical data in red onto a grey and black base map. It is expected that up to 30 maps will be produced, 10 for each sheet. For the other elements, the data will probably be such that a computer listing of the concentrations will be sufficent. A map showing all sample locations and sample numbers will also be released, so that the user may produce his own maps for elements not contoured.

Geological, geochemical and topographical keys are printed on each published map and interpretative notes for each element will be included on the margin of each map. These notes will vary in detail and in length depending on the available geological and metallogenic information available on the particular element. The maps will be published at a scale of 1:250,000.

Examples of Results from Previous Studies

The pilot study for this operation, carried out in 1971 (Allan, et al., 1972), dealt with lake sediment and water data in conjunction with rock chip traverse data from several specific locations in the Bear and Slave Provinces. All aspects of the interpretation of these data are given in this publication (op. cit.) and as such this should be obtained by any user of the Bear-Slave data. Some of the contour maps for the small areas (Fig. A) sampled in 1971 are presented here (Figs. 5, 6, 7, 8 and 9) so that the reader can appreciate the trace element concentrations to be expected in lake sediments. We found in 1971 that the lake sediment concentrations were very closely related to the average trace element content of the rocks of the area. Figure 5 shows the general geology of the areas sampled in the pilot study and presented here.

During 1971, bedrock samples were collected from various rock units in five pilot study areas. Analyses of these samples for Zu, Cu, Pb, Hg and As are given in Table 6. Zn and Cu values for the various rock units

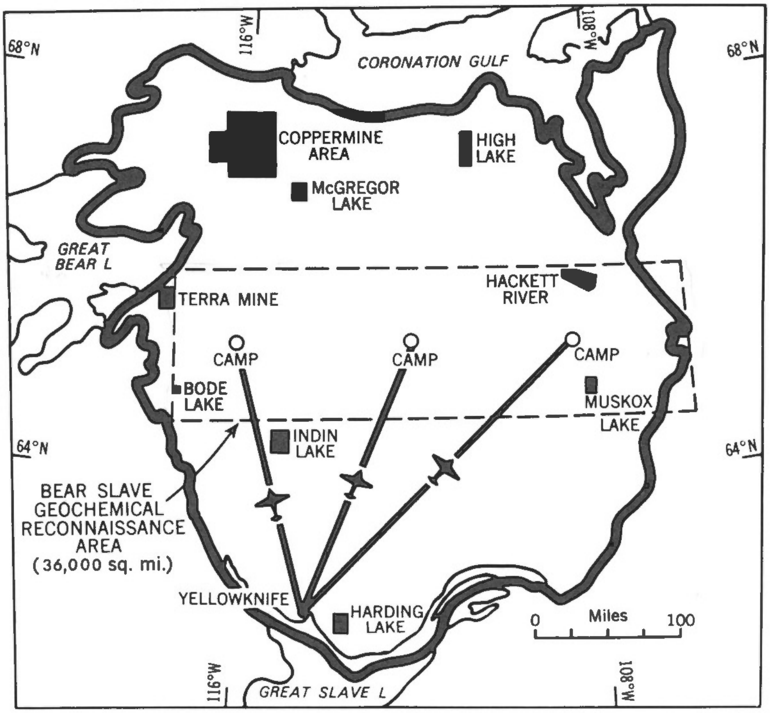


Figure 4. Location of the Bear-Slave survey area and locations of the pilot study areas.

can be compared with the concentrations of these trace elements found in the lakes of the High Lake and Hackett River areas as given in Figures 7 and 8. The concentrations of the other trace elements in bedrock can be used as background information on levels of certain elements in rocks of areas close to those surveyed during the Bear-Slave Operation.

The areas presented here are (1) High Lake - This area is underlain by volcanic rocks and associated sediments, with surrounding granitoid rocks. A known Cu-Zn occurrence of about 5 million tons (diamond symbol on Fig. 7) is located here. (2) Hackett River - This is an area formerly mapped as underlain by Yellowknife Supergroup sediments, but now known to contain acid volcanic rocks, and sediments of volcanic exhalative origin. Hackett River contains a known occurrence of >10 million tons of Zn-Pb-Ag-bearing ore (diamond symbol on Fig. 8). (3) Harding Lake - This is an area of predominantly granitic rocks with no known ore deposits. The geology of the three areas has been more fully discussed elsewhere (Allan, et al., 1972). All three areas are in the Slave Province (discussed in a previous section).

The contour levels presented for these small areas can be compared with those of the published maps for the much larger Bear-Slave Operation area.

Another source of major element data for some rocks in the survey area is to be found in a publication of Eade and Fahrig (1971). Parts of two of their rock sample areas occur within the Bear-Slave Operation boundary. One area, Hardisty Lake, is in the Bear Province, the second, Fort Enterprise, is in the Slave Province. Rock averages for several elements, e.g., Ca, Mg, U, etc. are compared. These can be related to the average lake sediment concentrations obtained in the same areas. Drs. Eade and Fahrig have been kind enough to let us analyze their composite samples from the Hardisty and Fort Enterprise sheets. Data from these analyses for trace elements will be included in the marginal notes on relevant map-sheets.

NOTES ON GEOCHEMICAL MAP INTERPRETATION

The data from this survey can be used (1) by government agencies for resource appraisal; (2) by individuals and companies exploring for minerals in this part of the Shield; and (3) by environmental scientists.

This section is included for the benefit of all three groups, so that they are aware of the strengths and limitations of the data. The next section on proposed follow-up procedures is included specifically for geologists engaged in mineral exploration. The authors do not imply that these procedures are the only way to follow-up the results presented. Undoubtedly, many company exploration divisions, particularly those with staff geochemists, will have much different philosophies of follow-up. However, these procedures are those which we feel are most likely to result in success for the minimum expenditure of exploration dollars.

The computer-drawn Bear-Slave Operation contour maps are based on the raw data derived from the sediments or waters using the sample preparation treatments and analytical methods described. There has been no attempt to, (a) alter the raw data concentrations as affected in the natural environment of lake sediments by organic matter, Fe, Mn, or (b) to use statistical treatment on the raw data such as factor analysis or trend surface analyses. These approaches will be discussed in future papers.

Evironmental Effects

Sorbtion by Iron and Manganese Oxides and Organic Matter:

Manganese and iron oxides and hydroxides are present in surficial sediments as amorphous coatings on mineral particles. Often in drainage sediments these coatings are closely associated with humic and fulvic acids decay products of organic material. These organic acids and the iron and manganese oxides are often intimately mixed and form complex organo-metallic coatings on minerals, particularly grains in the finer particle size ranges. However, they may also coat coarser particles.

Organic material, iron and manganese oxides and organo-metallic complexes of all three, have a strong affinity to sorb certain trace elements. The trace elements are either physically bound into sites during the aging of the iron and manganese hydroxides and oxides, or are sorbed at specific sites in these materials. Likewise, for organic acids or organo-metallic complexes, trace elements can be physically occluded or be actively sorbed on exchange sites, but can also be chelated by certain of the organic compounds, particularly those with a ring structure such as prophyrins. The elements most affected by sorbtion by these compounds are those that are transported in solution. Of the elements that have been analyzed in this survey Cu, Zn, U and Mo are those most likely to have been affected by sorbtion processes. This may result in their enhancement at certain sample sites.

Despite the above, we believe that these factors are unlikely to have significantly altered regional trace element patterns in the survey area. The contents of both iron and manganese in the samples are relatively low. From preliminary results available, the iron and manganese contents correlate well with other elements such as Mg, Cr, V, Ni and Ti found in ferromagnesian and heavy minerals. This implies that most of the iron and manganese is present in minerals in the lake sediments and not as free oxide coatings.

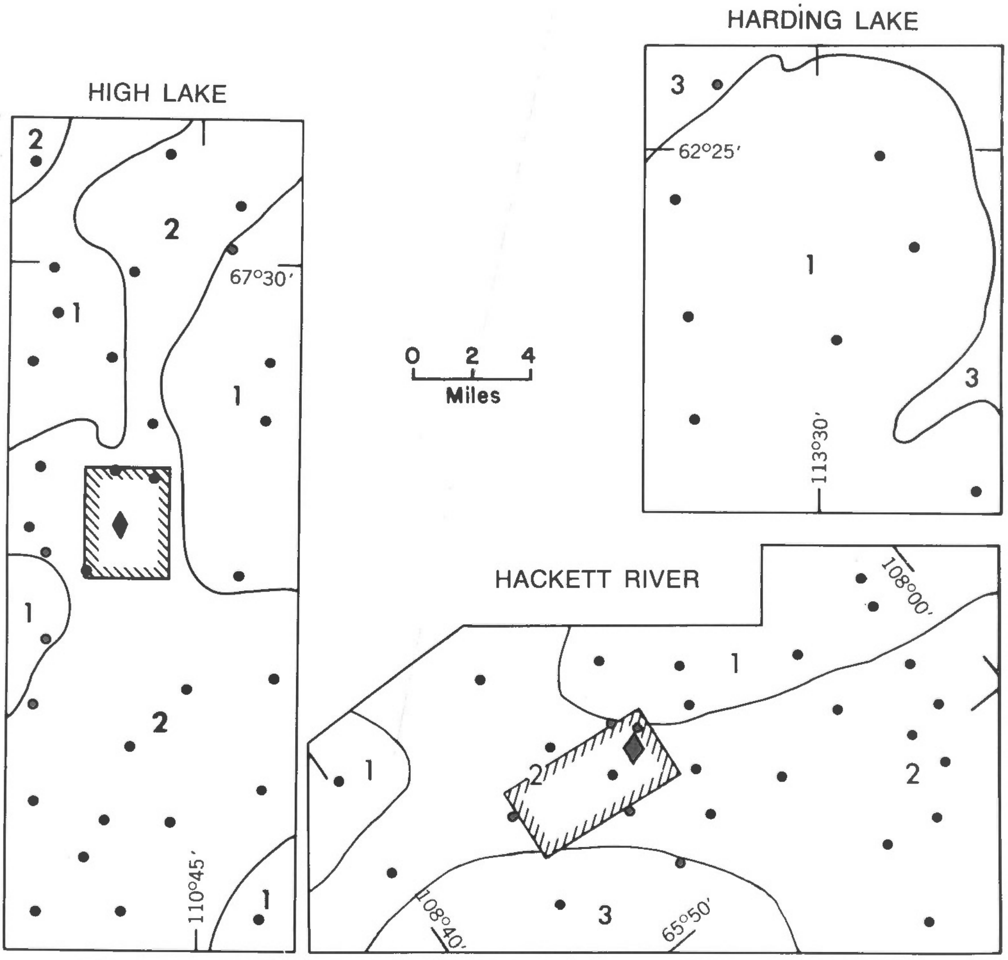


Figure 5. Geology at High Lake, Hackett River and Harding Lake, Northwest Territories.

HIGH LAKE

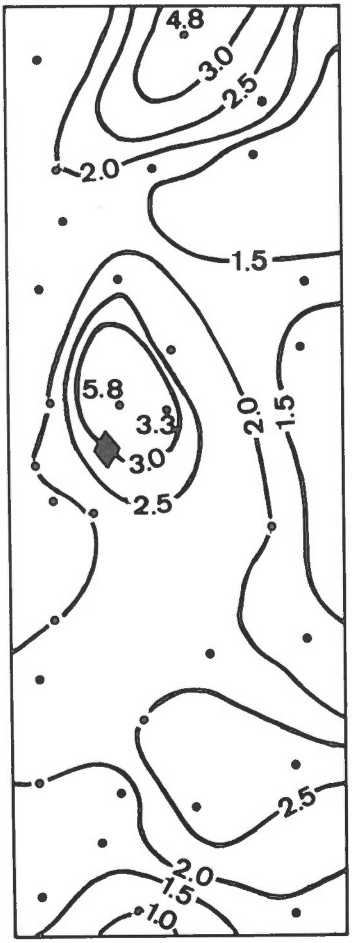
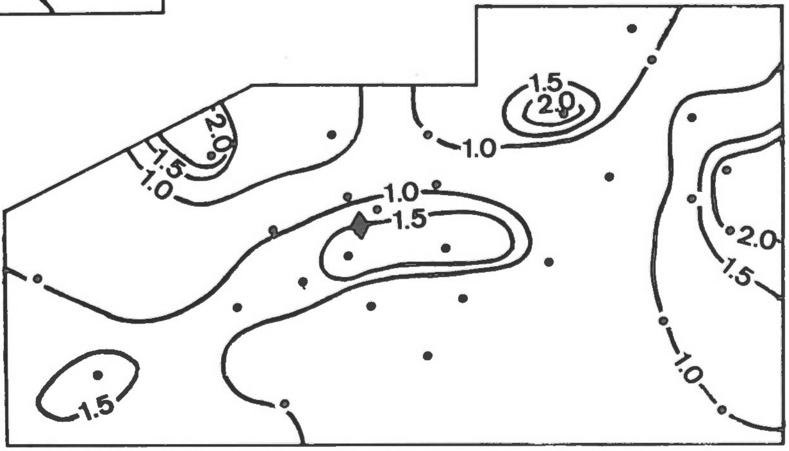
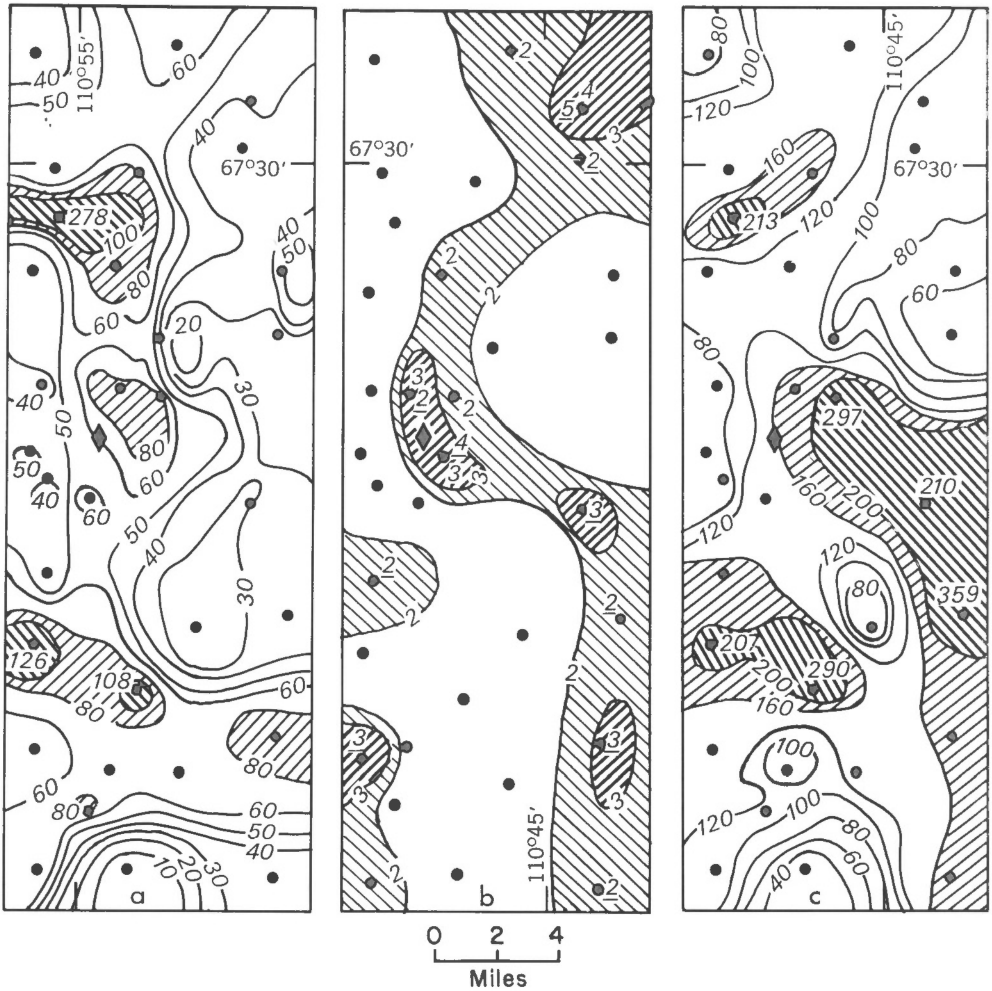


Figure 6.

Percent MgO in lake sediment in areas with Archean massive sulphide deposits.

HACKETT RIVER



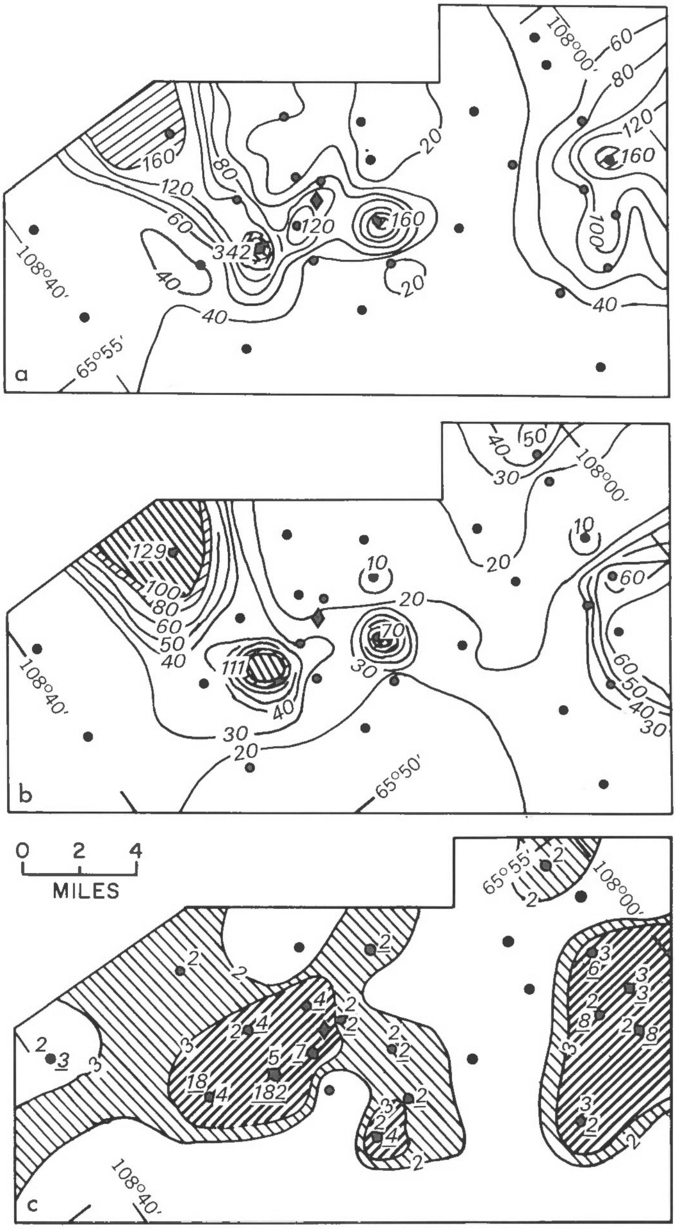


a. Copper in ppm in lake sediment.
b. Copper and zinc in ppb in lake water.
c. Zinc in ppm in lake sediment.

Figure 7. Copper and zinc in lake sediment and lake water at High Lake, Northwest Territories.

On sampling, the lake sediments are usually blue, grey, or greenish in colour. This indicates that most of the iron and manganese is present in a reduced state. Free iron oxides are unlikely to occur as ferric hydroxides, the material usually associated with sorbing and trapping trace elements in surficial sediments. It is probable that some sample sites within the survey area will contain anomalous contents of one or more trace elements and also enhanced contents of manganese and iron. Such sites should be treated with caution. However, it would be unwise to treat all such sites as spurious, since all of these anomalous metals, including iron and manganese, may be associated in primary mineralization. For these reasons, the trace element maps that will be published, will not be "corrected" for the effects of iron and manganese.

In the original samples, few could be referred to as "organic-rich". However, on sieving to minus 250 mesh, the organic matter, which is usually present as very fine particles, is concentrated in the sample used for analysis. In most cases this is insignificant; however, a minor percentage of sieved samples contain moderate amounts of organic matter following sample preparation. The effect of enhancement of anomalies due to sorbtion by organic matter is not simple. There must always be a source for the element. In this respect, the behaviour of lake sediments may be similar to



a. Zinc in ppm in lake sediment.

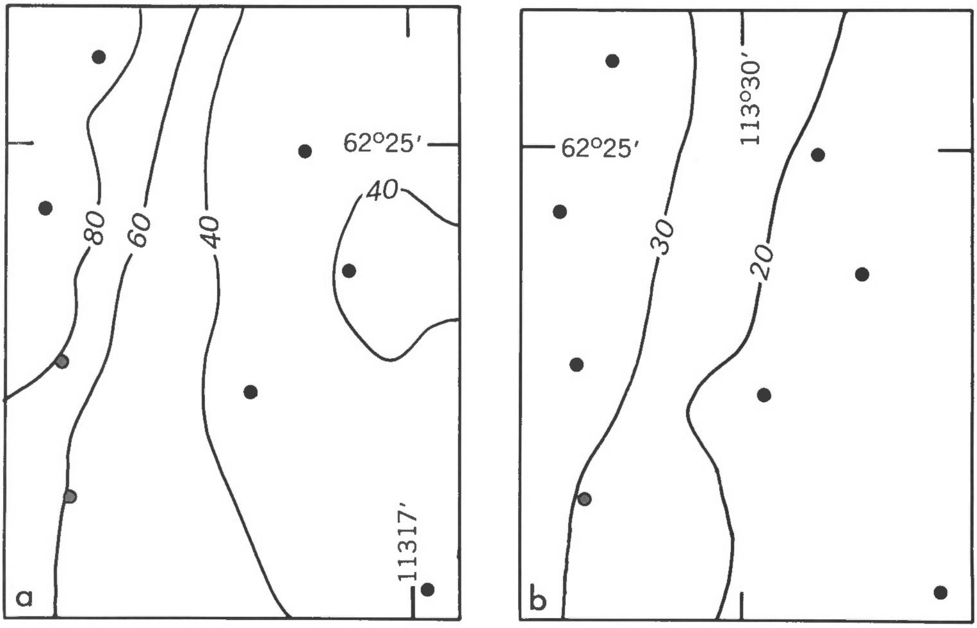
b. Copper in ppm in lake sediment.

c. Copper and <u>zinc</u> in ppb in lake water.

Figure 8. Copper and zinc in lake sediment and lake water, Hackett River, Northwest Territories.

that of black shales (Cameron and Jonasson, 1972) that required a source for the given heavy metal before substantial enrichment was possible. It should not, therefore, be assumed that an anomalous result is false if it happens to occur in an organic-rich sample. The organic matter may enhance the anomaly; it is less likely to have created it.

Organic matter concentrations in the minus 250 mesh sediment have been determined and will be shown on the maps along with the iron and manganese. The user of the map set is thus in a position to reach a judgement on the effect of these components on the distribution of trace elements. Single-point anomalies should be regarded with more caution than coherent, multiple-point anomalies. Ultimately, the most satisfactory way to check doubtful anomalies is to resample the areas in question.



a. Zinc in ppm in lake sediment.
b. Copper in ppm in lake sediment.
(No Copper and zinc concentrations were greater than or equal to 1 ppb in lake water from this area).

Figure 9. Copper and zinc in lake sediment at Harding Lake, N.W.T.

Sorting Effects in Lake Sediments

Another type of environmental process may result in the formation of spurious trace metal anomalies in lake sediments. The processes of sorbtion described above, may cause enhancement of chemically transported elements. Another environmental process, that of sorting and deposition, may affect elements transported mechanically to lakes, as constituents of mineral particles.

Lake sediment, less than 250 mesh, consists of several fractions which may contain trace metals. As mentioned previously, the three main non-particulate components are free iron and manganese oxides and organic material. Chemically transported trace metals are either sorbed or occluded by these components or are sorbed onto or into mineral particles. The remaining and predominant component of the less than 250 mesh material consists of mineral particles.

In the coarse silt fractions (50 to 10µ), particles are mainly monomineralic, either quartz, feldspar, and usually lesser quantities of ferromagnesian minerals, micas and heavy minerals. Particles consisting of several minerals and actual rock fragments, usually occur in surficial sediments in glaciated areas in only the coarser than 50µ mesh material. In the finer silt and clay fractions (less than 10µ) the content of quartz and feldspar usually decreases and the content of primary and secondary layer silicates increases. Heavy minerals are usually only significant in the coarse silt fractions. Ferromagnesian minerals occur in all size ranges. In special situations minerals reflecting special rock types may be present, e.g., dolomite, or minerals of economic elements, e.g. willemite. The latter will probably be present in only small amounts.

From the above, it is clear that variations in the proportions of certain minerals can cause changes in the trace element content of the samples. This is in fact the concept of using the sediments to map the "geology", i.e. mineralogy of an area by analysis of the sediments. Because certain minerals, e.g. ferromagnesian minerals, are more abundant in certain areas, the elements normally found in such minerals will tend to correlate with the geology. Maps for different elements, normally found together in the same mineral, will show a very good spacial correlation.

It is accepted that in lakes, sorting of particle size fractions occurs, and that this could result in variations in the trace element content of the bottom sediment. The greatest variation will be found between sediments deposited in distinctly different parts of the lakes, such as between nearshore, shallow water sediments; lake-centre, deep water sediments, and inflow stream estuary sediments. To minimize chemical variations due to the sorting effect, the samples were: (1) collected in water of 3 to 8 feet depth, which limits the lake bottom environment to shallow water-usually near shore; (2) taken from approximately 2 to 6 inches beneath the surface of the lake bottom; (3) collected where possible from sites containing sediment of silt grade.

By this procedure, the sorting effects and also the effects of possible organic variations with depth in lakes, were kept to a minimum. With this control on the sampling, the major effect on anomalies for elements transported in minerals was considered to be the source of certain minerals in the drainage basin of a lake. It had already been shown (Allan, et al., 1972) by comparing the major and minor element variations in bedrock and and lake sediments from the same areas, that this was true for several divergent geological terrains. However, there is bound to be an influence of sorting on the regional results. In some cases, e.g. very coarse textured sediments, this could dilute anomalies, and in others, e.g., very fine textured sediments, could enhance anomalies, and this concept should be remembered in reviewing the regional results. Areas of coherent anomalies are unlikely to be caused by this effect, although as for uranium and organic matter, relative levels between adjacent sites may be influenced. One-point anomalies should always be treated with caution.

Source Materials in the Drainage Basin.

Following glaciation, the materials in the drainage basin of any lake are likely to comprise (a) bedrock; (b) glacial till ; (c) glaciofluvial deposits. The relative proportions of these materials in each lake basin could affect the resulting composition of the lake sediments. Lakes with sandy beaches, or sandy bottoms were considered to be influenced by primarily glaciolacustrine materials. Such lakes could be distinguished from the helicopters and were avoided by the sample crews. Also, whenever possible lakes selected for sampling had some bedrock in their drainage basin. All possible effort was made to restrict the sample to sediments in lakes which appeared to be in areas of predominantly till or rock outcrop so as to minimize effects due to different source materials in the lake drainage basin.

Geological and Metallogenic Effects

The chemical variation in lake sediments described by the contour maps represents variation in the underlying bedrock and surficial deposits plus the effects of variation within the sediments themselves. From our previous studies it appears that lake sediments are a good composite sample of the surrounding rocks and surficial material. Further, the fine-grained particles can serve as an excellent medium for the sorbtion of trace elements that are dissolved in groundwater during the weathering of nearby ore deposits. In the different areas that we have previously examined within the thinly till covered Bear and Slave Provinces, we have not observed any gross tendency for anomalies to be displaced or obscured as a result of glaciation. The major reason for this is, of course, that the glacial cover is in many places thin and thought to be of local derivation. By selecting such an area we have objectively maximized our chances of success, a procedure not often followed in geochemical operations.

Trace element anomalies shown on the contour maps are likely to be related to one or more of the following features:

1. Bedrock lithology. Trace elements are, commonly, much more abundant in certain rock types than in others. Thus Cu is approximately one order of magnitude greater in amount in basic volcanic rocks than in acid volcanic rocks. This type of variation relates only indirectly to mineral potential.

2. Economic mineralization. Superimposed on the variation due to lithological change is variation caused by the presence of sulphides or other mineralization. Elements present in sulphide masses are likely to be preferentially oxidized and weathered compared to the same elements contained in rock-forming minerals. We have argued elsewhere (Allan, et al., 1972) that if anomalous amounts of ore elements within a given area were confined to one or a few ore deposits, it is improbable that the resulting geochemical signal could be detected at a sample density of one per 10 square miles. For if the dispersion of the ore elements along the drainage system from the deposits is restricted, the resulting anomaly will be too small to be, in most cases, intersected. Alternatively, if the elements become widely dispersed, their signal will be too weak to be detected.

Cameron and Baragar (1971) have suggested that the condition is rare when ore-related mineralization within an area is confined to a few economic-sized deposits. Instead, they have proposed that ore masses are distributed by size in a probabilistic fashion, and that ore bodies are but the upper portion of more extensive populations of ore masses that are truncated by economic, not geological, considerations. These ore populations are continuous through non-economic "showings" to very small masses and grains ("microdeposits"). In terms of mass per cubic mile of rock, these microdeposits and showings probably exceed by many orders the mass of economic ore bodies. It is these widely distributed showings and microdeposits, as well as the ore deposit, that influence the composition of lake sediments for several miles around the deposit and allow such anomalous areas to be detected at a wide sampling interval.

3. Non-economic mineralization. If the above theory is correct, it is apparent that many populations of mineralization may be truncated at a size lower than that necessary for economic extraction. The geochemical anomalies derived from such populations will almost always require much detailed investigation before it can be ascertained whether or not economic mineralization is present.

PROPOSED FOLLOW-UP PROCEDURES IN AREAS OF INTEREST

Office Procedures

1. Examine the geology of the areas in question in order to establish whether the elevated levels simply reflect the geochemical character of particular rock types. Allan, et al. (1972) give the abundance of a number of trace elements in various rock types from the Bear and Slave Provinces (Table 6). Thus if Cu in lake sediments rises to say, 80 ppm, in an area of volcanic rocks this may simply reflect the presence of basic volcanic rocks. However, if it is known that the volcanics are of intermediate to acid composition (which generally contain 5-25 ppm Cu) it is possible that the enhanced levels are, in part, due to mineralization. Even in the absence of specific information on rock type it is possible to use some elements as an indicator of lithology, e.g. Mg, Ca, and then use this information to interpret the nature of an anomaly in another element e.g. Zn or Cu.

2. Having decided that the levels for the particular elements are higher than expected considering the geology, the user should consult the listings that will be provided of organic carbon content. Samples with a high organic content may or may not be spuriously high in certain trace elements. If there are other samples from the nearby region that have a similarly high content of the element of interest, but are not carbon-rich, this may tend to confirm that the high level in the carbon-rich sample is not spurious. Care should be exercised not to reach substantial conclusions on the basis of a few anomalous organic-rich sites. A similar procedure should be employed with samples enriched in free oxides of Mn or Fe.

3. Any existing information from the area-maps, reports, aeromagnetic cover, assessment files – should be studied. It is possible that observations that were previously considered to be of minor importance take on new meaning in the light of a nearby geochemical anomaly. An example of this is, say, minor gossans in a volcanic area. Before a geochemical anomaly was located such minor occurrences might be dismissed as insignficant.

TABLE 6.

ANALYSES OF BEDROCK SAMPLES FROM PILOT STUDY AREAS

	NUMBER OF SAMPLES	ARITHMETIC MEAN	STANDARD DEVIATION	GEOMETRIC MEAN	PERCENTILES													
					2.5	5	10	20	30	40	50	60	70	80	90	95	97.5	99
ZINC																		
HIGH LAKE, ALL SAMPLES	94	247.4	159.4	74.2	25	31	41	48	56	64	70	80	83	41	142	129	656	15500
HIGH LAKE, BASIC	22	85.6	36.2	80.1	45	45	55	67	70	75	80	81	83	102	182	190	190	190
HIGH LAKE, INTERMEDIATE	54	71.4	80.0	65.8	23	31	42	52	57	62	88	78	81	87	100	142	192	192
HIGH LAKE, ACID	16	1037.4	3857.3	80.5	24	25	31	37	46	47	52	70	82	142	307	15500	15500	15500
HIGH LAKE, TRAVERSE C1-C2	57	364.1	2042.7	81.4	25	31	37	46	55	69	78	81	89	102	190	307	15500	15500
HIGH LAKE, TRAVERSE C3	37	67.6	19.6	64.2	28	43	47	52	57	62	68	75	80	85	92	101	107	107
HACKETT RIVER, ALL SAMPLES	37	67.7	83.3	42.1	7	9	11	23	28	34	43	53	60	101	146	370	370	370
INDIN LAKE, ALL VOLCANICS	109	44.4	31.5	33.4	5	9	11	17	23	30	38	46	50	76	93	103	111	161
INDIN LAKE, BASIC	55	48.2	31.4	39.8	14	15	17	23	29	32	42	49	56	77	98	105	161	161
INDIN LAKE, INTERMEDIATE	21	50.4	33.4	38.4	12	12	13	18	24	30	50	70	83	91	96	100	100	100
INDIN LAKE, ACID	31	32.3	27.7	21.4	3	4	5	9	11	17	32	38	46	49	89	94	111	111
INDIN LAKE, SEDIMENTS	81	78.2	14.8	76.4	56	58	61	67	70	75	81	84	87	91	90	99	102	112
INDIN LAKE, GRANITES	5	66.8	14.7	65.5	47	47	47	62	63	63	77	77	77	85	85	85	85	85
BODE LAKE, ALL SAMPLES	57	82.9	25.4	79.8	54	56	64	67	70	75	79	83	88	93	105	156	172	172
TERRA MINE, ALL SAMPLES	65	117.7	163.3	74.0	20	21	30	30	43	51	72	86	103	146	273	383	787	1004
COPPER																		
HIGH LAKE, ALL SAMPLES	94	71.0	125.1	33.1	3	4	5	14	25	33	37	44	58	76	174	404	544	840
HIGH LAKE, BASIC	22	73.4	99.0	40.6	5	5	8	23	34	37	44	61	65	98	181	462	462	462
HIGH LAKE, INTERMEDIATE	54	62.9	123.2	31.6	3	4	5	18	28	33	39	43	50	60	83	183	840	840
HIGH LAKE, ACID	16	72.1	134.5	25.0	3	3	5	6	12	14	30	43	61	101	182	544	544	544
HIGH LAKE, TRAVERSE C1-C2	57	87.2	156.4	32.0	3	3	4	6	18	29	39	46	62	93	183	481	840	840
HIGH LAKE, TRAVERSE C3	37	46.0	36.3	35.0	3	8	12	28	31	33	37	43	51	61	79	169	174	174
HACKETT RIVER, ALL SAMPLES	37	28.4	29.7	17.1	3	3	4	5	7	16	23	35	40	47	59	63	163	163
INDIN LAKE, ALL VOLCANICS	109	57.6	58.4	24.6	2	2	3	3	8	18	42	65	88	109	138	160	170	280
INDIN LAKE, BASIC	55	98.2	52.6	80.8	6	29	42	57	78	85	93	107	118	138	160	170	280	280
INDIN LAKE, INTERMEDIATE	21	28.0	31.1	10.3	2	2	3	3	3	3	16	23	31	36	84	127	127	127
INDIN LAKE, ACID	31	6.7	6.2	5.0	2	2	3	3	3	3	4	5	8	12	15	18	30	30
INDIN LAKE, SEDIMENTS	81	42.2	25.9	34.8	9	12	17	21	27	31	35	41	50	67	83	04	113	115
INDIN LAKE, GRANITES	5	24.2	13.3	21.1	10	10	10	13	24	24	32	32	42	42	42	42	42	42
BODE LAKE, ALL SAMPLES	57	16.3	60.8	5.8	1	1	2	2	3	3	4	6	9	10	31	35	462	462
TERRA MINE, ALL SAMPLES	65	89.6	247.4	10.7	1	1	1	1	3	6	7	13	30	92	282	824	919	1522
LEAD																		
HIGH LAKE, ALL SAMPLES	94	21.1	70.8	11.2	4	4	4	7	8	9	11	12	14	18	24	42	87	687
HIGH LAKE, BASIC	22	14.7	8.7	12.7	7	7	7	7	11	12	14	15	18	18	32	42	42	42
HIGH LAKE, INTERMEDIATE	54	13.6	14.7	10.3	4	4	4	7	8	9	10	11	13	16	21	36	87	8
HIGH LAKE, ACID	16	55.1	169.4	11.7	4	4	4	4	8	8	9	10	11	18	75	687	687	687
HIGH LAKE, TRAVERSE C1-C2	57	30.1	90.0	16.0	7	7	8	10	11	12	14	16	18	21	36	75	647	687
HIGH LAKE, TRAVERSE C3	37	7.2	3.1	6.5	4	4	4	4	4	7	7	8	9	10	12	14	14	14
HACKETT RIVER, ALL SAMPLES	37	15.0	20.5	10.5	4	4	4	7	8	9	11	11	13	14	31	55	122	122
INDIN LAKE, ALL VOLCANICS	109	8.2	4.6	7.2	4	4	4	4	4	7	7	8	10	11	16	18	20	25
INDIN LAKE, BASIC	55	8.8	4.9	7.6	4	4	4	4	6	7	8	9	10	12	18	18	25	25
INDIN LAKE, INTERMEDIATE	21	8.0	4.0	7.1	4	4	4	4	4	7	8	9	11	12	16	16	16	16
INDIN LAKE, ACID	31	7.5	4.6	6.5	4	4	4	4	4	4	7	8	8	10	14	18	23	23
INDIN LAKE, ALL SAMPLES	81	13.6	4.1	12.9	8	8	9	10	12	12	13	15	15	17	18	20	26	27
INDIN LAKE, GRANITES	5	11.2	4.1	10.3	4	4	4	12	13	13	13	13	13	14	14	14	14	14
BODE LAKE, ALL SAMPLES	57	16.4	10.0	14.6	8	9	9	11	12	13	14	15	16	20	25	32	69	69
TERRA MINE, ALL SAMPLES	65	27.2	67.0	15.7	8	8	8	10	12	13	13	14	15	20	49	75	184	522
MERCURY																		
HIGH LAKE, ALL SAMPLES	94	20.8	57.6	9.7	2	2	5	5	6	7	10	12	14	15	25	56	310	458
HIGH LAKE, BASIC	22	15.9	29.6	8.5	2	2	2	5	6	7	9	10	12	15	43	143	143	143
HIGH LAKE, INTERMEDIATE	54	11.0	7.1	9.3	2	5	5	5	6	7	10	12	14	15	17	19	47	47
HIGH LAKE, ACID	16	41.3	112.7	10.2	2	5	5	5	5	6	6	8	9	56	67	458	458	458
HIGH LAKE, TRAVERSE C1-C2	57	26.4	73.6	8.7	2	2	4	5	5	6	7	7	10	17	47	143	458	458
HIGH LAKE, TRAVERSE C3	37	12.2	3.5	11.6	5	6	6	10	12	12	13	14	14	15	16	17	19	19
HACKETT RIVER, ALL SAMPLES	37	17.5	18.6	14.6	9	10	10	12	12	13	14	14	15	16	29	45	120	120
INDIN LAKE, ALL VOLCANICS	109	10.5	5.9	9.2	2	5	5	6	7	8	10	11	12	14	16	17	32	38
INDIN LAKE, BASIC	55	3.5	5.9	7.4	2	5	5	5	6	7	8	8	9	10	12	17	38	38
INDIN LAKE, INTERMEDIATE	21	12.3	6.9	11.1	6	6	6	7	10	10	12	12	15	16	16	38	38	38
INDIN LAKE, ACID	31	13.3	2.7	13.0	8	10	11	11	12	13	14	14	14	15	17	17	22	22
INDIN LAKE, SEDIMENTS	81	10.3	3.7	9.8	5	6	7	8	9	9	10	10	11	12	14	15	21	30
INDIN LAKE, GRANITES	5	4.0	2.8	3.3	2	2	2	2	2	2	6	6	6	8	8	8	8	8
BODE LAKE, ALL SAMPLES	57	6.0	2.0	5.6	2	2	4	5	5	5	6	7	7	7	9	10	10	10
TERRA MINE, ALL SAMPLES	65	7.4	2.7	6.9	2	4	4	5	6	7	7	8	8	9	10	13	16	17
ARSENIC																		
HIGH LAKE, ALL SAMPLES	94	5.5	7.9	3.8	3	3	3	3	3	3	3	3	3	3	10	30	40	40
HIGH LAKE, BASIC	22	5.0	6.2	3.8	3	3	3	3	3	3	3	3	3	5	15	30	30	30
HIGH LAKE, INTERMEDIATE	54	4.7	7.1	3.5	3	3	3	3	3	3	3	3	3	3	5	10	40	40
HIGH LAKE, ACID	16	6.9	8.5	4.7	3	3	3	3	3	3	3	3	5	15	15	35	35	35
HIGH LAKE, TRAVERSE C1-C2	57	6.3	8.8	4.2	3	3	3	3	3	3	3	3	3	5	15	35	40	40
HIGH LAKE, TRAVERSE C3	37	4.3	6.2	3.4	3	3	3	3	3	3	3	3	3	3	3	10	40	40
HACKETT RIVER, ALL SAMPLES	37	4.9	11.0	3.3	3	3	3	3	3	3	3	3	3	3	3	5	70	70
INDIN LAKE, ALL VOLCANICS	109	3.8	3.6	3.3	3	3	3	3	3	3	3	3	3	3	3	15	15	30
INDIN LAKE, BASIC	55	4.0	4.5	3.3	3	3	3	3	3	3	3	3	3	3	3	15	30	30
INDIN LAKE, INTERMEDIATE	21	3.9	3.0	3.4	3	3	3	3	3	3	3	3	3	3	10	15	15	15
INDIN LAKE, ACID	31	3.5	2.2	3.2	3	3	3	3	3	3	3	3	3	3	3	5	15	15
INDIN LAKE, SEDIMENTS	81	16.9	11.7	12.4	3	3	3	5	10	10	15	20	20	30	30	40	45	50
INDIN LAKE, GRANITES	5	3.4	0.9	3.3	3	3	3	3	3	3	3	3	3	5	5	5	5	5
BODE LAKE, ALL SAMPLES	57	3.1	0.4	3.0	3	3	3	3	3	3	3	3	3	3	3	3	6	6
TERRA MINE, ALL SAMPLES	65	6.2	9.1	4.1	3	3	3	3	3	3	3	3	3	5	25	30	40	45

Field Procedures

A possible approach to field follow-up is as follows:

1. The geology of the area should be re-examined. At the scale of most mapping in the Bear and Slave Provinces, the detailed geology may be substantially modified from that shown on present maps. Areas mapped as one rock type may actually contain a variety of lithologies. An example of this, discussed earlier, is the presence of acid volcanic units within areas defined as Yellowknife Supergroup sediments at Hackett River. While the geology is being re-examined, sufficient representative samples of the different rock units should be collected to allow the background level of the element or elements of interest to be determined for these units. As mentioned above many anomalies may be caused by a high content of a metal in a rock unit that is unrelated to a population of ore mineralization. As a rough and ready rule a fairly uniform content of a trace element in different rock samples from a particular unit generally indicates that this content is not related to ore mineralization. Highly variable contents of metal from sample to sample and average abundances greater than normal for that rock type are more likely to be associated with ore mineralization.

2. Systematic, detailed resampling should initially be confined to lake sediments. The area covered should be 50-100 % larger than the anomalous area. This approach is suggested since we have observed in a number of cases, e.g. at Hackett River (Fig. 6), that an ore deposit lies at, or somewhat beyond, the margin of the anomaly, perhaps at a geological contact. Sampling should be done at a density close to one site per square mile. Thus for an original 200-square mile anomaly, 300-400 samples are required. This will entail less than one week's work with one helicopter. Arrangements should be made to obtain the analytical information as soon as possible after sampling, to allow the desirability of further follow-up work to be assessed. At this stage analyses are perhaps required for only one or two critical elements. These analyses may be done in the field or in a small trailer laboratory flown to the nearest airstrip.

3. If there are encouraging results from step (2) above, more detailed geological, geochemical and geophysical work should be carried out in the vicinity of the best geochemical anomalies. For suspected base metal deposits, an airborne electromagnetic survey covering major anomalies and adjacent areas may be carried out at this stage. For all deposit types, this stage may also involve making a more detailed geological appraisal and collecting a number of samples from rock units near anomalous lakes. This work should define the essential trend of mineralization and allow for planning of very detailed geological mapping, stream, soil and basal-till geochemical sampling, and if relevant to the deposit type, ground geophysical measurements. If used, the latter should include seismic and resistivity measurements of conductors in an attempt to avoid drilling of overburden anomalies.

It should be kept in mind that the geochemical anomalies produced regionally in lakes and discovered by use of this sample media, are largely a result of trace element leaching from sub-outcropping and near surface rock and thawed zones in permafrost. In anomalous areas, there may well be ore grade and ore size deposits, that occur at considerable depth in the bedrock.

First order electromagnetic conductors in or near such surface geochemical anomalies are more likely to represent such geochemically blind ore deposits than conductors outside regional geochemical anomalies. In detail this may result in the follow-up of a good conductor in the vicinity of a highly anomalous lake, although the lake shows no obvious directional variation in trace element content. Also, geophysical anomalies within small highly anomalous areas should be treated as prime targets even if in themselves they have no geochemical expression. They should be considered to be of secondary importance only to coincident geophysical-geochemical anomalies.

COSTS OF THE BEAR-SLAVE OPERATION

Introduction

The cost of the operation consists of the following items:

1. Pre-season costs - e.g. fuel caching.
2. Field operation costs.
3. Analytical costs.
4. Interpretation Costs - e.g. computing, preparing publications.
5. Overhead Costs, e.g. the office and laboratory space used by personnel.

The first three items are the major expenditures of the operation and are relatively easy to cost. They are discussed below. The latter two items are more difficult to estimate, since prior to and following the field season, personnel and facilities are being employed on other duties in addition to Operation Bear-Slave. Further, overhead costs will vary widely from organization to organization, and many of those incurred will not be absolutely necessary to perform an operation of this type.

Pre-field costs

Aviation gas purchase	$ 15,500
Caching of fuel and camp equipment	22,000

Field costs

Helicopter contract	84,000
DHC3 Otter contract	29,000
Casual aircraft charter for camp moves	6,500
Costs of travel to field location by personnel plus board at camp for 18 men	9,000
Amortization of E.M.R. field equipment at 20% per year	6,000
Salaries of all permanent and casual employees for period of three months	24,000
TOTAL pre-season and field costs	$ 196,000

During the operation 4102 lake sediments and 4102 lake waters were collected. The direct sampling costs per site at two samples per site are therefore $48. At the sample density employed this amounts to a cost of approximately $5 per square mile.

Analytical Costs

The direct costs to the Geological Survey of Canada for sample preparation and analysis for 23 elements in sediments and 4 in waters is about $25.00 per site this includes salaries for analysts, and cost of supplies, with a contribution for amortization of equipment. It must be emphasized that this does not include other overhead costs. Comparative commercial costs for sample preparation (to minus 250 mesh) plus the analytical costs for the elements determined could be provided by geochemical service companies.

The inhouse cost per square mile is then $2.50 for sample preparation and analysis and the total cost per square mile for collection, preparation, and analysis is $7.50. The average unit cost per element at the stated sample density is thus approximately 30 cents per square mile.

ACKNOWLEDGMENTS

Eighteen personnel were involved in the field operations including the authors of this report. Logistics, organization, equipment, administration and supervision of all field operations were the responsibility of the three authors. R.J. Allan, Operation Chief and E.M. Cameron, Head Geochemistry Section were responsible for all major decisions and overall general logistics and organization of the operation both in the field and in Ottawa. C.C. Durham supervised the pre-season caching of gas and equipment, organized the summer field equipment, and acted as deputy chief on the field operation. In the field, all aspects of the operation were organized and supervised by one or other of the authors.

The writers would like to thank all people involved in the field operation (Table 3) for an excellent job. The degree of interest and the quality and quantity of the work put into this operation by all members of the field crew as far in excess of what can normally be expected. The team effort which developed during the season was one of the major reasons for the unexpectedly rapid completion of the survey.

The authors also wish to thank several people in Yellowknife who contributed significantly to the early completion of the operation. Mr. N. Murphy, Base Manager, Gateway Aviation, Yellowknife was as we have found in previous years, extremely helpful in storing our equipment, providing us with extra airplanes on short notice, and doing small expediting services for us which made the season all the easier and more enjoyable. Most of the Gateway pilots flew for us at some time during the summer and thanks are due to them all. Also, in Yellowknife, Mr. R. Hornal, Resident Geologist, Department of Indian Affairs and Northern Development, was, as in other years, our official-unofficial expediter. This service involved a lot of work and all of us out in the field fully appreciated every effort made on our behalf. Mr. Hornal was also our main radio contact in Yellowknife although we were also in contact with Mr. Murphy, at the Gateway Base.

Mr. F. Dornan, Manager, and Mr. R. Parsons, Bristol Freighter Pilot, Wardair Ltd., are to be thanked for their efforts in caching our gasoline and equipment during the winter. During the pre-season period, numerous discussions by phone with Mr. C.B. Brown of Precambrian Mining Services Limited, were of great help to us in our planning of the operation. Others in Yellowknife were M. Braden, T. O'Farrell and B. Weaver. We wish to thank Mr. F. Benoit whose culinary skills raised and maintained a high morale in the camps throughout the summer.

The men who deserve our praise most were the four pilots (Table 3) who were directly involved in the operation. We can only say their effort was excellent.

The complete sample preparation and analytical procedures for all sample types was under the overall supervision of J.J. Lynch, Chief Analyst, Geochemistry Section. The direct reading spectrometer analyses, using the methods developed by M. Timperley, were under the supervision of R.W. Horton. Sample preparation was under the supervision of P. Lavergne.

The authors fully realize that the development of analytical techniques and the volume of routine analyses are parts of this operation of great importance. The authors wish to thank all persons involved in any aspect of the sample preparation and analyses (Table 5) for an excellent effort. Early release of the results from this type of operation is very dependent on the organization of the routine analyses of thousands of samples. In detail individual duties are given in Table 5.

The GPCP program required several modifications prior to being routinely used to draw the contour maps. Thanks are due to I. Crane who made these modifications to suit our publication purposes. Before paper tape output from the direct reading spectrometer could be used to produce maps, it had to be transferred to magnetic tape. This operation turned out to be far more complicated than first anticipated and we would like to thank R.G. Garrett for solving this problem. The day to day running of data lists and contour maps for different elements is being carried out by D. Hobbs.

Pierre Debain and his colleagues in the Cartographic Services Unit of the Geological Survey of Canada have been resourceful and have been patient to our many requests during preparation of the geochemical maps.

J.C. McGlynn made available a compilation map of the Bear and Slave provinces, which was used as a geological base for the geochemical maps. Both he and R. Thorpe have freely added to our knowledge of the geology of this part of the Shield. J.C. McGlynn, A.G. Darnley, and W.W. Shilts have offered helpful comment on this manuscript.

Finally, our personal thanks to those persons who have encouraged and supported us in this rather different approach to the study of the Canadian Shield. By doing so they have made the operation possible.

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Appendix 1

Photographs of the Bear-Slave Operation.

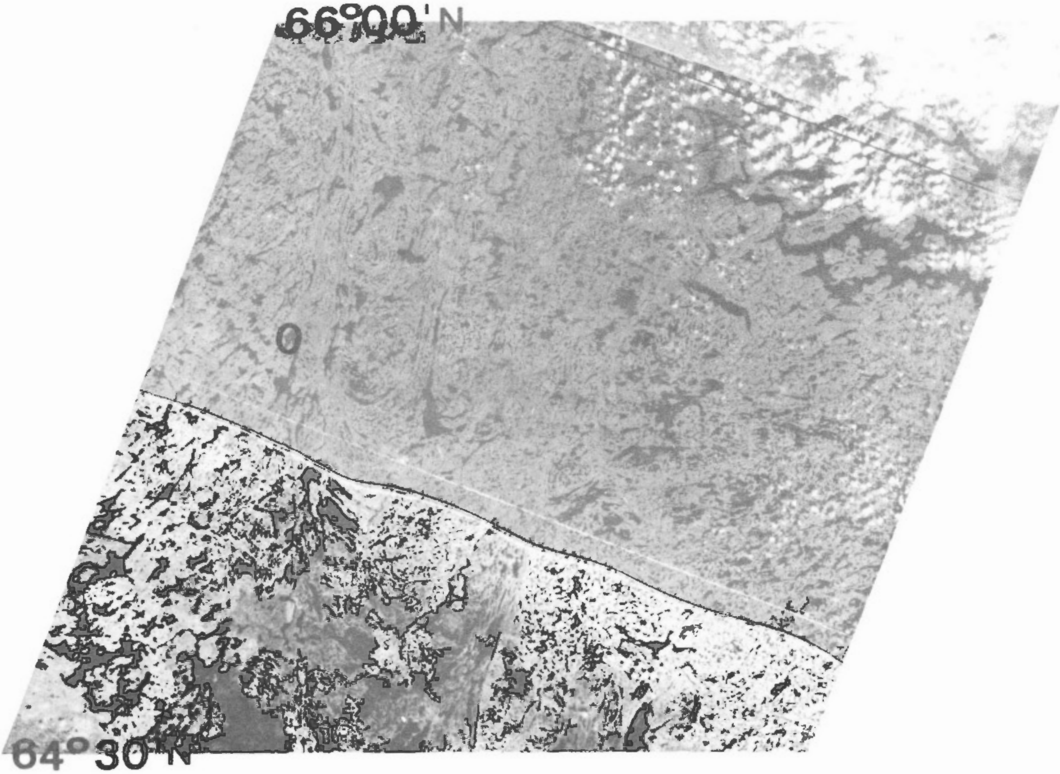

Plate 1. ERTS satellite view of the Sheet 1 area. Camp 1 is located on the photo as a black circle at the north end of Wopmay Lake. Exmouth Lake can be seen due east of Wopmay Lake. The Wopmay Fault zone is clearly seen.

Plate 2. A typical base camp - Camp 2.

a. Base camp from the air.

b. Helicopter landing pads.

GSC Photos 202132 A, B

Plate 3. Sampling near shore lake sediment from the Bell G4A helicopter. GSC Photo 202132C.

Appendix 2

List of Geological and Aeromagnetic Maps Published by the Geological Survey of Canada, relating to the Bear-Slave Operation Survey area.

(1) BEDROCK GEOLOGICAL COVERAGE

(a) G.S.C. Papers with maps:

63-26	Arseno Lake	McGlynn, 1963
63-40	Northeastern District of Mackenzie	Fraser, 1964
65-21	Contwoyto Lake	Tremblay, 1966
66-28	Contwoyto Lake	Tremblay, 1967
66-24	Itchen Lake, District of Mackenzie	Bostock, 1967
49-10	Indin Lake	Fortier, 1949
*41-2	Great Slave Lake to Great Bear Lake	Bulkwill, 1941

(b) G.S.C. Maps (only)

18-1960	N. Central District of Mackenzie	Craig *et al.*, 1960
*296A	Great Bear Lake, McTavish Arm	Kidd, 1933
332A	Rae-Great Bear Lake Centre Sheet	Kidd, 1936
*333A	Rae-Great Bear Lake North	Kidd, 1939
977A	Lac De Gras	Folinsbee, 1949
1014A	Camsell River	Lord and Parsons, 1952
1031A	Aylmer Lake	Lord and Parsons, 1950
1173A	Mesa Lake (in G.S.C. 124)	Ross, 1965
1216A	Southeastern Barren Grounds	Lord, Wright *et al.*, 1967
1219A	Winter Lake, District of Mackenzie	Fraser, 1968
1224A	Hardisty Lake W 1/2,	Fraser, 1967

* Out of Print

(2) AEROMAGNETIC COVERAGE

(a) G.S.C. Map Nos.

2914G to 2925G
3025G to 3078G
3615G to 3617G
3608G to 3610G
3601G to 3603G
3594G to 3596G
3587G to 3589G
3580G to 3582G

Appendix 3

A SELECTED BIBLIOGRAPHY

This selected bibliography has been compiled from the reference list of the following seven papers because all deal with aspects of the overall reasons for the use of and results obtained by the lake sampling method. This list is then one of references many of which are important in understanding the basic philosophies and scientific hypotheses that are involved in the detection of ore deposits by regional geochemistry, and in the way in which elements may be released and transported from rocks and ores in permafrost areas, and the resulting concentrations derived in lakes. The references are then included here as one readily available list for the map users.

1. Allan, R. J.
   Lake sediment: A medium for regional geochemical exploration of the Canadian Shield.

2. Allan, R. J., Cameron, E. M., and Durham, C. C.
   Lake Geochemistry - A low sample density technique for reconnaissance geochemical exploration and mapping of the Canadian Shield.

3. Boyle, R. W., Hornbrook, E. H. W., Allan, R. J., Dyck, W., and Smith, A. Y.
   Hydrogeochemical methods-application in the Canadian Shield.

4. Cameron, E. M., and Baragar, W. R. A.
   Distribution of ore elements in rocks for evaluating ore potential: Frequency distribution of copper in the Coppermine River Group and Yellowknife Group Volcanic Rocks, N. W. T., Canada.

5. Cameron, E. M., Siddeley, G., and Durham, C. C.
   Distribution of ore elements in rocks for evaluating ore potential: nickel, copper, cobalt and sulphur in ultramafic rocks of the Canadian Shield.

6. Dyck, W., Dass, A. S., Durham, C. C., Hobbs, J. D., Pelchat, J. C., and Galbraith, J. H.
   Comparison of regional geochemical uranium exploration methods in the Beaverlodge area, Saskatchewan.

7. Jonasson, I. R., and Allan, R. J.
   Snow - a sampling medium in hydrogeochemical prospecting in temperate and permafrost regions.

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