GEOLOGICAL
SURVEY
OF
CANADA

DEPARTMENT OF ENERGY,
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REGIONAL GEOCHEMICAL EXPLORATION IN
THE COPPERMINE RIVER AREA, DISTRICT
OF MACKENZIE; A FEASIBILITY STUDY
IN PERMAFROST TERRAIN

(Report, 6 tables and 17 figures)

R. J. Allan; and (in part) J. J. Lynch and N. G. Lund

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."The regional use of geochemistry has the advantage that it is not necessary to know in detail the process by which the metals are dispersed. The object is merely to establish areas of interest, in contrast to detailed investigation which aims at delineating ore."

(Bolviken, 1967, Geological Survey of Norway)

CONTENTS

Illustrations

LEGEND

N = NORWAY
F = FINLAND
S = SWEDEN

90°E

U.S.S.R.

(NOVAYA ZEMLYA)

F
N S

ARCTIC

N (SPITSBERGEN)

180°

NORTH POLE

0°

OCEAN

ARCTIC CIRCLE

U.S.A.

DENMARK
(GREENLAND)

CANADA

90°W

117°00'W

116°00'W

115°00'W

RICHARDSON RIVER

COPPERMINE

OVERLYING ROCKS

BASALT GROUP

86-N-9

86-O-12

67°45'N

DRAINAGE DIVIDE

BOUNDARY OF REGIONAL GEOCHEMICAL SURVEY

NORTH

67°30'N

Dismal

86-N-7

Lake

86-N-8

COPPERMINE RIVER

86-O-5

GEOLOGICAL BOUNDARY

BASALT GROUP

67°15'N

LEGEND

COPPER CONCENTRATION GREATER THAN 100ppm; HOT HNO$_3$ LEACH OF LAKE BOTTOM SEDIMENTS

86-N-1

86-O-4

SCALE
0   4   8
MILES

UNDERLYING ROCKS

Figure 1.   Location map showing generalized geology, area surveyed, and anomalous copper zone located by regional geochemical exploration, Coppermine River area, Canada.

REGIONAL GEOCHEMICAL EXPLORATION IN THE
COPPERMINE RIVER AREA, DISTRICT OF MACKENZIE;
A FEASIBILITY STUDY IN PERMAFROST TERRAIN

INTRODUCTION

Canada has more fresh water lakes than any other area of comparable size in the world. This is particularly true of the low-lying, glaciated, Precambrian Shield. Two-thirds of the Canadian Shield are underlain by permafrost; an area where lakes typically occur as part of a complicated, extremely disorganized drainage system. As part of this system, lakes provide sample media in the form of their sediments and waters that are representative of the final products of weathering and leaching processes. Such samples by virtue of their origin, in many instances represent nature's average of the overall trace element content of the rocks and drift in each lake drainage basin, as do stream sediments and waters for smaller areas in other geological regions of Canada.

During the summer of 1970, the Geological Survey of Canada carried out helicopter-supported regional and detailed lake sediment and water sampling programs over a 1,500-square-mile area of the Coppermine River basalts. The survey extended over the geographic centre of the basalt belt and adjacent overlying and underlying sediments.

The Coppermine area (Fig. 1) is situated near the centre of the northern coast of North America. As early as two hundred years ago, tales of copper occurrences had drawn explorers to this area. In the late 18th century the prospectors were Hudson's Bay Company employees such as Richard Norton and Samuel Hearne. In the early 19th century the rock types were surprisingly well documented by Dr. Richardson, a member of Sir John Franklin's first Arctic expedition. Much later, in the early 20th century, several companies sporadically and unsuccessfully explored the Coppermine area. The year 1967 saw the greatest ever staking rush in the Northwest Territories. At the end of the claim rush, much of the land under and adjacent to the Coppermine basalts was held by mining and exploration companies.

Other than some detailed uses of soil geochemistry during the late sixties on some of the smaller claim blocks and a pilot study by the Geological Survey of Canada (Allan and Hornbrook, 1970), geochemical exploration methods have never been extensively employed in the Coppermine area. The study described here was the first regional geochemical survey undertaken.

Exploration of the Coppermine area has passed through several stages. Pre- and early 20th century work simply involved surface examination of some of the showings. In the 1960's following considerable ground geophysics, an aeromagnetic survey was made and soon a few companies were using several geophysical exploration methods. Selection of drill targets in the late 1960's was based on all previous techniques and often included combinations of a suitable showing, structure, aeromagnetic, E.M. and I.P. anomalies. Ground I.P. surveys were carried out extensively on the major fault systems but by

R. J. Allan and J. J. Lynch: Geological Survey of Canada, Ottawa.
N. G. Lund: Graduate Student, Carleton University, Ottawa.

1970 the only significant mineral occurrence was still the 47-zone of the Coppermine River Company. The surface expression of this deposit is in the form of minor copper minerals and staining and there was no specific geophysical reason which separated it from any of the other essentially barren anomalies that were previously drilled at great expense. The high costs of airborne and ground geophysics, coupled with expensive diamond drilling of numerous barren anomalies, did not result in the discovery of other significant ore occurrences but did result in the virtual termination of exploration in the area by 1970. It was in the previous year the Geological Survey of Canada carried out a pilot geochemistry study (Hornbrook and Allan, 1970). Total abandonment of the Coppermine area by industry was complete by 1970 when the regional geochemical exploration survey described herein was carried out. A previously untested regional geochemical exploration method for Cu employing lake sediment and water as the sample media was applied to the central part of the Coppermine basalts (Fig. 1), during late June, July, August and early September of 1970.

The objectives of the detailed studies were to determine the following: the degree of dispersion by streams of copper from a known significant mineral deposit; the variation in copper concentration in lake water with position in the lake; the variation in copper concentration in lake water during the sampling season; and the variation in copper concentration in lake sediment with sample site location in the lake. These objectives were to apply to both lakes selected for detailed studies and to any anomalous lakes located in the regional study. The objectives of the regional study were: to determine the sample density necessary to outline the copper-rich basalt group; to determine the sample density necessary to outline, within this group, members or areas of members with the greater copper mineralization; to determine the optimum sample density for this geological environment, i.e., that density which provides the greatest return of information for exploration expenditure; to show the position of structures favourable for exploration; to evaluate the potential of known mineral occurrences; and finally to evaluate the geochemical expression of mineralization in those areas where considerable unsuccessful diamond drilling had been recommended on the basis of geological and geophysical information.

The area is underlain by the Coppermine Group, a gently dipping Proterozoic sequence of basaltic flows and interlayered red sediments. The stratigraphy and petrology of the basalts has been described by Baragar (1969)[1]. The basalts contain a number of copper prospects, commonly in faults, veins or fractures. Kindle (1970) listed fourteen classes of mineral deposits in the Coppermine River area four of which he considered to be syngenetic and the remaining ten epigenetic. The copper is mainly present as chalcocite, bornite, chalcopyrite, and native copper with some secondary copper minerals near the surface. The area has been extensively glaciated but from observation

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[1] Throughout this paper the basalts are referred to as lower, middle and upper members, as described by Baragar (1969). However, the upper and middle members have now been combined (Baragar and Donaldson, 1972 (in press)). The lower member remains unchanged. The two new members, upper and lower are collectively referred to as the Copper Creek Formation. The overlying basalts and red beds form the Husky Creek Formation. These two formations comprise the Coppermine River Group.

in the area in 1969 and 1970 and from several pits dug at the 47-zone Cu
deposit most of the till does not appear to have travelled far and may be pre-
dominantly local in origin. The area is a cold desert, underlain by perma-
frost and has many cryologic phenomena, such as felsenmeers, frost boils
and solifluction lobes.

As a study site to assess the effectiveness of regional geochemical
exploration in permafrost areas, it was considered ideal for several reasons:

(1) the geology had been mapped by the Geological Survey of Canada at a
reconnaissance scale of 4 miles to the inch (Baragar, 1969) and several
company maps were available at a scale of 1,000 feet to the inch;

(2) the occurrence and type of mineral showings were documented and
locations of showings were made available prior to the survey (Kindle,
1970);

(3) detailed reports on the exploration programs of the companies involved
in the Coppermine area between 1966 and 1968 were available before
the survey was carried out;

(4) a glacial geology map of sheets 86 N/7, 86 N/8 and 86 O/5 was drawn
from aerial photographs and was made available by the Terrain
Sciences Division of the Geological Survey;

(5) there was documented evidence as to the general vertical distribution
of copper in the volcanic pile (Baragar, 1969) and an assessment of the
ore potential of the separate basalt members had been presented
(Cameron and Baragar, 1970);

(6) a pilot study in 1969 had shown regional variation in copper concentra-
tion for water from 25 lakes (Hornbrook and Allan, 1970);

(7) there were more than enough lakes in the area to carry the regional
sample density down to a scale of greater than one site per square mile
if necessary. (In fact, randomly selected areas show that lake samp-
ling at a density of one site per 10 square miles (Fig. 2) is feasible for
most of the Canadian Shield);

(8) an aeromagnetic map of the area was available (Lockwood Surveys Ltd.);

(9) permission to use the Hope Lake Mining Camp of the Coppermine River
Ltd., located almost in the centre of the widest part of the basalt belt
meant that an equipped field laboratory could be established;

(10) a rapid field analytical method to determine copper in lake and stream
water and sediment had been tested in some detail at the Geological
Survey.

ACKNOWLEDGMENTS
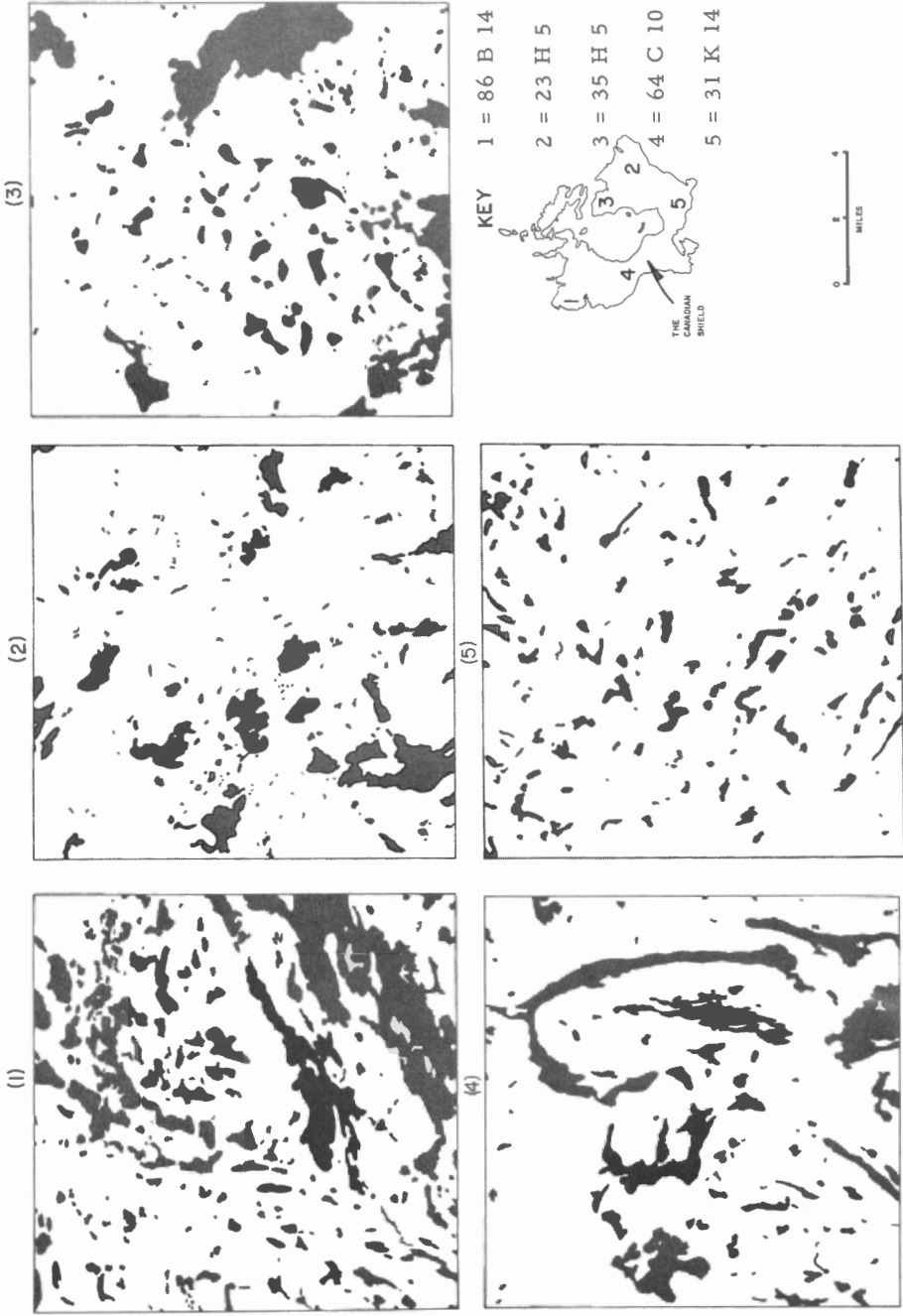
Figure 2. Lake densities in five randomly selected, 100-square-mile areas of the Canadian Shield (lakes are black).

KEY 1 = 86 B 14
     2 = 23 H 5
     3 = 35 H 5
     4 = 64 C 10
     5 = 31 K 14

Coppermine River Company Ltd., and in particular Mr. P. Taylor,
Vice-President, Newconex, who arranged for our use of the Hope Lake
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R. J. Allan designed the regional and detailed studies, organized and
supervised the overall program, collected regional samples, drafted dia-
grams and wrote the report; N. G. Lund organized the field laboratory, was
responsible for the field analyses, helped to organize the detailed program,
collected detailed samples and drafted diagrams; J. J. Lynch supervised the
analyses carried out in Ottawa, and designed and tested the field analytical
methods.

ESTIMATED COSTS OF THE SURVEY AND HELICOPTER EFFICIENCY

The total cost of the regional and detailed survey was $30,000, excluding
salaries, analytical costs and computer services in Ottawa. Field operations
stretched over a period of twelve weeks so that variations in Cu content of
waters could be monitored over the summer season. The time taken to col-
lect the regional samples is best estimated from the helicopter hours used.
When the helicopter was operating, regional sampling was carrried out
extremely efficiently. The rate of sampling in the regional program was
roughly the same at all site densities from more than one site per square mile
up to one site per twenty-five square miles. This was because the time taken
to fly between sites was nominal compared with that spent in landing, taking
off and on the ground at the site (Table 1). However, time on the ground at a
site was usually less than five minutes and the helicopter was therefore never
shut down. One water and one sediment sample per site were collected in a
time of ten minutes. This ten minutes includes five minutes of helicopter
time on the ground at the site. At a cost of $120 per hour for the helicopter,
the cost is approximately $20 per site. By choosing a sample density,
ascertaining support costs, commercial analytical costs, and adding the
salaries of the field crew, one can arrive at a cost for covering a given area.
For example, as will be shown later, the optimum sample density for the
exploration geochemical survey of the Coppermine area was found to be about
one site per ten square miles. At one site per ten square miles, the cost of
sampling such an area of 1,000 square miles by helicopter is $2,000 or $2
per square mile. This density and the resulting information on surficial Cu
distribution rapidly eliminates some 80 per cent of the area as unfavourable.
The time needed to collect samples from these 100 sites would be 30 hours
of helicopter flying or 3 to 4 days. The resulting samples could be analyzed
in the field in 4 man-days. All helicopter times referred to above are based
on the assumption that in this type of program the base camp is approximately
in the centre of the survey area, as it was at Hope Lake in the Coppermine

basalt survey. However, it may be better to use a Bell 47G4A helicopter which could carry two geochemists. The Bell 47G2 was rather small and as mentioned previously it was necessary for the pilot to assist with the sampling. This cannot be depended upon in most cases.

SAMPLING PROCEDURES

In 1969 a pilot study (Allan and Hornbrook, 1970) had indicated the possibility of lake water as a regional sampling medium. Because the metals content of lake water is suspected of being influenced by variations in chemistry of drainage basins, it was concluded that lake sediment would provide a more reliable sample to measure regional trace element variations. In the 1970 regional program both lake water and sediment samples were collected. The water samples were collected in 500 ml polyethylene bottles and the sediment samples in waterproof paper bags. Each bottle was washed three times in the water to be sampled. The water sample was carefully taken to avoid any contamination by suspended inorganic or organic loads. There is of course the possibility that the waters have submicroscopic, transparent organisms but this is likely to be common to all lakes in a given area.

The lake pattern in the Coppermine area consists of two types. In the more rugged areas (map-sheets 86 N/8 and 86 O/5) many of the lakes have no obvious inflow or outflow streams, whereas in the areas of low relief the lakes are interconnected by numerous small, swampy or stony streams. In the former case most of the samples were taken wherever a good inorganic sediment was seen as the helicopter came in to land. In the latter case samples were taken from the lake bottom in outflow bays. A few inflow bays were sampled where the lake only had an inflow stream and no obvious outflow stream. Most of the lakes were very shallow at their edges, and the geochemist by wearing hip boots could take samples by hand after walking into the lake. In other areas of the Shield, more sophisticated bottom samplers such as a post hole auger or the Phleger Corer will have to be tested. Often the lake sediment sample had a surface skin (2-3 cm) of organic slime or iron hydroxides. The sample was cleaned of this so that the true sample came from a depth of three to ten centimetres. A depth of five to ten centimetres is recommended as this removes the surface few centimetres where complex redox reactions and biological activity are thought to occur at the water-sediment interface. However it may well be that this surface skin is useful in tracing elements that have an affinity with iron hydroxides or organic matter, for example Hg and As.

1. Detailed Lake Studies

As a control for the regional program and to more fully understand reasons for the variations found for Cu content both within an individual lake and between several lakes, sites were sampled at regular time intervals during the ten-week field season. Two lakes were studied in the most detail; one was anomalous in mean Cu content and was the closest lake to the 47- zone Cu deposit; and the other a lake near no known mineralization. At these two lakes, sediment was collected once in early July from all in- and out-flowing streams and across the lake bottoms. Water samples were also taken at the

same sediment sample sites and were subsequently collected every four days throughout the period of July 5th to August 28th.

Another 17 lakes were selected for detailed study on the basis of the Cu concentrations found in the water from 25 lakes in the 1969 pilot study (Allan and Hornbrook, 1970). At these lakes, a suite of sediments was collected and a water sample was taken at the same place at each lake every ten days from July 5th to August 24th. To assist in the interpretation of the time studies, meteorological records were maintained from July 1st to September 10th, 1970 (see Appendix 1).

At the end of the regional survey, three of the 45 lakes found to have the highest Cu concentration in water, sediment or both, were selected for detailed study. These lakes were sampled in a manner similar to that for the lake closest to the 47-zone.

2. Regional Lake Studies

The regional sample site density (Fig. 3) was experimental in that only a guess could be made at what would be required to fulfil the regional objectives described previously. For this reason, the site density varied for adjoining one-mile map-sheets (Table 1). The total number of sites sampled

Table 1. Sample densities and helicopter efficiency.

NTS Sheet[1]	Approx. area in sq. miles	No. of sites[2]	Site density (sq. miles per site)	Helicopter time per site in minutes[3]
86 O/12	240	38	6.2	12.6
86 N/1, 86 O/4	240	22	10.7	12.9
86 N/7	240	75	3.1	12.0
86 O/5	240	138	1.5	10.9
86 N/8	240	271	0.9	9.9

[1] 93 water and 45 sediment samples were collected from sheet 86 N/9. Helicopter time on this sheet was 20 hours, as the base camp had been moved to Coppermine because of poor weather. The water samples were collected regionally at one site per 3 square miles. Sediments came from lakes in two strips; one in the basalts, below the unconformity to the overlying sediments and one in the overlying sediments above this unconformity.

[2] At every site a lake water and a lake sediment were collected.

[3] Time per site is low and is attributed to the fact that the helicopter pilot assisted with the sampling and in essence was an integral member of the sampling team.

LEGEND

GEOLOGICAL BOUNDARY

FAULT

AEROMAGNETIC LINEAMENT

SAMPLE SITE

ROCK TYPES

BR	INTERLAYERED BASALTS AND RED BEDS
R	RED BEDS
B	BASALTS
UB	UPPER BASALTS
MB	MIDDLE BASALTS
LB	LOWER BASALTS
D	DOLOMITES

SCALE

MILES
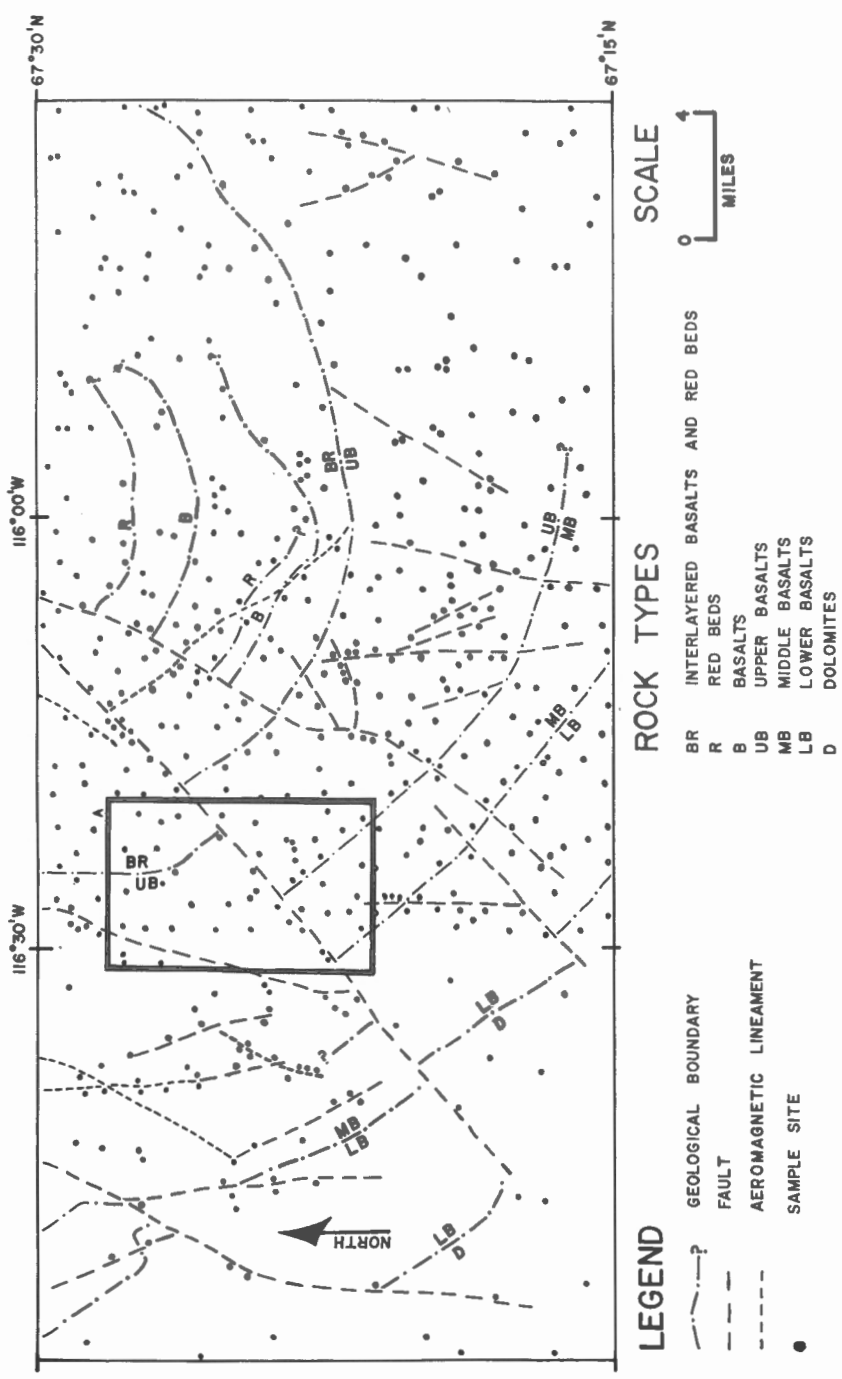
A: The area of the lakes studied in detail (Fig. 7) is from 67° 20'N to 67° 27'N and 116° 20'W to
116° 31'W. The exact locations can be arrived at by comparing the geological boundaries of
the two diagrams. Geology after Baragar, 1969.

Figure 3. Geology and sample sites in three of the one-mile map-sheets surveyed, Coppermine basalt area.

in the regional survey was 637 for which a water and sediment sample was collected at each site. In all, including the detailed studies, 945 water and 706 sediment samples were collected. In addition to these random sites many others on structures such as faults, major geological boundaries, lineaments and adjacent to known mineral showings were sampled (Table 1).

ANALYTICAL METHODS

All the water and sediment samples from the sites shown in Figure 3 were analyzed for Cu in the field by a colorimetric method (Canney and Hawkins, 1958). All the water samples were acidified in the field immediately after analysis to prevent precipitation and sorption of the trace elements present. Some of the water samples were analyzed in Ottawa by atomic absorption spectroscopy for Cu and Zn. All of the sediment samples, sieved to <80 mesh in the field, were analyzed in Ottawa for Cu and Zn.

1. Field Methods

Both the water samples and <80 mesh sediment samples analyzed in the field used 2, 2' biquinoline as the Cu indicator. The basic method, including modifications is included in Appendix 2. The basic method for soils and sediments has been expanded at the Survey to include analyses of waters. Appendix 3 is a detailed list of the procedures, reagents, and equipment used in this survey.

2. Laboratory Methods

The analyses carried out in Ottawa were by atomic absorption spectroscopy. The water samples were preconcentrated by a chelation-extraction method and then analyzed for Cu and Zn using a Perkin-Elmer 303 Atomic Absorption Spectrophotometer. The <80 mesh sediment samples were leached with hot nitric acid and the resulting solutions were analyzed by atomic absorption spectrophotometry for Cu and Zn.

GEOCHEMICAL ANOMALIES IN LAKES

Much of the material referred to in this section has been discussed in more detail elsewhere (Allan, 1971). Only brief summaries are presented below under the appropriate headings.

1. Previous Applications of Lacustrine Exploration Geochemistry

The use of lakes in exploration geochemistry has received relatively little attention. However, the method is probably quite suitable for Shield-permafrost areas such as northern Canada, Sweden, Norway, Finland, and the Siberian Platform.

To the writer's knowledge, only a few companies have used lakes in exploration programs in Canada. These are Rio Algom, outside the Shield; Brinex, in Labrador and Newfoundland; and Barringer, in northern Ontario. All of these companies have found some success with the method and note discoveries of mineral deposits but few details are available since the method is relatively new and results confidential (personal communications from respective company geochemists). In the near future, studies of lake sediment and water will become an increasingly important field of research. The Department of the Environment will undoubtedly become involved in studies of lake sediment and water as there is a much greater aspect in relation to awareness of pollution in our environment. One of the major lake study programs, although not yet trace element oriented, is that of the Canada Centre for Inland Waters. This is the Experimental Lake Area (E. L. A.) study in southwestern Ontario (Brunskill et al., 1971). Government surveys utilizing lake water (Boyle et al., 1971) and lake sediment (Allan, 1971b) have, until 1970, been mainly involved with uranium (Dyck et al., 1970). In 1970, the Geological Survey of Canada started to use the methods both in search for Cu, Zn and Ni deposits, and as a means of differentiating rock types in drift covered areas (Allan, 1971b; Hornbrook, 1971; Hornbrook and Jonasson, 1971).

No references to the systematic regional use of lake water or sediment in exploration could be found in the literature for Scandinavia or the USSR. However, it may be possible that such surveys have been made. Sugawara and co-workers (Sugawara et al., 1967) in Japan have undertaken lake water and sediment surveys (Cu, Ni, Mo, V) as part of their programs of study of geochemical trace element cycles.

2. Mechanisms of Element Transport and Deposition

After release by weathering processes from rock or ore outcrop or suboutcrop, trace elements find their way into lakes by three main processes. These processes involve groundwater flow, stream flow and surface run-off. The trace elements can accumulate in the lake water as free ions or as complexes with inorganic or organic compounds. In the sediments, trace elements will accumulate either by sorption on uncontaminated sediment (sediment which had no significant trace element concentration when first deposited in the lake), or by deposition of particles carried by stream or surface flow with trace elements sorbed[1] to them; and by deposition of sulphides, silicates or primary minerals. Subsequent reactions may then occur to establish a trace element equilibrium between the water and sediment. Such reactions include precipitation of sulphides, oxides or hydroxides, coagulation of clay or organic particles when they settle to the lake bottom, and slow settling of very fine clay size ($<0.08\mu$) particles.

Groundwater flow to lakes in permafrost areas may be associated with thawed zones beneath lakes (Brewer, 1958) and rivers. The concept that permafrost areas show little chemical weathering has hindered the use of geochemistry in such zones. This concept is refuted by Soviet geocryologists (Pitul'ko and Shilo, 1970). The relationship of trace element variations in groundwater to the nature of bedrock and ore has been extensively studied in

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[1] Sorbed is used here to include: (1) adsorption; (2) absorption; (3) chemisorption; (4) cation exchanged.

the USSR (Goleva, 1968). Processes by which lakes produce geochemical responses have been the subject of theses by Schmidt (1956) and Gleeson (1960). Geochemical responses in stream sediment and water, a closely related process, are standard and successful exploration tools in Canada outside the Shield (Boyle et al., 1966; Gleeson, 1965) and in other parts of the world. The fact that considerable quantities of trace elements are carried in the suspended loads of rivers has been well documented (Turekian and Scott, 1967). Rapid response of large lakes to changes in trace element addition to their drainage basins has been shown for Lake Michigan by the Illinois Geological Survey (Ruch et al., 1970; Shimp et al., 1970 and 1971; Schleicher and Kuhn, 1970). Sorbtion of trace elements on bottom sediments has been proposed by Schmidt (1956) for lakes and for ocean sediments by Turekian (1965) and MacDougall and Harriss (1969). The concept that sorption is the major process by which trace element variations in drainage basins are reflected in lake sediment, is partly dependent on the sediment containing clays with high sorption capacities. Such clays exist in Lake Michigan (Lineback et al., 1970; and Gross et al., 1970); in lakes of the Experimental Lakes Area (E. L. A.) of northern Ontario (Brunskill et al., 1971) and in ocean sediments in the Arctic (MacDougall and Harriss, 1969) and other oceans (Turekian, 1965). In addition to sorption on clay or silt particles, there is recorded evidence of sorbtion by larger sediment particles, even up to sand size (Brøtzen, et al., 1966; and Malcolm and Kennedy, 1970).

The occurrence of trace elements in lake sediment as comminuted primary sulphide particles is not noted in the literature but this is a possibility in areas where the occurrences of disseminated sulphide minerals is widespread. However, this means of producing a lake anomaly at least on a regional scale seems unlikely because sulphide minerals are readily susceptible to oxidation and weathering. Sulphides as primary minerals in bedrock or glacial deposits are dissolved but may reappear under suitable conditions in lake sediments as secondary sulphides.

3. Usefulness in Regional Geochemistry

The sampling density in a regional geochemical exploration survey is governed by several factors. These include geochemical ones such as weathering intensity and hydrochemical mobilities of the elements concerned, and nongeological ones such as time available for the survey, the degree of information required relative to mineral exploration or resource potential. In general, a regional geochemical survey of an area of unknown mineral potential is expected to do three main things:

(1) permit the selection of areas of interest, at an early stage in exploration and at a minimal cost. Such areas are those which have excess trace elements in the surficial environment and are thereby more likely to be of primary interest for exploration;

(2) effectively differentiate regional variations in background trace element contents for lake sediments underlain by different rock types; and

(3) broadly outline areas of significantly higher trace element content within these regional background areas so that they can be prospected in more detail using geology, geochemistry and finally ground geophysics and drilling.

Geophysics and diamond drilling account for most present day exploration expenses. The specific objectives for the regional use of lake sediment and water as a geochemical exploration tool for the Coppermine River basalts is its relative economy and high degree of effectiveness in outlining areas as exploration targets. The main advantage of lake sampling over rock sampling in a blanket regional survey is that each lake water or sediment sample provides a natural average of the trace element content of the particular drainage basin. To obtain a meaningful average for the rocks of each lake drainage basin, a very large number of samples would have to be collected and analyzed at very high costs.

Soils and tills in a particular environment may lose trace elements by weathering and leaching or accumulate trace elements by sorption and precipitation. Lakes are characteristically sites of accumulation by sedimentation and record the continuing processes since the lakes came into being which develop and gradually amplify regional trace element variations. Sorption processes are such that traces of Cu, Ni, Pb, Zn, Co, Ag, Hg and other heavy metals are taken up by sediments in preference to the major elements such as Ca, Mg, Na or K. Lakes in essence act as heavy metal "sumps". For example, samples of lake sediment from southern Lake Michigan are beginning to reflect man's industrial activity (Ruch, et al., 1970; Shimp et al., 1970 and 1971; Schleicher and Kuhn, 1970). In areas where there is no mineralization, the major elements are found on most sediment sorption sites.

4. Problems in Sampling and Interpretation of Results

The most obvious problem that could arise would be a deficiency of lakes in a certain area. Canada probably has a greater lake area than any other country and these lakes are mainly in the Canadian Shield (Fig. 2). In most parts of the Shield, there are sufficient lakes for a sample density of one site per ten square miles. The second problem is that lakes may not contain sediment that can be economically sampled (by economically we mean a method that will allow collection of regional samples to proceed at a rate of about 5 to 6 sites per hour). Before lakes are to be sampled regionally, a preliminary survey of the area is essential at least to establish if sediments are present in the quantities required and if they can be sampled without excessively elaborate bottom sampling techniques.

Variations in trace element concentrations at different points in the same lake bottom could cause one to doubt the method if only one or two lakes are studied. However, as shown later, variations in Cu concentration in individual lake bottoms are both an advantage in detailed studies as they indicate direction to local mineral occurrences and are no disadvantage in regional studies where enough lakes are sampled.

Type of sediment can cause variation in the results. Organic sediments were found in the Coppermine survey to have a higher mean Cu concentration. For this reason, the sediment type collected should be noted and should be as uniform in organic content as possible. Strong relationships between organic carbon and trace element contents in the surface 3 cm of lake sediment have been noted in southern Lake Michigan (Shimp et al., 1971).

One of the least studied factors that could affect trace element contents in lake water and sediments is the bacterial reactions involved. However,

it seems that for the few detailed studies available of trace element reactions in lakes, variations in concentration below the few surface centimetres can be rationalized without resorting to biological and microbial trace element cycles (Riley, 1939; Schmidt, 1956; Gleeson, 1960; Hutchinson, 1970; and Shimp et al., 1970). However, there may be many other factors that affect trace element contents of lakes, such as lake size, relative number of inflow and outflow streams, or rate of flow through the lake. Studies to elucidate the influence of these variables would necessarily be extremely long term, in the order of years or tens of years.

To more fully interpret the results of a survey of trace elements in lake sediment and water, numerous subsidiary measurements should be carried out in addition to the cold acid leach and atomic absorption methods. These subsidiary measurements include:

(1) ph and redox measurements;
(2) extraction and analysis of suspended loads;
(3) techniques to differentiate between the ionic, organic and sestonic trace element contents (Riley, 1939) of water;
(4) X-ray diffraction of sediments;
(5) analyses of separated fractions of bottom sediments;
(6) sorption capacity measurements of separate size fractions of sediments; and
(7) several selective extractions to estimate available, fixed and total trace element contents.

Complete series of this type for trace elements in the same lake waters and sediments have to the best of the authors' knowledge, not been carried out. At present, the complexities of the trace element geochemistry of lakes are only beginning to be studied in Canada. However, they should not be a deterrent to the application of the method as an effective exploration technique.

PRESENTATION OF THE RESULTS[1]

Most of the tables list the trace element content of certain lake sediments or waters. Some of the diagrams show the trace element content of Cu in either water or sediment at particular sites in streams or lakes. Most of the diagrams are computer-drawn contour maps of the trace element concentrations in either lake water or sediment. The contours are drawn from trace element concentrations calculated on a regular grid. These regular grid concentrations are calculated within a uniform circular search. The search area around each grid point is large enough to include several of the original values used in the calculation of each regular grid point irrespective of the site density employed. This procedure smooths the data and reduces the effect of extremely high values. As the search area in all diagrams is circular, the northwest to southeast linear trend (Fig. 1) of the contours is due entirely to the lithogeochemistry of the different rocks in the area and is independent of the contouring technique.

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[1] The basic data on which this report is based are on open file at the Geological Survey of Canada. The basic data are listed on computer printout, and include geological and limnological information for each sample site along with the results of the field and laboratory chemical analyses. The sample sites are given on airphoto maps at a scale of 2 inches equals one mile.

RESULTS OF THE DETAILED SURVEY

The results from the detailed studies of copper concentration in streams and lakes in the Coppermine area are presented in Tables 2 and 3; and Figures 4, 5, 6, 7 and 8.

1. Copper in Stream and Lake Water

(a) Stream at the 47- zone deposit

During the Coppermine area survey, a dried-up stream which crossed the position of the 47- zone mineral deposit, resumed flow after two days of heavy rain in August (Appendix 1). The concentration of Cu in this stream was determined in the field two days after flow resumed (Fig. 4). In the laboratory in Ottawa, atomic absorption analysis gave a figure of 91 ppb for the 56 ppb value determined by the field colorimetric method. This concentration is much higher than those recorded for lakes in the regional survey and shows that there is considerable weathering and leaching of Cu into the water of the drainage system in this cold Arctic desert. The stream water collected at the 47- zone was absolutely clear and the presence of Cu sorbed on a suspended load was not suspected. The high copper concentrations begin some 400 feet downstream from the ore outcrop (Fig. 4). This is probably due to subsurface flow of water through the fault breccia noted on the diagram. However, it was noticed that the waters of a few lakes north of the basalt belt were cloudy due to the presence of suspended loads. These results and observations allow two conclusions to be drawn: (1) chemical transport of Cu occurs in stream waters; and (2) mechanical transport of suspended loads may also contribute to the dispersion of copper. Although these dispersion mechanisms may only be significant during the spring thaw and autumn rains, they are rapid and lakes would have had ample time since the last glaciation to deposit or develop in the original sediment, concentrations that reflect the trace element content of their respective drainage basins. This should adequately reflect the metal distribution in the surrounding rocks providing there is sufficient outcrop, suboutcrop or incorporation of material by frost processes into the surficial deposits.

(b) Copper in water from the surface of a lake

Variation in Cu concentration in the surface water of a fairly large lake is shown in Figure 5. Samples were collected when the lake was completely calm. Higher concentrations in the northwest corner of the lake may be due to water entering from the stream at this point as this stream drains an area where there are several minor showings of a variety of Cu mineral types.

(c) Secular variations in copper content in lakes and their associated streams

The variations in Cu concentration in two lakes and their respective inflow and outflow streams, one (A) near no known mineralization, and the other (B), the closest lake to the 47-zone ore body, are given in Table 2. The respective sites referred to in Table 2 can be located in Figure 6. The concentration of Cu in the inflow and outflow streams and lake water of lake (A)
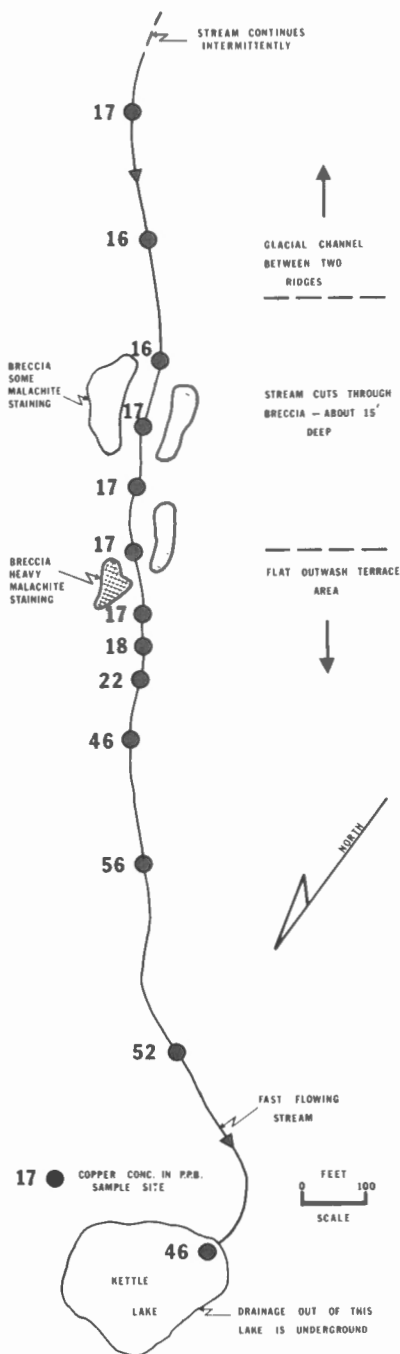
Figure 4. Copper concentrations in stream water at the 47-zone
deposit, Coppermine River area (samples collected
on August 13, 1971). This stream crosses the
47-zone copper deposit from southeast to northwest.
Its location can be seen, relative to Hope Lake, on
Figure 7.

Table 2

Copper concentrations in lake water, Coppermine basalt area.

SAMPLE[1]	DATE OF COLLECTION; Cu IN ppb[2]									
(A)	July 5	July 11	July 17	July 23	July 29	Aug. 4	Aug. 10	Aug. 16	Aug. 22	Aug. 28
Stream 1	3	5	3	4	4	3	3	3	4	6
Stream 2	4	6	3	3	4	4	4	5	3	6
Stream 3	3	3	1	3	3	3	3	6	4	4
Lake site 1	2	4	2	3	3	3	6	4	4	6
Lake site 2	1	3	2	3	3	3	4	5	4	3
Lake site 3	1	3	3	3	4	3	3	4	3	5
(B)										
Stream 1	8	18	16	13 stag.[3]	12 stag.	17 stag.	18	18	18	25
Stream 2	8	s.d.u.[4]	s.d.u.	s.d.u.	s.d.u.	s.d.u.	12	s.d.u.	s.d.u.	16
Stream 3	6	8	6	6	4	5	10	7	8	13
Lake site 1	7	8	4	6	3	4	6	9	9	8
Lake site 2	9	8	8	7	4	4	8	9	9	10
Lake site 3	8	8	8	6	5	4	6	9	8	8
Lake site 4	8	8	8	5	4	5	8	8	8	8

Changes during July and August, 1970 in:

(A) a lake near no known mineralization, and (B) the lake closest to the 47-zone deposit

[1]Location of sites shown in Figure 6.
[2]Colorimetric analyses in the field.

[3]stag. = stagnant stream, no visible flow.
[4]s.d.u. = stream dried up completely.
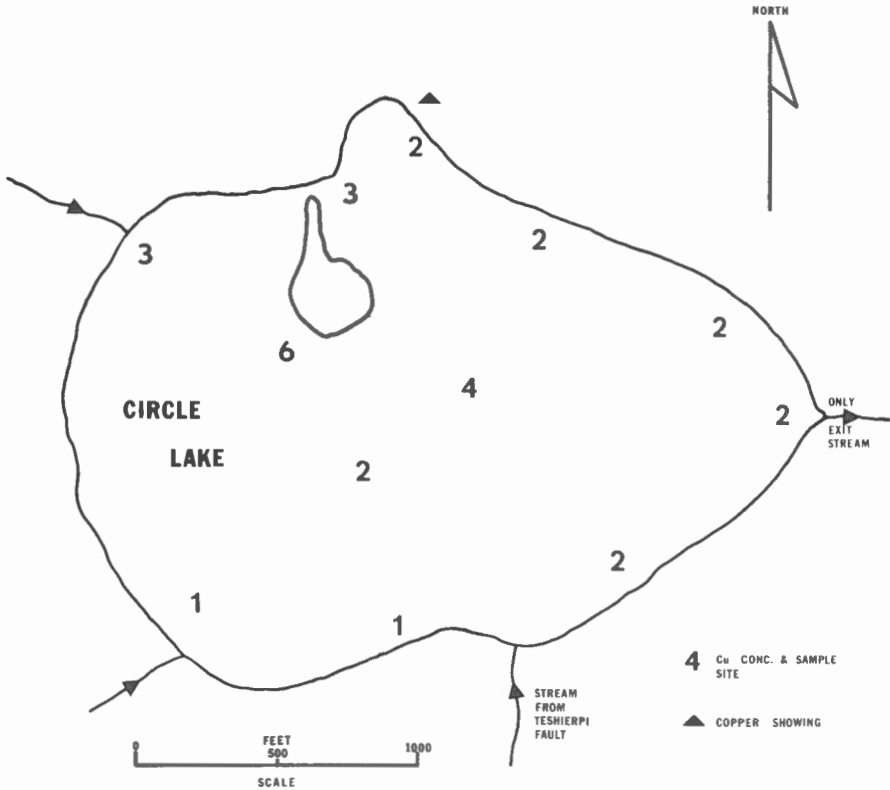
Figure 5. Copper concentrations in ppb in surface lake water: lake over the
upper Coppermine basalt member. This lake can be located on
Figure 7, as that immediately south of Hope Lake.

remained virtually constant throughout the sample period. Flow in all of
the streams at lake (A) continued throughout the sampling period. The out-
flowing stream had the same concentration as the inflowing streams and the
lake water samples implying that an "equilibrium" had been established.

For lake (B) there were variations in the Cu content during the summer,
caused by the drying up of certain streams feeding the lake (Table 2). During
the latter half of July and the first week of August when the two streams which
carried the most Cu had become stagnant or dried up completely, Cu concen-
trations in the lake reached their lowest value. Any lake water that had a
higher copper content than this lowest value for lake (B) was referred to as
anomalous. After rainfall in early August the concentrations quickly increased
to their former level. This lake had no visible outflow stream and as the
levels of Cu in the streams entering the lake were higher than the Cu levels
in the lake, this indicates a "non-equilibrium" situation. In this case, Cu
is probably rapidly accumulating in the lake bottom sediment.
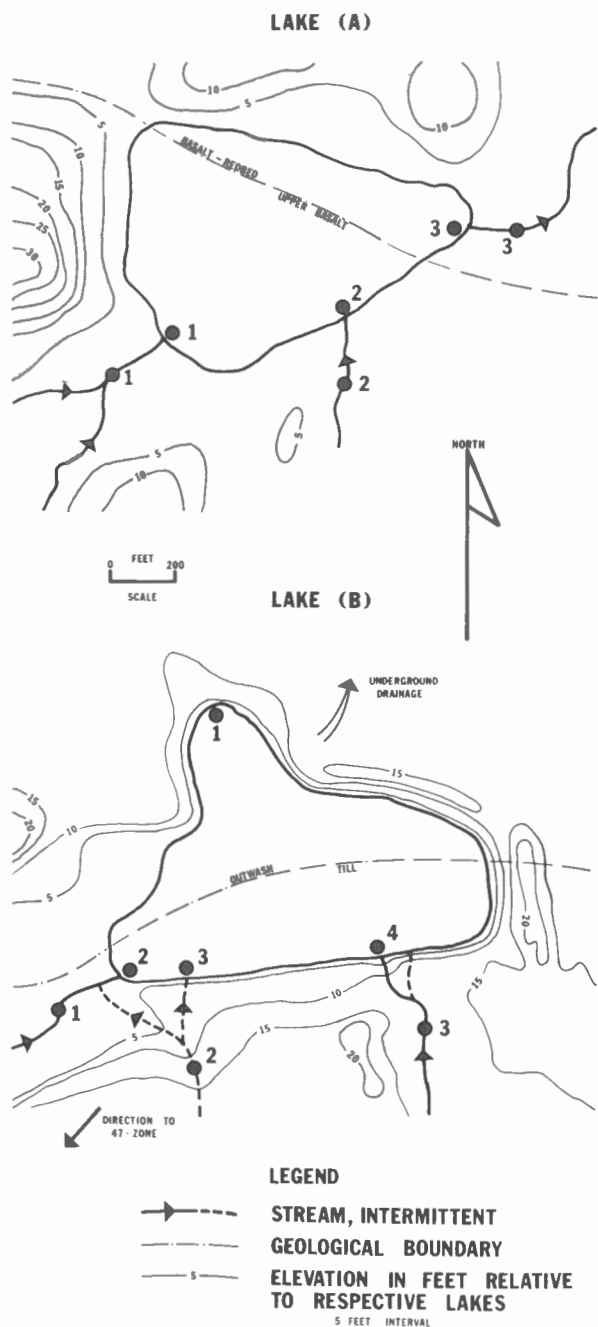
Figure 6. Sample sites: lakes A and B: a study to determine secular variations in copper concentrations. These lakes can be located on Figure 7. Lake (A) is the lake immediately east of Hope Lake. Lake (B) is the lake closest to the 47-zone. It can be recognized by its outline.

The main conclusions drawn from the study of these two lakes are as follows: If no mineralization is found nearby, the Cu level in the lake and stream water and sediment reaches an "equilibrium" state depending on the source and quantity of trace element available; i.e. a background value is established that can be related to large areas such as geochemical provinces. In a regional survey to assess overall trace element variations most lakes studied will be of this type. Secondly, if a lake occurs near mineralization of some quantity so that excess trace elements are supplied to the lake, then an "equilibrium" is not established but instead trace elements accumulate in the sediment. In a regional survey, the accumulation of Cu in the lakes and the separation of a higher concentration area (metalliferous province) as shown in Figure 1 is due to the first process and can be due to extensive low grade ore occurrences. Certain lakes affected by the second process were also found in the regional study but these are chance occurrences and may be directly related to local high grade ore occurrences.

(d) Seasonal copper variations in lakes in the Hope Lake area

This section describes several lakes sampled regularly throughout the summer (Table 3). Most of the lakes remained almost constant in their Cu concentration. This also applied on a yearly basis (Table 3). The exceptions, lakes 8, 9 and 14, were near known mineralization and could be explained by the resumption of flow of streams after rainfall in August. The main fact to be emphasized is that only lakes that are already highly anomalous in a regional context change their concentrations and that this change during and immediately after rainfall is usually an increase.

2. Copper in Stream and Lake Sediment

(a) Study of lakes in the Hope Lake area

So far in the discussion of the detailed results, variations in Cu concentrations in water have been emphasized. Lake sediments were collected at several points at each of 19 lakes (Fig. 7) in the Hope Lake area. The variations for most lakes were such that they did not affect the eventual regional pattern. For a background lake such as that at the extreme southwest corner of Figure 7, the concentrations of Cu in ppm around the lake were 11, 28, 34, 37 and 46 with a mean value of 31. For the lake closest to the 47-zone (Fig. 7 (c)), they are 432, 727, 1,046, and 1,224 with an average of 857 ppm Cu. In any regional assessment of Cu distribution in the Coppermine basalts and adjacent rocks, these variations within a lake are not significant. The most extreme example encountered was for the lake second from the southwest end of the Teshierpi Fault (Fig. 7). At opposite sides of this lake, concentrations were 15 and 1,660 ppm Cu. The 1,660 ppm sample was collected at a point on the lake bottom only 30 feet from the site of extensive trenching, bulldozing and drilling of a minor showing. The high value is probably due to contamination of sediment by sulphide particles at this point. However, the following is of interest. The other four uncontaminated sediment samples gave a mean value of 58 ppm Cu and the outflow bay sediment contained 95 ppm Cu. Both of these fit the regional Cu distribution discussed later. Furthermore, these Cu concentrations of 58 and 96 ppm would have shown that known mineralization in the immediate vicinity of this

Table 3

Copper in lake water, Coppermine basalt area.

Number	(A) Date of Collection; Cu in ppb[1]						(B) Date of Collection; Cu in ppb[2]		
	July 5	July 15	July 25	Aug. 4	Aug. 14	Aug. 24	July 1969	July 1970	July 1971
1	0	0	1	0	0	0	2	1	-[4]
2	1	1	3	0	0	0	5	4	3
3	8	8	8	8	9	11	15	13	-
4	1	0	2	1	3	1	4	1	-
5	0	1	2	4	2	1	3	2	-
6	0	0	3	4	1	0	2	1	-
7	0	0	1	1	2	0	1	0	1
8	9	8	9	8	11	11[3]	20	17	-
9	4	2	4	4	2	11	12	7	10
10	6	6	6	5	6	8	9	10	-
11	1	1	3	3	3	3	7	5	-
12	3	1	3	2	2	2	5	4	-
13	1	1	2	2	3	2	6	4	-
14	11	9	9	16	17	16	20	20	0
15	1	1	1	2	3	1	6	4	-
16	1	2	2	2	3	2	8	2	-

(A) Changes during July and August 1970.

(B) Concentrations in July 1969 and July 1970.

[1]Analyses were done in the field by a colorimetric method using 2,2' biquinoline as the indicator.

[2]Analyses were done in Ottawa by atomic absorption spectroscopy, following an extraction procedure. The 1969 samples were analyzed by the Inland Waters Branch Laboratories; the 1970 samples by the Geochemistry Section of the Geological Survey of Canada.

[3]Lake 8 overflowed into Lake 9 after very heavy rainfall between the 14th and 24th of August, 1970.

[4]No sample taken.

lake should not have been considered as a drill target when compared with results for other showings. Also, a few of the lakes in Figure 7 have a higher Cu concentration in their outflow bays than other bottom locations. This same trend has been noted previously for uranium (Dyck et al., 1971) and for zinc (Schmidt, 1956). Insufficient data on individual lakes were collected in the Coppermine area to make a definite conclusion on this relationship. However, in the regional study, mean Cu concentration for outflow bay sediments and lake sediments from no special position are very similar (Table 4(5)). The lower value for inflow bays may be unreliable due to the small number of samples classified in this way.

(b) Lakes of very high copper content

At the termination of the regional sampling program, 22 lakes were located that had anomalous Cu values in both sediment and water. Of these less than half could be related to known sites of mineralization within one mile. Ten of the anomalous lakes could not be explained by known mineral occurrences. Locations of these lakes have been presented previously (Allan, 1971a). There were, in addition, 23 lakes that were anomalous for Cu in either lake water or sediment, within the 1,5000-square-mile area surveyed. The majority of these anomalous lakes were in the upper basalt member. Of these 45 lakes, three were revisited and studied in similar detail to that lake closest to the 47-zone deposit. The results are presented in Figure 8. Two of the three (A and D) had high Cu concentrations at most sites around their bottoms and would merit further stream and frost boil geochemical investigation. The third (B) had an anomalous Cu concentration at only one point and would be rated low on a priority scale for follow-up work. (For the location of all anomalous lakes and of the three lakes A, B and D referred to in this section see Geol. Surv. Can., Paper 71-1, Pt. A.) It should be noted that all the anomalous lakes found in this survey could be studied in detail at little extra cost. In the case of the 1970 survey, if all the 45 lakes with highest Cu concentrations in sediment and/or water were sampled at 6 points, collection of samples would take 6 man-days and analyses 8 man-days. However, this type of follow-up was not part of this survey. Lake C is the lake closest to the 47-zone Cu deposit and is shown in Figure 8 for comparison with the other three lakes.

RESULTS OF THE REGIONAL SURVEY

Some of the more specific relationships derived from the regional results are presented in Tables 4, 5 and 6, and in Figures 9, 11, 12, and 16. Otherwise, the regional results are presented as computer-drawn contour maps showing the distribution of a trace element in either lake water or sediment (Figs. 10, 13, 14, 15 and 17). The geological key for the regional maps is given on Figure 3. Cu and Zn concentrations for samples of water and sediment at sites outside the three map-sheets represented in Figure 3 were very low. No high values were recorded in map-sheet 86 O/12 and the north halves of map-sheets 86 N/1 and 86 O/4, and these are not included in the majority of the figures. A small anomalous area for Cu in sheet 86 N/9 is outlined in Figure 1. One reason for extending the survey into these sheets was to show the relatively low Cu concentration for lakes in the dolomites

which underlie the basalts and in the sediments which overlie the basalts. These lower mean concentrations are given in Table 4(1). This may not apply for other trace elements.
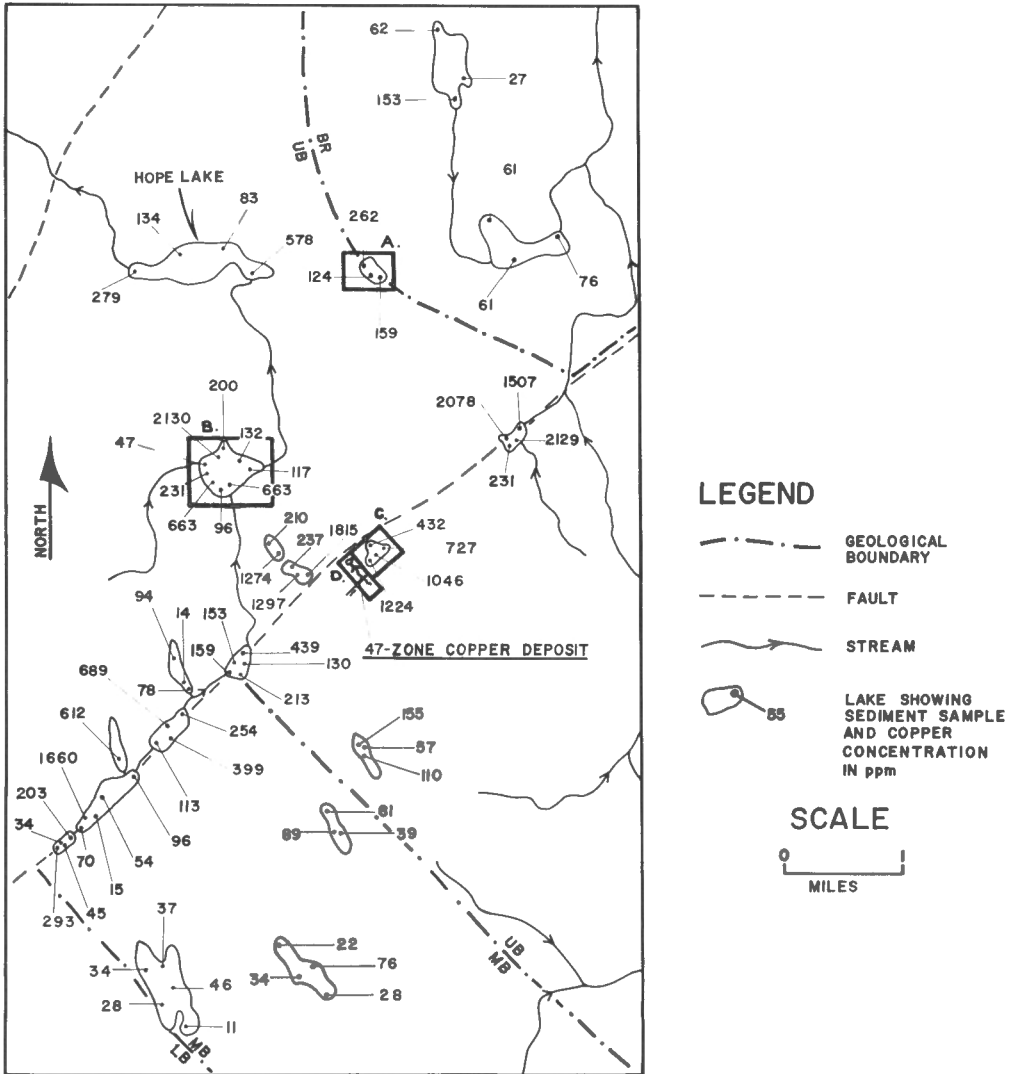
Figure 7. Copper concentrations in lake sediment of nineteen lakes studied in detail, Coppermine basalt area. The location of the area of this figure is given on Figure 3.

A: area around lake A on Figure 7.   C: area around lake B on Figure 6.
B: area of Figure 5.   D: area of Figure 4.

Table 4

Statistical results: relationships of copper concentrations in lake sediment to geological and geographical variables and textural properties of lake sediment.

Variable	Arithmetic mean	S. D.	Number of sites
	Cu ppm		
(1) Geological: Bedrock in vicinity of lake:			
Sedimentary rocks[1]	42	32	191
Upper basalts	118	480	92
Middle basalts	50	36	41
Lower basalts	38	32	45
All basalts[2]	158	326	367
Basalts + red beds[3]	48	29	15
Dolomites[4]	19	9	36
(2) Geological: Glacial deposit in vicinity of lake:			
Till + rock[5]	119	294	394
Rock + till[6]	211	302	57
Colluvium	28	15	9
Water laid	37	78	149
(3) Geological: Structure in vicinity of lake:			
Fault nearby	158	333	145
Aeromagnetic lineament	94	152	23
Unconformity	59	50	40
None known	100	246	401
(4) Geographical: Drainage basin lake belongs to:			
Coppermine River	65	123	390
Richardson River	192	390	219
(5) Geographical: Position of sample in lake:			
No special[7]	126	301	329
Outflow[8]	125	256	149
Inflow[9]	91	113	14
(6) Textural: texture of sediment[10]:			
Sand	52	63	91
Silt	113	270	483
Clay	66	41	7
Organic	279	415	28

[1]Rocks overlying the Coppermine basalts.

[2]Includes all upper, middle and lower basalts and all samples from sites in basalts not separated on the geological map into these members. The reason for the mean copper content of the variable "all basalts" is higher than that for "upper basalts", is that in many parts of the area surveyed the basalts have not been separated into members. In such, many of the values used in the "all basalts" calculations are probably from lakes underlain by the copper-rich upper basalt member.

[3]Interlayered basalts and red beds.

[4]Dolomites underlying the Coppermine basalts.

[5]Mainly till covered with some rock outcrop.

[6]More rock outcrop than 5 but still mainly till covered.

[7]Lake had no obvious outflow stream and was sampled where a sediment could be found.

[8]Bottom sampled close to exit of outflow stream.

[9]Bottom sampled at position of inflow stream, usually a lake with no obvious outflow stream but with a major inflow stream.

[10]Texture determined in the field by touch test.

1. Copper in Lake Water

In 1969, a pilot study (Hornbrook and Allan, 1969) had shown for 25 lake waters in the area, that most concentrations for Pb, Ni, Co and Mn were below the detection level of the analytical method. Because of this, Cu and Zn were the cations used in the regional hydrogeochemical survey of the Coppermine basalt area.

(a) Colorimetric results

The regional Cu distribution in lake water (Fig. 9), as determined in the field laboratory by a colorimetric method, reflected only the outline of the area with the highest Cu concentrations in lake sediment. However, from an exploration viewpoint, this would have been sufficient to focus on the anomalous area ultimately outlined by Cu concentrations in lake sediment. It may be possible that even a lake water sample taken at a density of one site per 10 square miles would have indicated the highest Cu zone. However, at such a site density the zone may have been overlooked.

(b) Atomic absorption results

Water samples at an approximate sample density of one site per two square miles were selected at random from sheet 86 N/7. These samples were analyzed in Ottawa by preconcentration and atomic absorption spectro-photometry. The results are shown in Figure 10. These analyses more clearly outlined the close relationship of higher Cu values with the upper basalt member.

(c) Correlation of lake water and lake sediment results

Copper concentrations as determined in the field by colorimetric methods for both water and sediment show a good relationship (Fig. 11) (r=0.63). This may indicate the equilibrium mentioned previously between Cu in lake sediment and water.

(d) pH

There is also a significant negative correlation (r=0.36) between Cu concentrations in lake water and pH. If the level of Cu in lake water was controlled by precipitation of hydroxides, the curve of Cu $(OH)_2$ with pH shows that 20 ppb Cu can be in solution at pH 7.7 and 8 ppb Cu at pH 8.2 (Schmidt, 1956). pH values in all the Coppermine lakes were within this range. However, the true system is far more complicated and probably involves precipitation of a variety of compounds, sorption by clays, iron-phosphate gels, organic complexes and gels, and organisms in suspended loads and bottom sediment.

The water survey in the Coppermine area was successful but if the water chemistry had been such as not to allow Cu to travel in true solution, the composition of the lake sediment, which is derived from both Cu moved in several ways including ionic and sorbed forms, would still have provided a viable representative sample. Moreover, local short term variations in water chemistry could give rise to confusing variations in the regional Cu distribution

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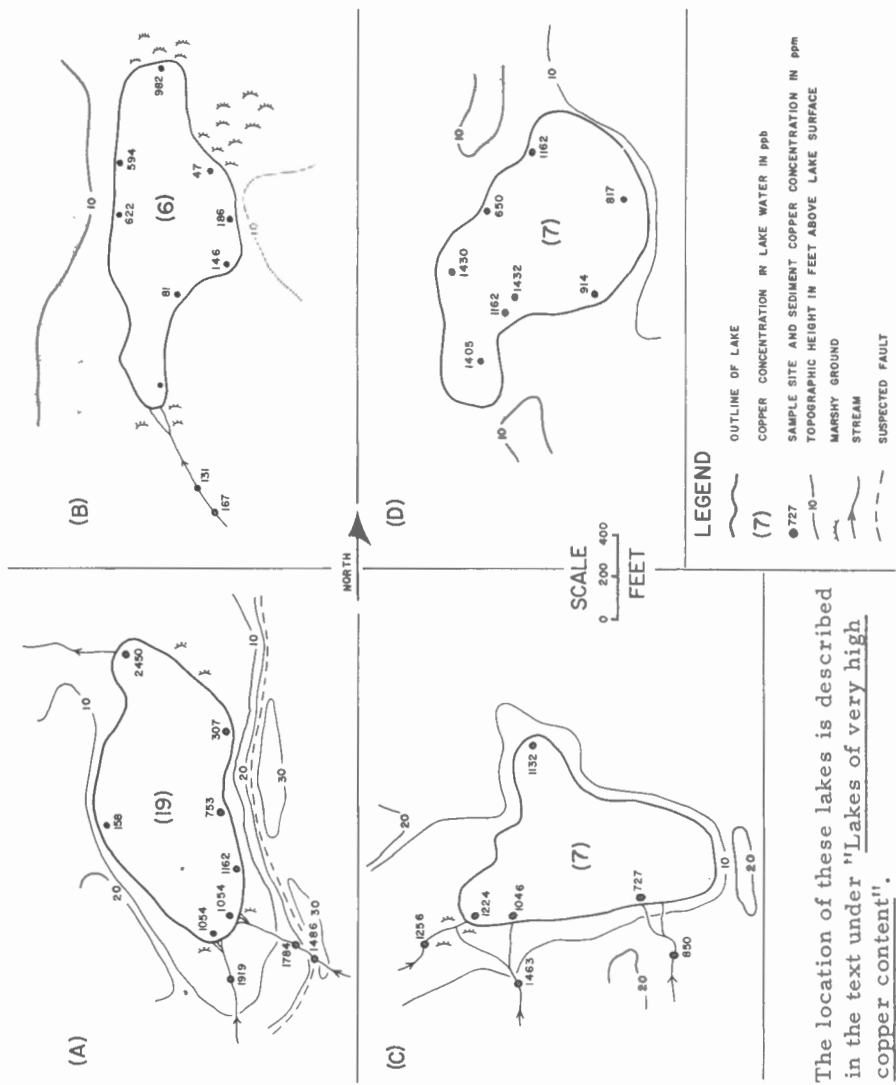
Figure 8. Copper concentrations in four anomalous lakes located in the regional survey of the Coppermine River area.

The location of these lakes is described in the text under "Lakes of very high copper content".
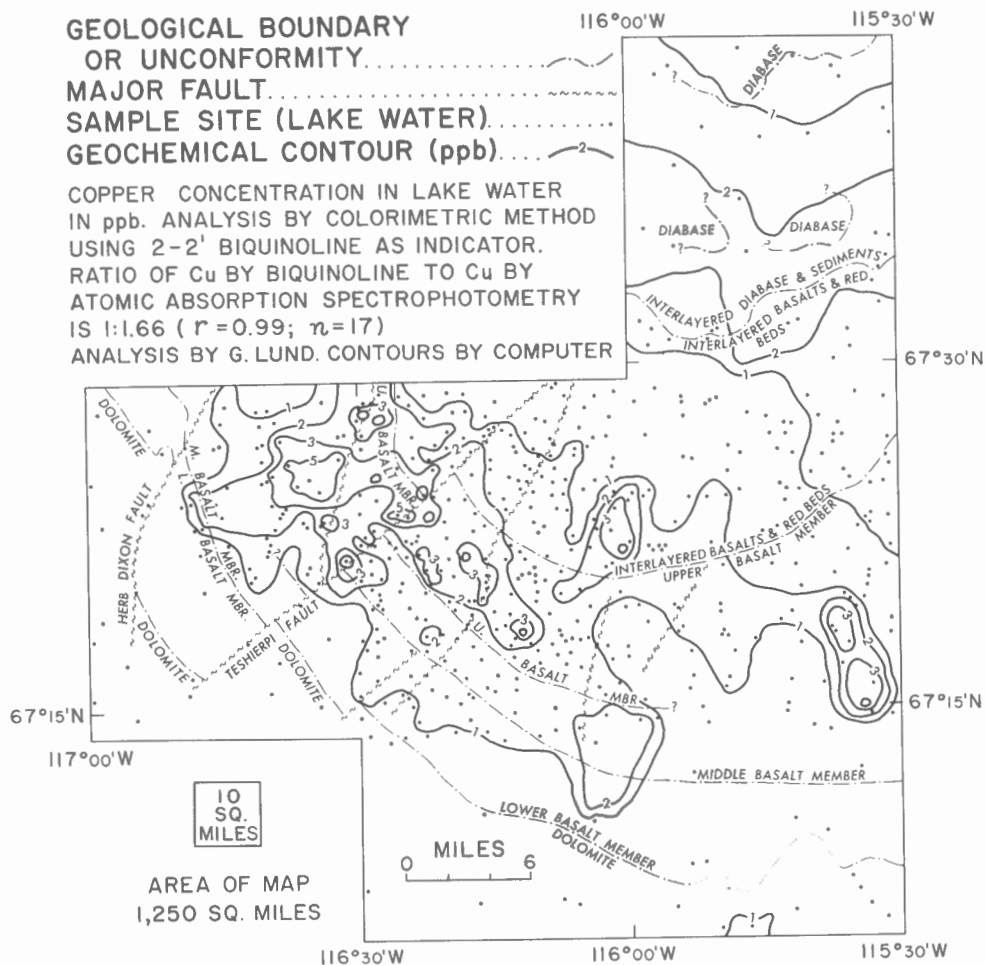
Figure 9. Copper concentrations in lake water, Coppermine basalt area; colorimetric field method (geology after Baragar, 1969).

in water but these are less likely to influence sediment copper contents. However, if a regional sampling program is designed to collect lake sediment, simultaneous collection of water which is rapid and simple, can be easily added. The extra time spent at the sample site is minimal and the water results may substantiate the sediment results, as they do in the Coppermine area. Alternatively, water analyses costs are high but the fact that they do substantiate the sediment results makes water analyses worthwhile. The use of graphite furnaces in conjunction with atomic absorption spectrophotometers will eventually greatly increase the value of water collection on a regional scale.

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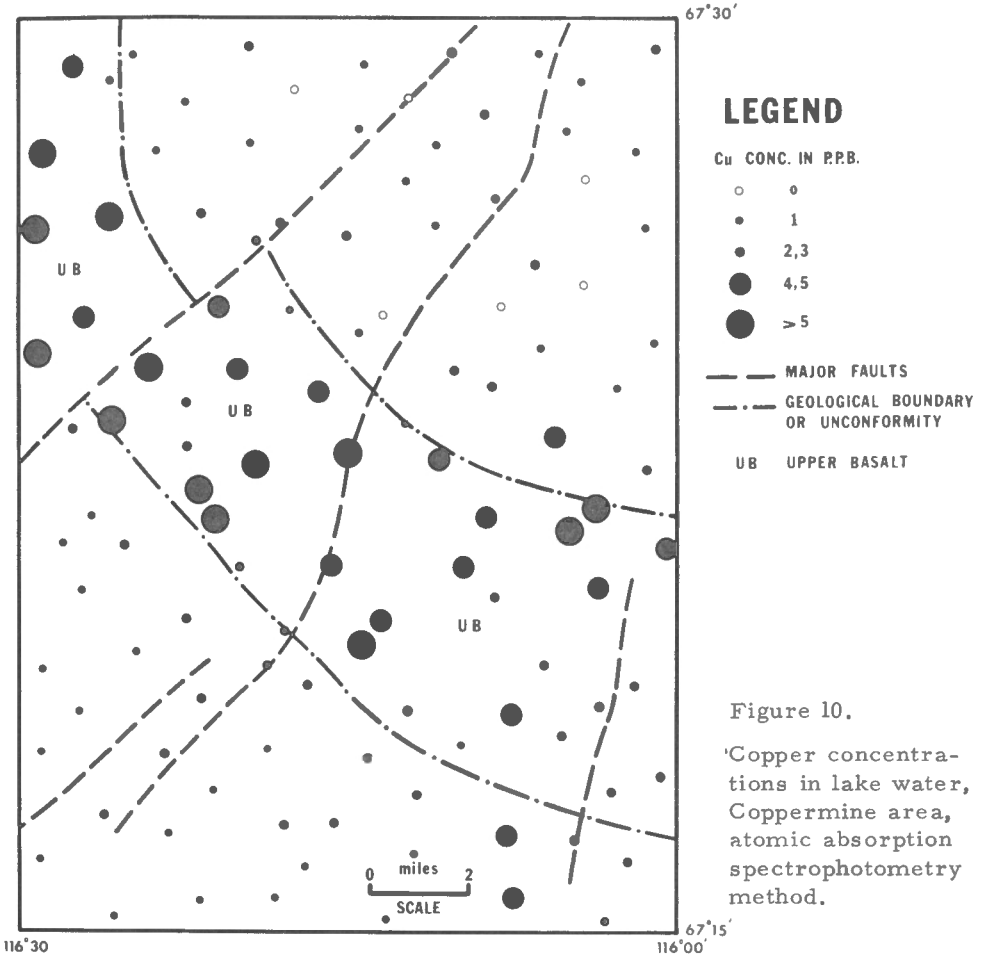
Figure 10.

'Copper concentra-
tions in lake water,
Coppermine area,
atomic absorption
spectrophotometry
method.

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2.　Copper in Lake Sediment

(a)　Results using all sample sites

The regional distribution of Cu in lake sediment is shown in Figure 12.
Figure 12(A) shows the distribution arrived at from a nitric acid-hot leach
of the <80 mesh size fraction and Cu analyses by atomic absorption spectro-
photometry.　Figure 12(B) is the distribution arrived at from a hydrochloric
acid-cold leach of the <80　mesh size fraction and a colorimetric Cu test.
There is a great similarity between the two computer-contoured diagrams.
This reflects the very good correlation found between concentrations of Cu
obtained by these two analytical methods (Fig. 13).　The correlation was
maintained from the lowest to the highest concentrations.　The relationship
between average Cu concentration for lakes in each rock type and the specific
rock-unit are given in Table 1(1).
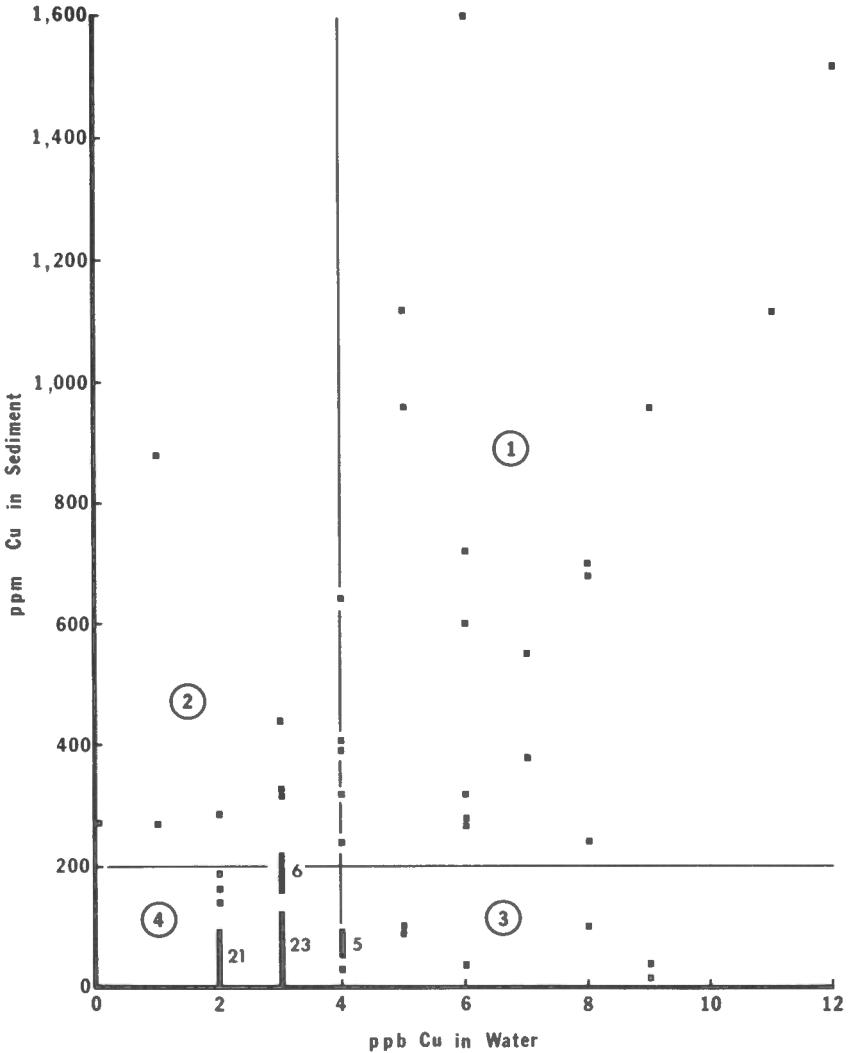
Figure 11. Copper concentration lake sediment vs. lake water, Coppermine River area. The diagram is divided into four sections. From an exploration viewpoint, investigation of the lakes should proceed in the order 1, 2, 3 and 4. That is, the lakes to be investigated first should be those with high copper concentrations in both water and sediment.
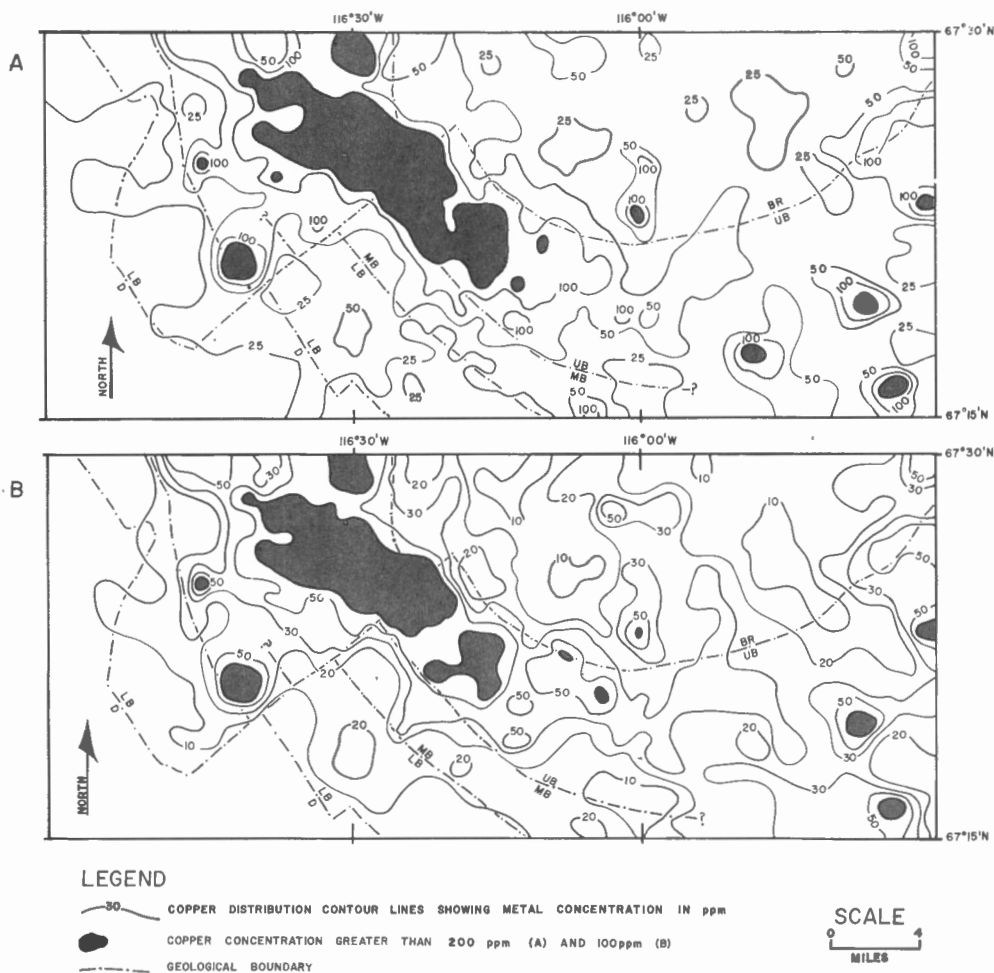
Figure 12. Copper concentrations in lake sediment, Coppermine basalt area.
Map based on all sample sites: (A) Hot leach-atomic absorption
results; (B) cold leach-colorimetric results.

A rough correlation between certain Cu concentration contours and
geological boundaries can be seen in Figure 12(B). The 10 ppm Cu contour
corresponds to the dolomite/lower basalt boundary; the 20 ppm Cu contour to
the lower/middle basalt boundary; the 30 ppm Cu contour to the middle/upper
basalt boundary; the 30 ppm Cu contour to the middle/upper basalt boundary
and upper basalt/red-bed plus basalt boundary (as mapped by Baragar, 1969).
The 50 and 100 ppm Cu contour define the highest Cu area in the upper basalt
member. By extrapolating along the 50 ppm contour, it may be possible to
map in the limits of the upper basalt member where it is drift covered north-
west of the Teshierpi Fault (Fig. 3). There is also some indication due to
the flexure in the 50 ppm Cu contour that the Teshierpi Fault has a left lateral
shear, or if it is a hinge fault, that the west side is downthrown.
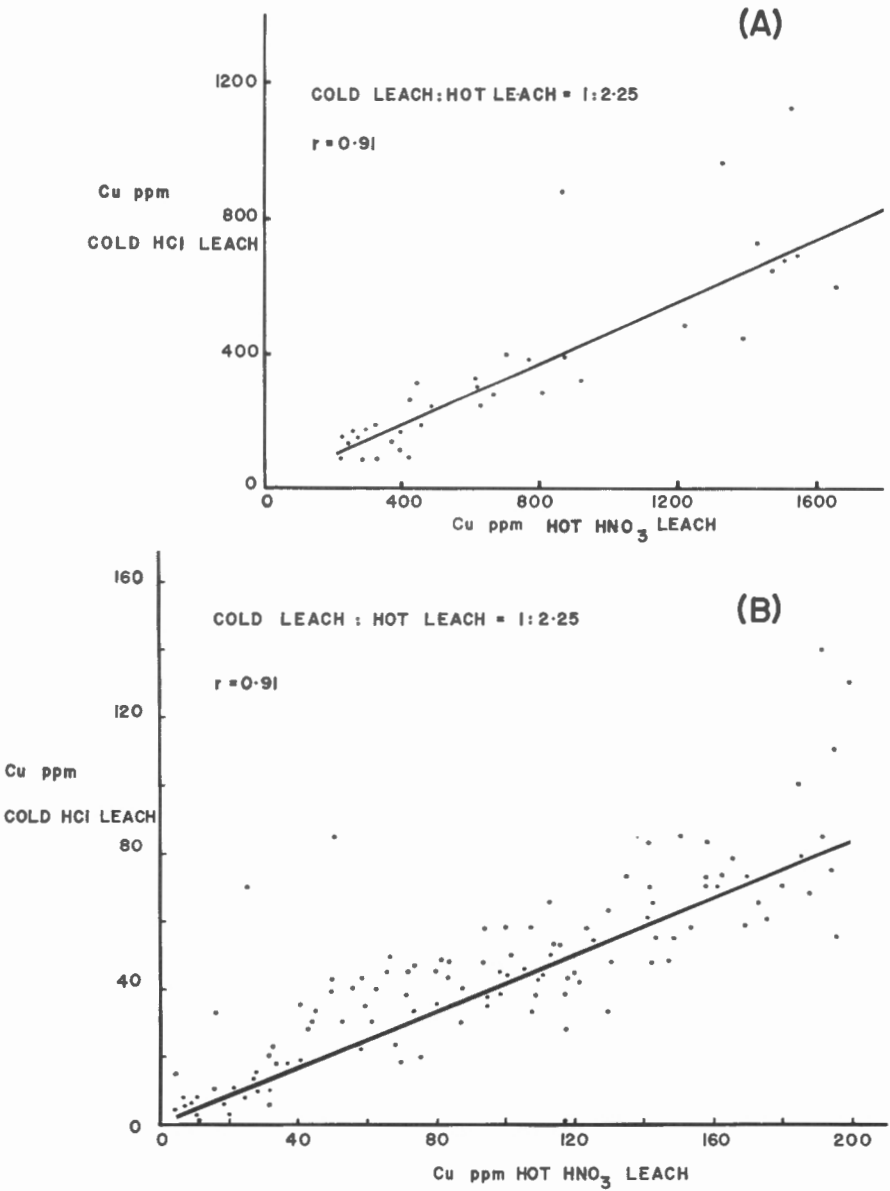
Figure 13. Copper concentrations in lake sediment; cold vs. hot acid leach analyses.

(b) Studies to determine optimum regional sample density

The objectives previously listed for the regional geochemical survey of the Coppermine basalts are fulfilled by the results presented in Figure 12.
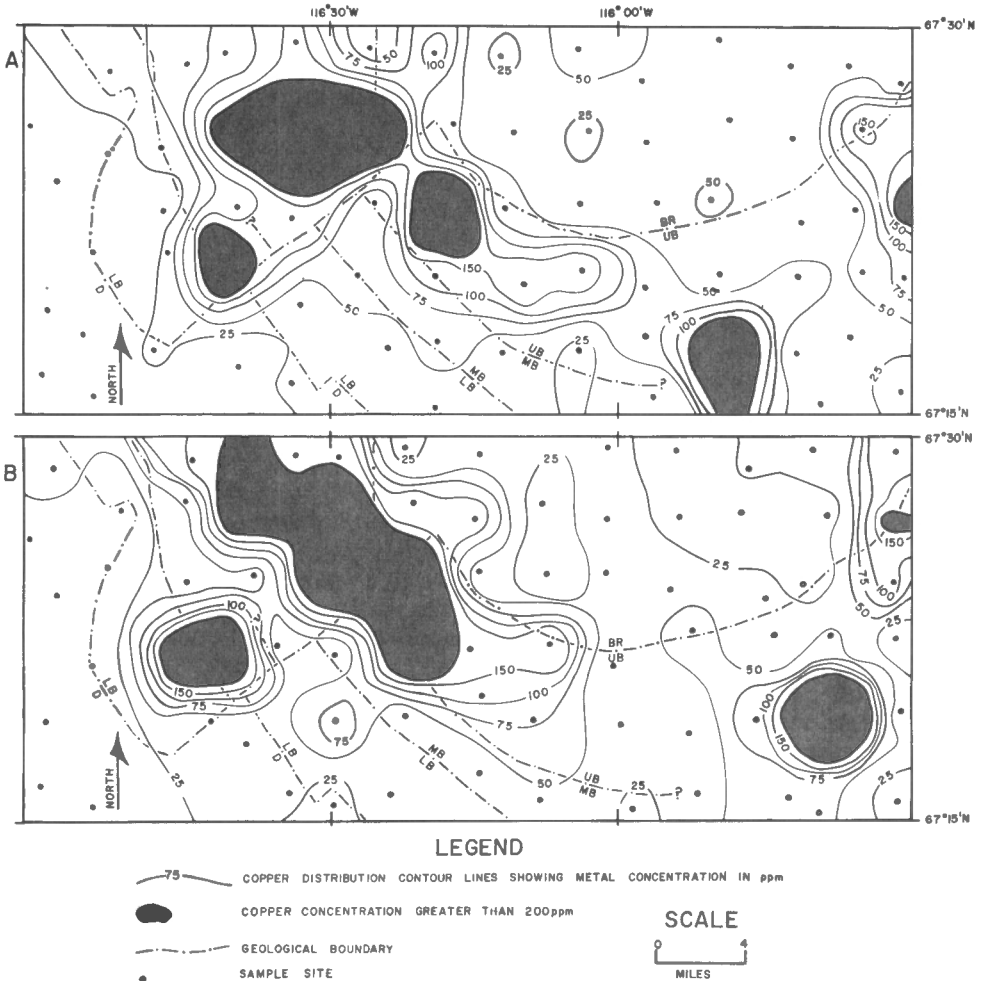
Figure 14. Copper concentrations in lake sediment, Coppermine River area.
Map based on one sample site every 10 square miles: (A) and
(B) randomly selected.

Further computer manipulation of the basic total data was used to find the
optimum lake site density at which the original basic objectives are still
satisfied. The optimum sample density in relation to regional assessment of
economic mineral potential, is that which gives the maximum return of mean-
ingful information for each exploration dollar spent. Meaningful information
in the context of the Coppermine objectives would be:

(1) to outline the general changes in regional Cu distribution related to the
various rock types in the survey area; and,

(2) to delineate the anomalous area shown in Figure 12.
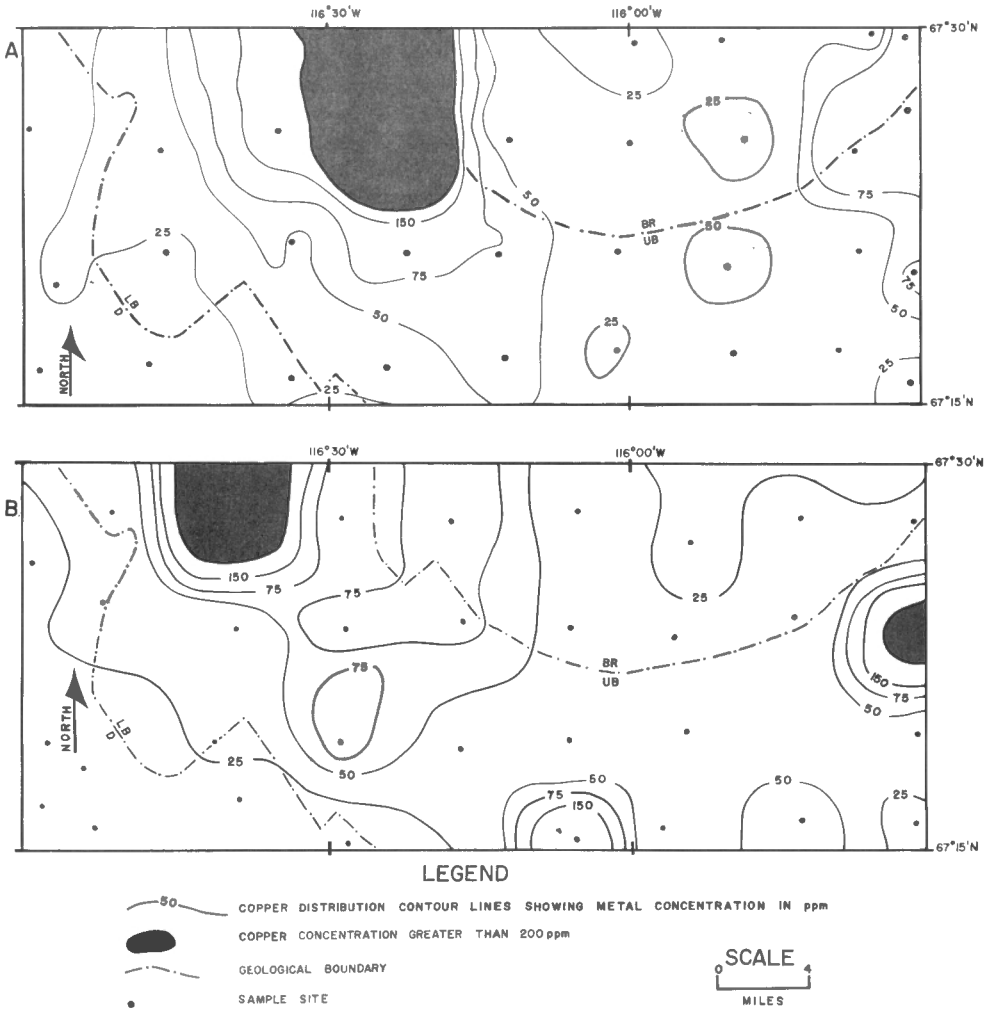
Figure 15. Copper concentrations in lake sediment, Coppermine River area.
           Map based on one sample site every 25 square miles: (A) and
           (B) randomly selected.

To determine such a site density only the hot-leach, sediment results
were used. Sites were selected by having the computer pick a random starting
point within the survey area. A square grid was set up from this point. The
closest sample sites to the centre of the squares in this grid were selected.
Sites were selected from the available points, for two random starting points
at density of:

   (1) one site every 10 square miles (Fig. 14(A) and (B)); and
   (2) one site every 25 square miles (Fig. 15(A) and (B)).

In each case the random starting point results in selection of different sites and thereby different concentrations to be contoured by computer. This closely simulates independent field parties starting from a grid system with its origin at their respective base camps. Comparisons of Figures 12, 14, and 15 show that one site per ten square miles gives the best return of information for number of sites visited and dollars spent. In fact the information relative to trace element distribution and thereby exploration value is virtually the same in Figures 12 and 14. Even at one site per 25 square miles (Fig. 15) the basalt belt is outlined as Cu-rich relative to overlying and underlying rock types and there is an indication of the position of the highest Cu zone. Figure 12(A) and (B) are each based on some 500 sites; Figures 14(A) and (B) are each based on some 75 sites; Figure 15(A) and (B) on some 37 sites each. The cost of sampling each site has been shown to be equivalent to approximately 10 minutes of helicopter time irrespective of site density. One site per 10 square miles is obviously close to, if not, the optimum sample density for the Coppermine basalt area.

(c) Comparison of lake sediment and rock chip results

One rock chip traverse line crossed the geochemical survey area. The variation in Cu concentration on this traverse with depth in the volcanic pile is presented in Figure 16 after Baragar (1969). From this and other traverse lines, Baragar concluded that the upper basalt member was richest in Cu; a conclusion which is borne out areally (Fig. 12) by this regional geochemical survey. To compare the lake sediment results directly with the rock traverse line concerned, a two-mile-wide belt was sampled across the basalts one mile on each side of the rock traverse line. Concentrations from all lakes sampled within this two-mile-wide belt were plotted on Figure 16 at their correct stratigraphic position in the volcanic pile. The lake sediment results show the same trend as the bedrock samples but with a more defined Cu anomaly in the upper basalts. Unfortunately, the rock traverse line ran approximately along longitude 116° 10'W (Fig. 12) and does not pass through the highest Cu area of the upper basalt member located by this survey. From an economic standpoint, the 52 lakes used in Figure 16, were sampled in 9 hours of helicopter time and the field analyses took 1.5 man-days. In total, the results shown for lake sediments in Figure 16 were arrived at in 2 days from initiation of sampling to plotting.

(d) Effects of glacial deposits, structures, and drainage basin on surficial copper distribution

Several statistical relationships between geological and geographical variables, and the texture of lake sediments and thin Cu concentrations are presented in Table 4. The bedrock variations have already been mentioned.

Glacial deposits in the Coppermine area were divided into four groups on the basis of a map constructed from air photographs and provided by the Terrain Sciences Division of the Geological Survey of Canada. The map where it was checked on the ground was very accurate. These four divisions were:
(1) till with rock outcrop;
(2) rock outcrop with till (the till cover was still at least 50 per cent);
(3) water laid deposits; and
(4) colluvial deposits.

ppm Cu in Lake Bottom Sediment

LEGEND

———— DISTRIBUTION OF COPPER IN LAKE BOTTOM SEDIMENTS

------ DISTRIBUTION OF COPPER IN BEDROCK

— · — GEOLOGICAL BOUNDARY

SAMPLE POSITION IN STRATIGRAPHIC SEQUENCE

THICKNESS OF SECTION IN THOUSANDS OF FEET

UPPER BASALTS

MIDDLE BASALTS

LOWER BASALTS

ppm Cu in Rocks
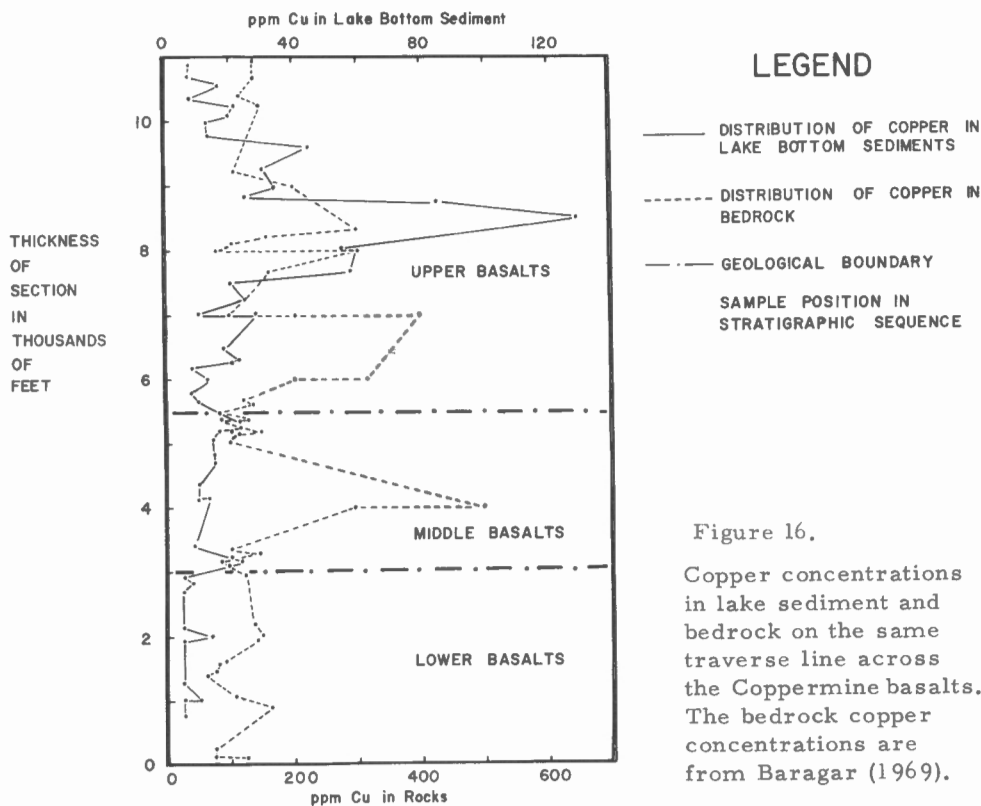
Figure 16.

Copper concentrations in lake sediment and bedrock on the same traverse line across the Coppermine basalts. The bedrock copper concentrations are from Baragar (1969).

The difference in Cu content of lake sediments between areas of deposits (1) and (2) was not noticeable (Table 1(2)). The water laid and colluvial deposits had lake sediments with lower mean Cu concentrations but unfortunately there were few samples classified in this way and those that were happened to be in the low Cu areas.

There is some indication (Table 1(3)), that Cu is concentrated in lakes associated with faults relative to those in the basalts in general. This may imply that Cu concentrations are higher in rocks in fault zones. Lakes on aeromagnetic lineaments have almost the same mean Cu concentration as lakes in the basalts in general. Faults, lineaments and fractures are all common sites for lakes in the Canadian Shield. In a specific type of regional program, lakes could be sampled in such structures as a means of assessing their mineral potential. However, there were just as many anomalous lakes located during the regional survey that were not associated with faults as were.

The mean Cu concentration in lakes from the Richardson drainage basin is three times as high as that in lakes in the Coppermine basin (Table 1(4)). By sampling a sufficient number of lakes, drainage basins of different mineral potential may be separated. If the Coppermine basin were eliminated from Figure 1, the search area would have been reduced by about 60 per cent.

Notably, the 47-zone drains to the Richardson. By comparing Figures 1 and 14, a sample density of one site per ten square miles could also be used to selectively grade river basins as to mineral potential. The remaining variables in Table 4 have been mentioned previously.

(e) Effects of known mineral occurrences

One of the factors that made the Coppermine area such a popular region for renewed surges of exploration is the presence of innumerable small copper showings (Kindle, 1970). In the area covered by this survey (Fig. 1), there are 75 documented mineral showings (E.D. Kindle; R.V. Kirkham; and Coppermine River Co., Ltd., personal communications). The types and origins of mineralization are documented by Kindle (1970). Some of these occur in the area outlined as higher in Cu by the regional results. However, many more are in areas where the lake sediments have very low Cu concentrations. The showings are, of course, where the bedrock outcrops but this does not appear to be the major influence on Cu concentration in lakes. For example, there is considerable outcrop and numerous showings in the southern thirds of sheets 86 N/8 and 86 O/5, and the western third of sheet 86 N/7. Lake water and sediment Cu concentrations in these areas are relatively low (Figs. 9 and 12 (A and B)).

At 54 of the showings where lakes occurred nearby, a sediment and a water sample were taken from the closest lake to the mineralization at the point closest to the showing. The results are given in Table 5. The showings are listed in decreasing order of Cu concentration in lake sediment. In Table 6, all sample sites with more than 500 ppm Cu in lake sediment are listed in decreasing order of hot HNO_3 extractable Cu. It can be seen that only six sites are common to Tables 5 and 6 and that two of these six are the closest lakes to the 47-zone deposit. In Table 6, the Cu concentrations in sediments of lakes near some of the showings, especially the 47-zone may be influenced by contamination. If so, then the greatest known occurrences of Cu may be falsely represented amongst the list of highest Cu concentration lakes located in the regional survey (Table 6). Otherwise, the relative importance of the showings (Table 5) shows that the 47-zone, Lars Showing and East-Grid, the three largest Cu finds in the surveyed area so far, would have been drilled amongst the first five. The methods described here may be of great importance in the assessment of degree of mineralization represented by visible mineral showings.

3. Zinc in Lake Sediment

The distribution of Zn in lake sediment (Fig. 17) closely follows that for Cu (Fig. 12). From the dolomites to the upper basalts the contrast for Zn is fourfold, for Cu tenfold. Only one extremely high Zn value was located (Allan, 1971) and this is not considered significant, although no explanation for it presently is known. In general the Zn occurs over a wider area, i.e. through a greater thickness of the volcanic pile. This is comparable with rock chip data (Baragar, 1969) and is probably related to the differentiation of the basalt magma.

Table 5
Copper concentrations in lake sediment from lakes
close to the known mineral showings of the area covered
by the regional geochemical exploration survey.

Mineral showing name	Distance of lake from mineral showing	Total Cu in lake bottom sediment[1]	Total Zn in lake bottom sediment[1]	Partial Cu in lake bottom sediment[2]
	miles		ppm	
47-zone (about 3 million tons Cu ore)	0.50	1815	127	1120
LARS	0.00	1533	96	1120
EAST-GRID	0.50	1527	95	360
47-zone (3 million tons Cu ore)	0.25	1224	150	480
KIL	0.00	870	55	390
DOT-106	0.25	633	134	330 [3]
JACK	0.00	334	72	190
TOLVO	0.00	266	166	60
HUSKY	0.25	195	86	110
24	0.50	163	69	73
K-GRID	0.50	158	50	73
KIL	0.25	151	50	85
TOLVO	0.25	144	73	55
MAB-9	0.50	142	93	83
CAM	0.50	123	83	nd[4]
DOT-;8, 20	0.00	117	69	55
7	0.25	113	132	65
MGB-325	0.00	109	53	40
MGB-101-180+	0.00	107	75	45
CAM	0.00	102	79	nd

Note: The following 34 mineral showings produced total copper concentrations
of less than 100 ppm in the bottom sediments of the nearest lake:

JIM M92-502	BUD 398-415	PAW
RAY	S-179-180	DIZ
DOT 145-156	GUY-1-30	DICK-PICKLE CROW
CORONATION	SAM	OOK
VIC	JIM N92-502	SWAK 11
19	18	BUD 942-949
BUD-AG-CASINO	SAL	CASINO-BUD
ROB MGB-277	DOT-725	20
PRO-HOC	JIM-N-93301-413	MAR-117
DOT-881	MGB-277	ALF
HM	IS-158	JOK
		MAR-1-100

The listing is in decreasing concentration of total Cu in lake bottom sediment.
[1]Total Cu and Zn are determined by a hot-HCl-HNO3 leach and atomic absorption spectroscopy.
[2]Partial Cu was determined in the field by a cold HCl leach and colorimetry.
[3]Showings above this line are included in Table 6 which lists the Cu concentrations of lake sediments above 500 ppm Cu, using a hot HNO3 leach.
[4]No analysis done in the field.

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Table 6

Copper concentrations in lake sediment from lakes sampled in the regional geochemical exploration survey.

Mineral showing name	Distance of lake from mineral showing (miles)	Total Cu in lake bottom sediment[1]	Total Zn in lake bottom sediment[1] (ppm)	Partial Cu in lake bottom sediment[2]
-[3]	-	2674	181	960
-	-	2450	94	1520
47-zone (3 million tons Cu ore)	0.50	1815	127	1120
LARS	-	1663	95	600
-	0.00	1533	96	1120
EAST-GRID	0.50	1527	95	360
-	-	1512	116	680
-	-	1464	188	640
-	-	1425	179	720
-	-	1330	127	960
47-zone (3 million tons Cu ore)	0.25	1224	150	480
-	-	982	72	1600
-	-	924	50	320
KIL	0.00	870	55	390
-	-	817	132	280
-	-	771	98	380
DOT-106	0.25	633	134	330
-	-	627	156	240
-	-	624	60	290
-	-	612	166	320
-	-	602	75	240

In all, 657 lake bottom samples were collected. As a contrast for the concentrations given, background concentration in the area underlain by dolomites were about 10 ppm Cu and in the lower basalt member about 25ppm Cu.

[1] As for Table 5.   [2] As for Table 5   [3] No known showing in the vicinity of lake

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LEGEND

ZINC DISTRIBUTION CONTOUR LINES SHOWING METAL CONCENTRATION IN ppm

ZINC CONCENTRATION GREATER THAN 100 ppm

GEOLOGICAL BOUNDARY
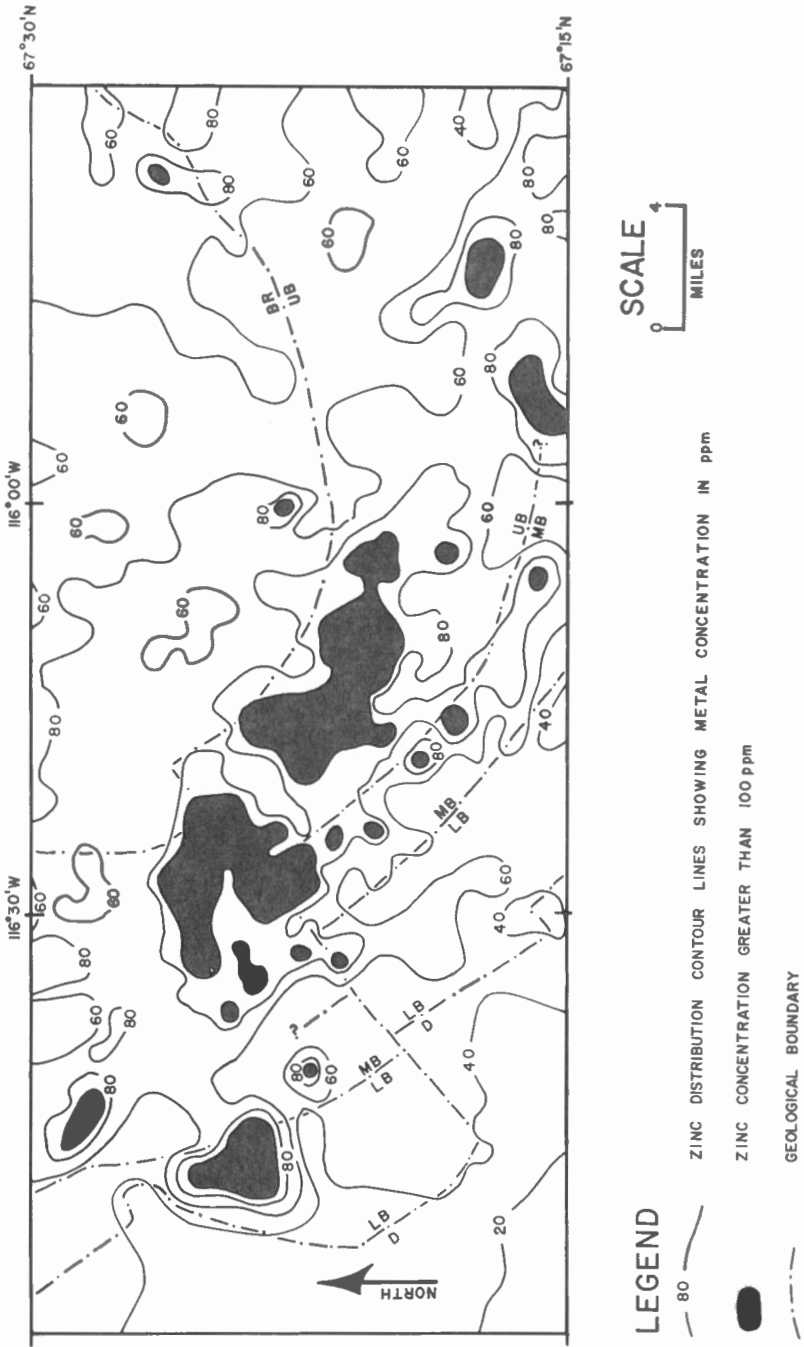
Figure 17. Zinc concentrations in lake sediment, Coppermine River area.

CONCLUSIONS

A significant quantity of data is presented to show that weathering leaching, and periglacial processes in the cold desert area of the Coppermine River region in the zone of continuous permafrost, have been sufficient to produce dispersion of Cu and Zn in the surficial environment, in particular into lake sediment but also lake water. In general, when excess economic trace elements exist in rocks, whether outside or inside permafrost of the Shield, regional differences should be manifested in lake sediments and in lake water as these media enclose the final leaching, weathering and transport processes in the surficial environment.

The major objectives originally outlined for the regional geochemical exploration survey of the Coppermine basalt area and the methods by which they were to be tested have been completely satisfied. These major objectives were to determine the sample density necessary to outline the Coppermine River basalts; to determine the sample density necessary to outline within this group, members or areas with significantly higher copper concentrations, should such areas exist. The method of lake sediment sampling supplemented by lake water sampling is a feasible regional geochemical exploration tool for the Coppermine River area both for regional selection of areas of interest and[1] for identification of drill targets. Whether it can be used more generally in Canada will depend on the sample site densities required and on the applicability of the method to other geological terranes and to other types of deposits. One sample per ten square miles was found to be suitable in the Coppermine area, but in other areas where sulphides are not so widely distributed in the host rocks greater sample densities may be required. At present based on similarities of rock type, the method may be quickly applied to the volcanic areas of Bathurst Inlet and Victoria Island, and possibly parts of the Cape Smith-Wakeham Bay belt and Labrador Trough.

Future operations of this type should use Bell 47G4A helicopters rather than G2's particularly if long distances are involved. Sampling even at density of one site per ten square miles will probably indicate the most favourable areas for detailed exploration. At this density, an area of 1,000 square miles can be sampled and the results obtained in the field laboratory in less than one week.

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[1] Areas of interest as referred to in this paper are defined as those which have abnormally high contents of economic trace elements widely dispersed in the surficial environment. Such areas are likely to reflect higher than normal trace element concentrations in the underlying rocks and thus are likely locations in which to search for ore deposits.

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APPENDIX 1

METEOROLOGICAL DATA FOR JULY, AUGUST AND
EARLY SEPTEMBER, HOPE LAKE AREA, N.W.T., CANADA

During the months of July, August and early September, climatic data was noted each day at 7:00 a.m. The data was collected and compiled by T. Alvero, of Precambrian Mining Services Ltd.

1970 - Field Season

Month	Date	Ceiling in feet	Visibility in miles	Temperature in °F		Wind direction and speed in m.p.h.	Remarks
				High	Low		
July	1	5,000	20	70	60	SE5	overcast
	2	4,000	15	70	63	S10	scattered cloud
	3	500	2	60	44	neg.	overcast
	4	6,000	20	60	48	SE10	scattered cloud
	5	clear	unlim.	62	48	E2	sunny
	6	clear	unlim.	70	64	S10	sunny
	7	clear	unlim.	70	60	SE10	sunny
	8	5,000	25	62	54	E5	scattered cloud
	9	300	1/2	38		N15	fog clearing
	10	1,500	15	52	40	N15	cloud clearing
	11	clear	unlim.	60	48	E2	sunny
	12	clear	unlim.	62	50	E5	sunny
	13	clear	unlim.	62	46	E5	sunny
	14	clear	unlim.	60	42	neg.	sunny
	15	5,000	unlim.	62	46	NE5	25% overcast
	16	3,000	unlim.	62	44	NE5	75% overcast
	17	clear	unlim.	64	48	E5	sunny
	18	clear	unlim.	64	56	S8	sunny
	19	5,000	unlim.	66	58	SE2	25% overcast
	20	zero	zero	56	42	NE10	heavy fog
	21	zero	zero	56	40	N5	heavy fog
	22	zero	zero	60	40	NE5	fog
	23	clear	unlim.	56	44	E10	sunny
	24	5,000	20	66	39	S15	overcast
	25	500	1	64	44	N20	overcast, fog
	26	zero	5	49	34	NW20	low, overcast, rain
	27	zero	1/2	54	34	W15	50% overcast
	28	zero	zero	46	36	NE20	heavy fog
	29	2,000	15	47	36	ENE10	overcast
	30	1,000	2	50	32	ENE15	overcast
	31	clear	unlim.	48	30	E5	sunny

Month	Date	Ceiling in feet	Visibility in miles	Temperature in °F		Wind direction and speed in m.p.h.	Remarks
				High	Low		
August	1	clear	unlim.	56	36	S8	sunny
	2	2,000	2		48	W25 pm	overcast, rain
	3	clear	unlim.	48	41	W45-65	gusty wind
	4	3,000	10	52	43	NW10	overcast
	5	3,500	8	48	46	SSE25	overcast, rain
	6	2,000	2	60	45	WNW10	overcast
	7	5,000	15	57	45	E10-25	ceiling, vis. decreasing fast rain, fog-3:00
	8	zero	zero	44	42	NNE5-15	fog, drizzling rain
	9	zero	zero	54	42	NE10	heavy fog
	10	zero	zero	43	40	NE25	fog and rain
	11	zero	zero	46	41	NNE25	rain, fog; wind N at 2:00 pm
	12	1,000	1	43	42	N30-40	rain, overcast
	13	zero	zero	52	40	NE20	heavy fog
	14	6,000	unlim.	56	42	W5	clearing
	15	zero	zero	46	43	E5	heavy fog, wind ENE at 20 mph in pm, rain
	16	zero	zero	44	38	NE30	heavy fog, rain
	17	1,000	4	34	34	NE35-48	overcast, rain
	18	clearing	unlim.		35	NNE20	fog bank 1 mi W
	19	clear	unlim.	51	29	SSE14	wind SSW at 25 mph in pm.
	20	3,000	5	48	39	S15	overcast, rain; wind W late pm
	21	4,000	10	60	40	SSW10	overcast, rain
	22	5,000	unlim.	62	47	SSW5	scattered cloud, rain
	23	6,000	unlim.	56	47	neg.	fog bank to WNW, rain
	24	zero	zero	44	40	N20	overcast, fog
	25	4,000	unlim.	48	40	neg.	scattered cloud
	26	clear	unlim.	52	40	SSW15	scattered high cloud
	27	overcast 1,000	2	44	32	NE30	sleet, snow, overcast
	28	4,000	10	46	32	W20	overcast at 4,000'
	29	6,000	unlim.	60	40	S30-40	overcast at 6,000'
	30	clear	unlim.	67	40	S35-45	sunny 50-60 mph at 6 pm
	31	2,000	2	38	30	N40-50	overcast, rain

Month	Date	Ceiling in feet	Visibility in miles	Temperature in °F		Wind Direction and speed in m.p.h.	Remarks
				High	Low		
September	1	4,000	unlim.	45	30	neg.	75% overcast
	2	3,000	10-15	40	38	S14	overcast, rain
	3	zero	zero	44	39	10NNE	fog
	4	3,000	1	46	33	E25	overcast, fog
	5	2,000	8	49	40	SE40	overcast
	6	zero	zero	43	32	N35	fog
	7	zero	3,000	32	30	N40	fog, blizzard, snow
	8	zero	zero	29	26	NW50	drifting snow
	9	1,000	2	26	24	NW25	snow
	10	2,000	7	30	20	NW15	overcast

APPENDIX 2

FIELD ANALYTICAL TESTS AND EQUIPMENT LIST:
Cu IN WATER AND SEDIMENT

Both the water and sediment field analytical tests for Cu used 2, 2'
biquinoline, as the Cu indicator (Canney and Hawkins, 1958). The prepara-
tion of reagents; water test and standard preparation; sediment test and
standard preparation; and field laboratory equipment required is described
in detail below.

(a) Preparation of reagents

The Cu buffer solution is prepared as follows: dissolve 800 gm sodium
acetate, 200 gm sodium tartrate and 40 gm hydroxylamine hydrochloride
in 2 litres of metal-free water. The pH of this solution should be between
6 and 7 and should be adjusted with 1N NaOH if necessary; pour the solution
into 2 two-litre separatory funnels and add 50 ml of 0.01% dithizone in carbon
tetrachloride to each funnel; shake vigorously for 60 seconds and allow the
layers to separate; drain and discard the dithizone layer; if the layer was
blue or pink repeat the extractions until the dithizone remains green; after
extraction with dithizone, extract two or three times with carbon tetrachloride
to remove excess dithizone.
The biquinoline solution is prepared as follows:
Weigh 0.2 gm 2, 2' biquinoline into a 1,000 ml beaker calibrated at 1,000 ml;
add 900 ml iso-amyl alcohol and warm with stirring on a hot plate; this oper-
ation should be carried out in a fume hood away from an open flame; when the
biquinoline has dissolved, cool to room temperature, dilute to 1,000 ml with
iso-amyl alcohol and mix; store solution in a glass bottle with a ground glass
stopper.
The dithizone solution is prepared as follows:
Dissolve 40 µg dithizone (diphenylthiocarbazone) in 400 ml carbon tetra-
chloride; store solution in a glass bottle with a ground glass stopper and keep
in a refrigerator. Also prepare 100 ml 1N HCl; 100 ml in NaOH and 4,000
ml of 6N HCl.

(b) Water test

Pour 100 ml of water into a 100-ml graduated cylinder; add 10 ml of Cu
buffer using an automatic dispenser; add 5 ml of biquinoline; stopper and
shake vigorously for 60 seconds; allow the two layers to separate and com-
pare the upper colour with the standards. If the colour is above the top
standard, smaller aliquots of water are used. Carry on with smaller aliquots
until the colour can be read.
Water standards are prepared by dilution of appropriate quantities of
1 µg/ml standard Cu solution in 100 ml deionised water to produce standards
of 0, 2, 4, 6, 8 and 10 ppb Cu respectively.

(c) Sediment test

Weigh 0.2 gm of sediment into a clean test tube (18 mm x 150 mm) cali-
brated at 10 ml. Larger or smaller sample weights may be used depending

on the concentration of Cu in a given area. Add 1 ml of 6N HCl and swirl
the sample in the acid for 30 seconds. Dilute to 10 ml with metal free water,
2 minutes after contact with the 6M HCl. Mix well, and allow to stand for
45 minutes. Pipette 2 ml of the test solution into a test tube containing 10 ml
of Cu buffer. Add 1 ml of biquinoline solution. Cork and shake vigorously
for 30 seconds. Allow the layers to separate and compare the colour of the
layer against standards. If the copper concentration is greater than 2 µg,
add 1 ml of biquinoline solution and compare. Alternately repeat the test
with a smaller aliquot of test solution.

Sediment standards are prepared as follows:
Into each of 10 test tubes (18 x 150 mm) add 10 ml of buffer solution and 1 m
of 1N HCl; pipette in suitable quantities of 5 µg/ml standard Cu solution to
give resulting concentrations of 0, 0.5; 1.0; 1.5; 2.0; 2.5; 3.0; 3.5 and
4.0 µg of Cu. Add 1 ml of biquinoline, cork and shake vigorously for 30
seconds. These standards are good for a month but should be stored in the
dark.

(d) Field Equipment Required

A small field laboratory was set up in one of the Coppermine River Co. Ltd.
huts at Hope Lake. The list of equipment and chemicals required in the field
is reduced to the absolute essentials. Duplicates in case of breakage or
spillage are not included in the lists. The list assumes that only one person
is doing analyses perhaps with some help in cleaning test tubes etc. by other
members of the field crew.

i. Either test requires:

1	Fluorescent lamp or illuminator
2	Five gallon polyethylene carboys
1	Retort stand
4 feet	Tygon plastic tubing
4	Plastic screw clamps
4	Finger pressure clamps
6	Polyethene wash bottles
3	Glass chemical jars
1	Automatic polyethene squeeze dispenser, 10 ml aliquots for Cu buffer
1	Pipette rack
1	Pipette, 1 ml, graduated
1	Pipette, 2 ml, graduated
1	Stop clock alarm
25 boxes	Kleenex tissues
6	Pada, result sheets
1	Basin
	Mixed bed mineralizers (quantity depends on number of analyses)

ii. Water test requires in addition to i.:

25	100 ml graduated cylinders with ground glass stoppers
2	5 ml serological pipettes

ii. Water test requires in addition to i.: (cont.)

1	pH meter-model N, with spare batteries and electrodes
25	50 ml beakers

iii. Sediment test requires in addition to i.:

3	Test tube cleaning brushes
100	Test tube corks
100	Test tubes (rimless 18 mm x 150 mm calibrated at 10 ml)
2	Test tube stand-10 places
1	Test tube stand-50 places
2	1 ml serological pipettes
1	Torsion balance, 500 µg capacity
2	Sheets of high gloss paper for weighing boats for balance

iv. Collection of water and sediment samples requires:

Polyethylene sample bottles (size of sample depends on number of elements to be analyzed for), 500 ml
Waterproof sample bags for sediments
Thermometer for water temperature
Notebooks
Numerous pens and magic markers

v. Preparation of the sediment samples requires:

2	<80 mesh sieves
2	Fine hair brushes for sieves
2	Rubber mallets
10	Scribble pads for sieving - or pans for sieve
Several boxes	Kleenex tissues to wipe sieves
	Plastic vials to contain sieved samples

vi. Pre-field equipment:

Before going into the field suitable quantities of all reagents should be prepared in a laboratory requires separatory funnels, a reagent balance, water-still, numerous beaker sizes and volumetric flask sizes, hot plate and magnetic stirrer and stirring bar. Also test tubes should be calibrated at 10 ml with a file or glass marking pen before going to the field.

vii. Reagents required to analyze 1,000 sediment and 1,000 water samples

Mixed bed resin deioniser column	5
5 mg/ml Cu standard solution	100 ml
1 mg/ml Cu standard solution	100 ml
Cu buffer	20,000 ml

vii. Reagents required to analyze 1,000 sediment and
      1,000 water samples

0.02% 2,2' biquinoline	12,000 ml
6N HCl	2,000 ml
pH 7 buffer	1,500 ml
pH 6 buffer	1,000 ml
Saturated KCl solution	50 ml
Conc. HNO_3	1,000 ml