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GEOCHEMICAL EXPLORATION FEASIBILITY STUDY WITHIN THE ZONE OF CONTINUOUS PERMAFROST; COPPERMINE RIVER REGION, NORTHWEST TERRITORIES

(Report, 4 tables, 16 figures and appendices)

E. H. W. Hornbrook and R. J. Allan

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CONTENTS

TABLES

APPENDICES

ILLUSTRATIONS

ILLUSTRATIONS (continued)

ABSTRACT

During the summer of 1969, the authors conducted a geochemical exploration feasibility study in the Coppermine River Basalt Belt, immediately north of Dismal Lakes, Coppermine River area, N.W.T. primarily to evaluate geochemical exploration methods in areas of continuous permafrost. The study was secondarily concerned with the detection of copper mineralization in this basalt series.

Because this was a feasibility study, samples were collected from a variety of surficial materials, O/A, B and C horizons of soils; mineral soil samples from silty frost boils; stream sediments; vegetation and lake waters. Most of the samples came from the vicinity of a known copper ore body (the 47-Zone of the Coppermine River Ltd.) and a mineralized quartz vein (the 13-Showing of the Coppermine River Ltd.). Lake waters were sampled in 25 lakes over an area of about 100 square miles. Background frost boils were sampled on a 25-mile traverse line across the study area. Analysis of all samples was by hot nitric acid leach and atomic absorption spectroscopy.

A study of copper concentrations in 25 lakes revealed that 4 lakes were anomalous, 7 were threshold and 14 were background. Anomalous concentrations were greater than 15 ppb Cu, threshold were about 8 ppb and background about 2 ppb. Significantly, 2 of the 4 anomalous lakes were adjacent to the 47-Zone.

Anomalous concentrations of copper in stream sediments were found only in the two streams which crossed the 47-Zone. For these two, concentrations immediately downstream from the ore body were three to four fold (about 3,000 ppm Cu) those upstream from the ore body (about 800 ppm Cu) in a background area.

O/A horizons were not an entirely satisfactory sample material for exploration purposes because of prolonged time and effort required for collection. Anomalous and regional background B horizon concentrations, 1,000 ppm Cu and 70 ppm Cu respectively, defined an anomalous zone immediately downslope from the 47-Zone ore body. Silty frost boils were collected on only one line across this ore body. A comparison of the anomalous to background ratios for silty frost boils, B horizon and O/A horizon on this line shows the following: silty frost boils, 60-fold; B horizon, 25-fold; and O/A horizon 50-fold. At three sites material from the C horizon in the thawed zone, immediately above the permafrost in the vicinity of the 47-Zone, had substantially higher (17-fold in one case) copper concentrations than B horizon material at the same sites. The phenomenum of increasing copper concentrations with depth was also found in silty frost boils at the 13-Showing, but the increase was considerably less pronounced (a maximum of 2-fold) and occurred only very close to the mineralized quartz vein.

Regional background obtained by analysis of 8 silty frost boil samples collected on a 25-mile traverse is in the order of 45 ppm Cu (range from 20 to 71 ppm Cu). At the 13-Showing analysis of silty frost boil surface samples showed dispersion of Cu to be limited to 100 to 200 feet downslope from the vein.

Results of biogeochemical studies (76 samples were collected over the 47-Zone) indicate that flowering shrubs in stream valleys and certain lichens have an exploration potential.

Dispersion of metals in this area by both physical and chemical processes is sufficient to develop geochemical halos in lakes, stream sediments and soils. Based on the results of this feasibility study, the following multistage approach for geochemical mineral exploration in the Coppermine Basalt Belt would appear to be effective: (1) lake water analysis (one axis of the lake should be at least 1,000 feet, followed by (2) stream sediment analysis (sample every 1,000 feet), followed by (3) silty frost boil surface soil analysis (sample every 100 feet on traverse lines or grids).

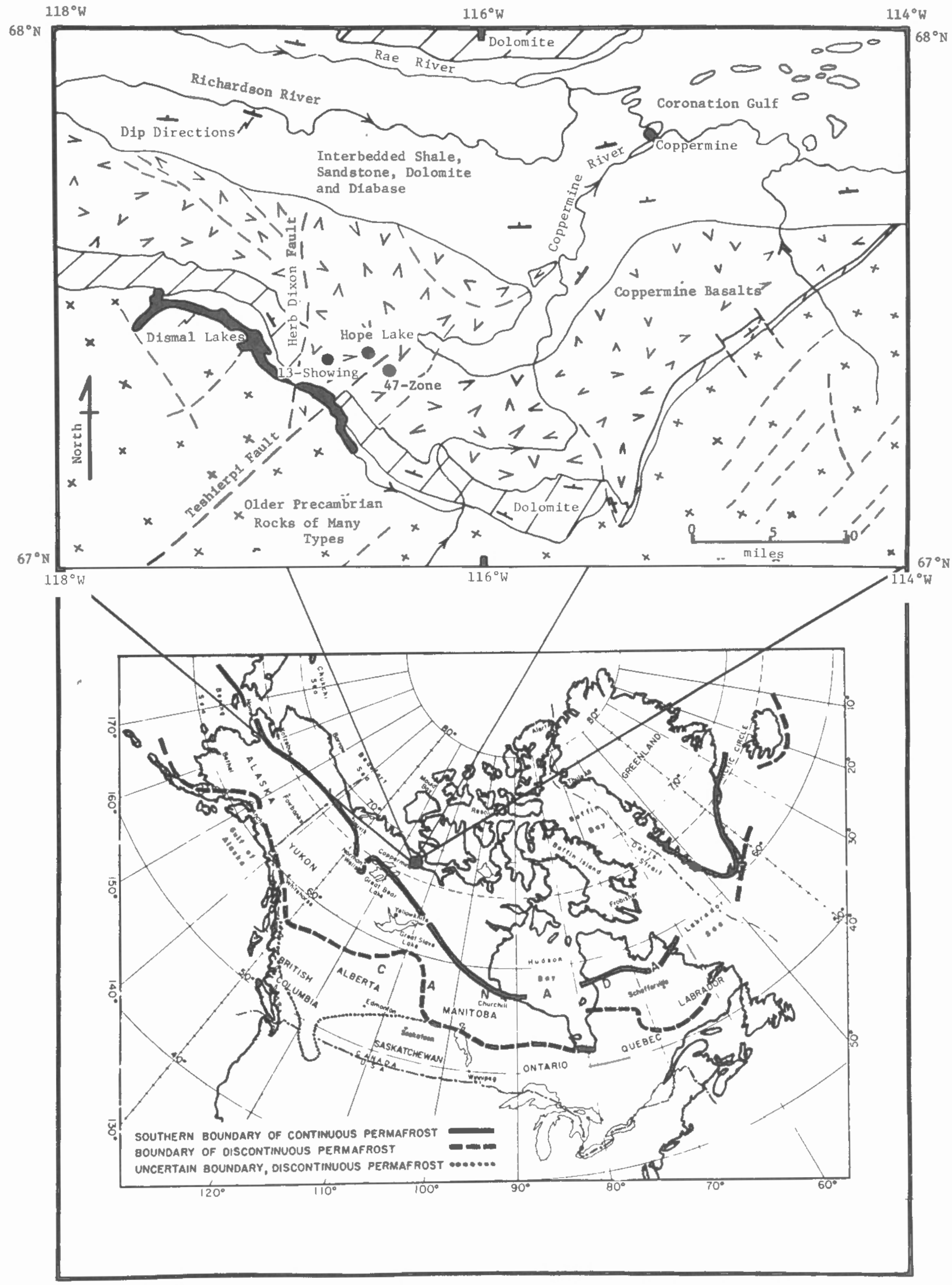

Figure 1. Location map of study area showing distribution of permafrost in Canada, general geology of the Hope Lake area (after Baragar and Donaldson, 1970), and location of the 47-Zone and 13-Showing.

GEOCHEMICAL EXPLORATION FEASIBILITY STUDY WITHIN THE ZONE OF CONTINUOUS PERMAFROST; COPPERMINE RIVER REGION, NORTHWEST TERRITORIES

INTRODUCTION

Development of geochemical exploration methods and the collection of geochemical data in regions of discontinuous and continuous permafrost have been seriously neglected in the past in North America. A program was initiated by the Geological Survey of Canada in 1969 to develop geochemical exploration techniques for permafrost regions and this report describes a preliminary study involving collection, preparation and analysis of soil, stream sediment, frost boil, vegetation and water samples from the vicinity of Hope Lake in the Coppermine River region of the Northwest Territories (Fig. 1). Two principal sites were examined, the 47-Zone (Fig. 2) and the 13-Showing (Fig. 3). Both are mineralized copper showings on ground held by the Coppermine River Ltd. This report details specific approaches to geochemical exploration within the Coppermine Basalt Belt which are also of potential value in other permafrost areas.

Hope Lake is 350 miles due north of Yellowknife and 35 miles southwest of the village of Coppermine on the Arctic coast. Summer access to the Hope Lake area is by aircraft from Yellowknife, although supplies can be brought in by winter road. The Hope Lake area was chosen because it contains the 47-Zone which at present is the only body of possibly economic size that has so far been located in the long-known (Tyrrell, 1913) highly copper-mineralized basalts of the Coppermine River Group. Further, the cold desert (Table 1) Coppermine area lies within the zone of continuous permafrost. The 13-Showing was also investigated as it represents a second type of mineralized occurrence, a vein as opposed to a fault breccia type and because the surface soils were more representative of the Hope Lake area in general than those found at the 47-Zone.

To the best of our knowledge previous geochemical investigations, of any size and extent, in areas of continuous permafrost in North America, are nonexistant. However, some geochemical exploration has been conducted by a few of the smaller companies active in the Northwest Territories. Only very few geochemical studies are reported in the literature, even for the discontinuous permafrost zone in Canada, such as at Keno Hill – Galena Hill (Boyle et al., 1954, 1955, 1956; Boyle and Cragg, 1957; Boyle, 1965). In the discontinuous permafrost region of southern Alaska, geochemical prospecting

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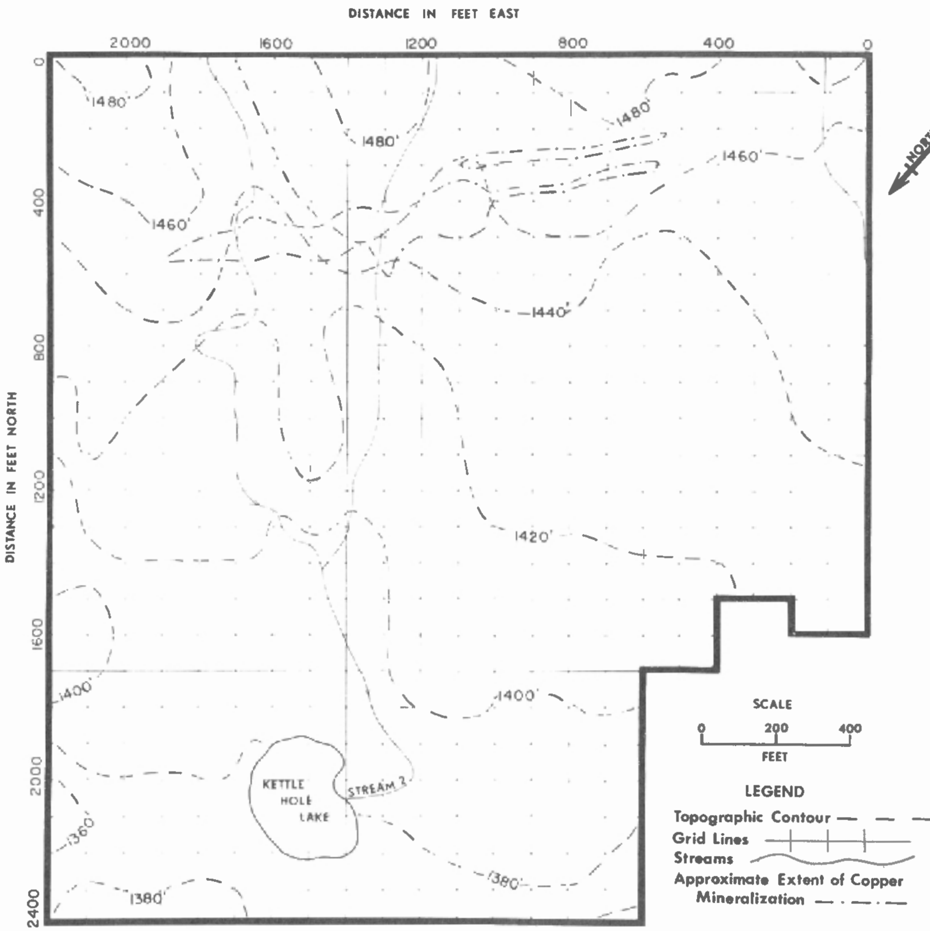

Figure 2. Topography and sample grid at the 47-Zone.

has been mainly limited to stream sediment sampling using the available road system (Burand, 1966, 1968; Burand and Saunders, 1966). This limited activity stands in contrast to the fact that Canada has some 2 million square miles or almost 50 per cent (a greater area than that of any other country except the U.S.S.R.) of its land area underlain by permafrost. A great deal of exploration geochemistry in the permafrost regions of the U.S.S.R. is believed to be reported in the Soviet literature but this material is usually contained in journals unavailable in the West or which are not translated.

TABLE I

CLIMATIC DATA FOR THE VILLAGE OF COPPERMINE*

Latitude 67°49'N – Longitude 115°05'W – altitude above M.S.L. -28 Feet

Month	Air Temperature							Percentage Frequency of Days with Minimum Temperatures at or Below-				Mean Cloud Amount - 10ths of Sky Covered
	Mean Daily	Mean of Daily		Mean of Monthly		Absolute Extreme						
		Maxi-mum	Mini-mum	Maxi-mum	Mini-mum	Highest Re-corded	Lowest Re-corded	-10°F	-20°F	-30°F	-40°F	
	°F	°F	°F	°F	°F	°F	°F					
Jan.....	-20.3	-13.3	-27.2	9	-45	27	-54	95	76	45	13	5.3
Feb	-24.8	-17.9	-31.7	5	-47	34	-58	98	86	63	25	4.3
Mar	-15.9	- 8.6	-23.1	17	-42	29	-56	87	64	31	6	4.6
Apr	1.1	9.9	- 7.8	35	-31	46	-47	47	25	7	1	5.3
May	22.1	28.7	15.4	50	- 7	74	-24	5	0	0	0	6.7
June....	37.4	43.2	31.6	65	21	82	5	0	0	0	0	6.7
July[3]...	48.0	55.0	41.0	75	34	87	31	0	0	0	0	6.5
Aug[3]....	48.0	54.4	41.6	74	32	83	27	0	0	0	0	7.1
Sept	36.9	41.4	32.3	59	18	79	7	0	0	0	0	8.0
Oct.....	19.9	25.1	14.7	41	7	57	-28	3	0	0	0	7.9
Nov	- 4.0	2.6	-10.6	23	-32	36	-42	52	25	7	0	6.2
Dec	-15.0	- 7.8	-22.1	11	-41	31	-49	87	63	28	7	5.2
Year ...	11.1	17.7	4.5	77	-50	87	-58					6.2
Period..	1951-60					1930-60		1951-60				

Month	Precipitation					Wind			Mean Days with-		Freezing and Thawing Degree-Days	
	Rain		Snow		Total (water)	Most Prevalent		Aver-age Speed	Fog-Visi-bility Less than 5/8 Mile	Blowing Snow-Visi-bility 6 Miles or less		
	Mean Amount	Days	Mean Amount	Days	Mean Amount	Direc-tion	Per-centage				Below 32°F	Above 32°F
	in.	No.	in.	No.	in.			m.p.h.				
Jan.....	0	0	2.8	8	0.28	SW	33	12.2	-[2]	9	1,636	0
Feb	0	0	1.6	5	0.16	W	32	10.5	1	5	1,610	0
Mar	0	0	3.4	8	0.34	SW	28	9.2	-[2]	5	1,458	0
Apr	0	0	2.7	5	0.27	W	29	8.7	1	4	937	1
May	0.05	1	2.2	5	0.27	W	20	8.5	4	2	329	25
June....	0.44	5	1.4	3	0.58	N	26	8.5	4	-[2]	22	180
July[3]...	0.94	9	0.6	-[2]	1.00	NE	26	9.6	2	0	0	498
Aug[3]....	1.76	10	-[1]	-[2]	1.76	NE	19	10.0	2	0	0	490
Sept	0.77	9	1.4	3	0.91	N	17	11.0	2	-[2]	27	186
Oct.....	0.11	1	6.6	11	0.77	SW	28	12.0	-[2]	2	388	12
Nov	0	0	5.2	11	0.52	W	28	11.0	1	5	1,065	0
Dec	0	0	3.7	9	0.37	SW	30	10.3	-[2]	8	1,482	0
Year ...	4.07	35	31.6	68	7.23			10.1	17	40	8,954	1,392
Period..	1951-60									1955-60	1950-59	

1 Average of less than 0.05 in.
2 Average of less than 0.5 day.
3 Best summer months for geochemical sampling programs.
* From Department of Transport, Coppermine, Northwest Territories.

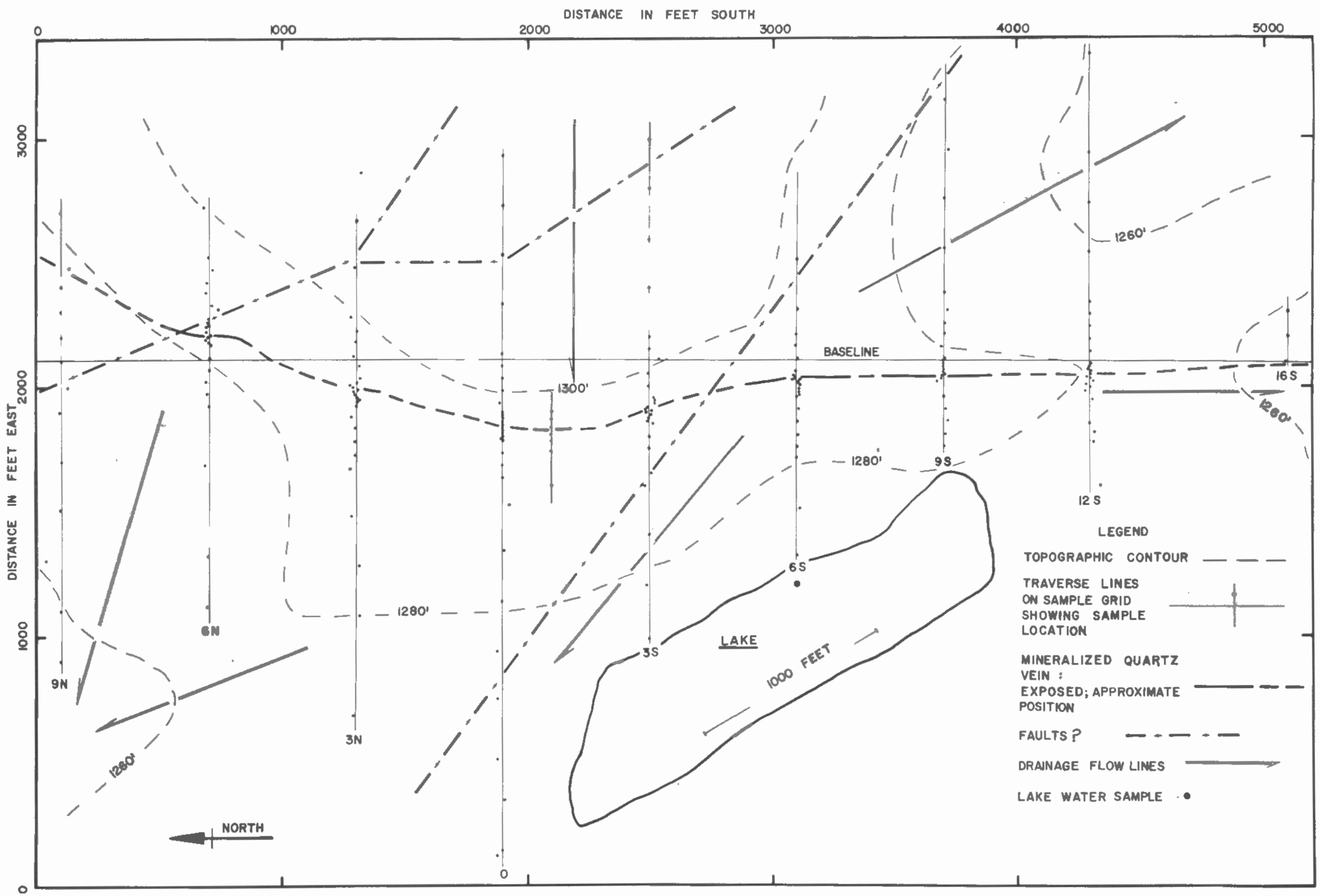

Figure 3. Topography and sample grid at the 13-Showing.

Acknowledgments

The authors wish to acknowledge the assistance of and thank the following people and organizations: Mr. David Coombes, Department of Anthropology, University of Victoria, who assisted with the field sampling; the officials of the Coppermine River Ltd., who gave permission to carry out the geochemical work on their property (information concerning the property, in the report, has been reviewed by the staff of the Company); Mr. J.J. Lynch under whose direction the laboratory analyses were carried out in Ottawa; the staff of the Hope Lake Mining Camp for their assistance during the field season; Mr. D. Hobbs who provided data processing and computing services; the analytical section of the Inland Waters Branch who determined the cation contents of the lake waters; Dr. B.G. Craig and Mrs. L. Arsenault who provided quaternary geological data which was of considerable help in carrying out the feasibility study.

General Description of the Landscape

Baragar and Donaldson (1970) have described the geology of the Coppermine region. The two main sites investigated lie in the Coppermine River Basalts, a belt approximately 120 miles long by 8 to 24 miles wide and with an estimated thickness of 14, 500 feet. Whereas the upper 4, 500 feet is composed of interlayered volcanic and sedimentary rocks, the lower 10, 000 feet is volcanic rocks only. The basalts are underlain by the Hornby Bay Dolomites (Fig. 1) and are overlain by 15, 000 feet of interlayered sandstones, shales and dolomites. The age of the Coppermine River Group ranges from 1, 200 for the lower to about 740 million years for the upper formations (Baragar, 1969). Flows in the basalts dip gently to the north at 0 to 11 degrees. The west portion of the belt is a gently dipping anticline with a northeast-trending axis; the central and east portion a gently dipping syncline with a north- to northeast-trending axis which plunges gently north. Faults in the basalts usually trend northeast to northwest and are either normal or strike slip faults.

The 47-Zone was discovered by the Coppermine River Ltd. in 1967. As outlined it is a 4.1-million-ton body averaging 2.96 per cent Cu, allowing 10 per cent dilution, and 0.6 per cent Cu in the wall-rock and is located in a feather fault off the main Teshierpi Fault. The fault is 48 miles long, trends north 50 degrees east, has a vertical dip, and is right lateral shear (see Fig. 8). The 47-Zone ore, exposed as a highly brecciated malachite-stained basalt outcrop in a prominent cut between two basalt ridges, occurs in a steeply dipping breccia zone which cross-cuts the basaltic flows. This zone of intense brecciation is some 800 to 1, 000 feet southeast of the Teshierpi Fault and may have been formed by competent basalts being dragged along the shear zone. The breccia zone host rock has a vertical dip and swells and pinches but is consistent over 1, 600 feet of strike length. The main economic minerals are chalcocite and bornite with minor chalcopyrite, covellite and pyrite. Sulphide minerals occur as: coarse disseminations and/or massive stringers in the interstices of the breccia; fine disseminations in the massive basalt; and amygdules in the flow tops. The mineralized zone has an average width of between 60 and 190 feet, the top is horizontal but the bottom has a gentle plunge to the southwest.

The 13-Showing consists of a mineralized quartz-vein 7 miles west of Hope Lake (see Fig. 8). The vein is 2 to 4 feet wide over some 4 miles of length and consists of massive sulphides, mainly bornite, in quartz. There are also minor quantities of chalcopyrite and pyrite but the vein is not of economic importance.

The Coppermine region is an area of intense Pleistocene glaciation with numerous features of both severe glacial erosion, such as roches moutonées at the 13-Showing, and glacial deposition, such as the esker complexes near the 47-Zone. The present climate is cold desert and many periglacial features such as frost boils, scree slopes, mud blisters, and ice wedge polygons abound.

In spite of the complexity of glacial deposits (Fig. 4) Arctic Brown soils cover most of the 47-Zone (Fig. 5) and are developed on both till and outwash (Descriptions (a) and (b) respectively in Appendix A). There are, however, a few areas where the 'soil' consists of little more than the vegetation-covered shear zone breccia (Description (c) in Appendix A). Based on the frost boil traverse line collected across the Basalt belt, the distribution of Arctic Brown soils (Fig. 6) generally appears to be very limited, and they occur only on very coarse deposits such as eskers or kame terraces. The Arctic Brown soils at the 47-Zone are possibly two-storey as they consist of a silt loam B horizon on a coarse gravelly loamy sand till or outwash C horizon. It is hard to imagine a process that would produce this drastic textural change in one original material. Also near the 47-Zone, the C horizons above the permafrost table are calcareous (see pH in profile descriptions (a) and (b), of Appendix A) and have cobbles covered in a white precipitate identified by X-ray diffraction as $CaCO_3$. This feature is in agreement with the cold desert climate of the area and also demonstrates that active solution and leaching of the soils occurs above the permafrost, which in this coarse till or outwash, was usually encountered at a depth of about 3 to 4 feet (Description (a) and (b) in Appendix A). The movement of water above the permafrost and through the active layer is both rapid and complex, as small kettles at the 47-Zone (see Fig. 9) would rapidly fill, then drain and the smaller streams would flow then quickly dry up after only slight rainfall, during a 24-hour period.

In general, however, the Coppermine region is more characterized by silty colluvium with numerous frost boils (Fig. 7), as at the 13-Showing. This showing is a planar hill slope with an active silty surface layer usually about 2 to 3 feet thick directly on bedrock. No Arctic Brown soils were found at the 13-Showing.

In general, the frequency of boils appears to be controlled by active layer texture, slope and latitude. In the Hope Lake area, density of boils is greatest in fine textured, flatter areas. In the sediments north of the basalts in the Hope Lake area there are often only boils with intervening borders of vegetation.

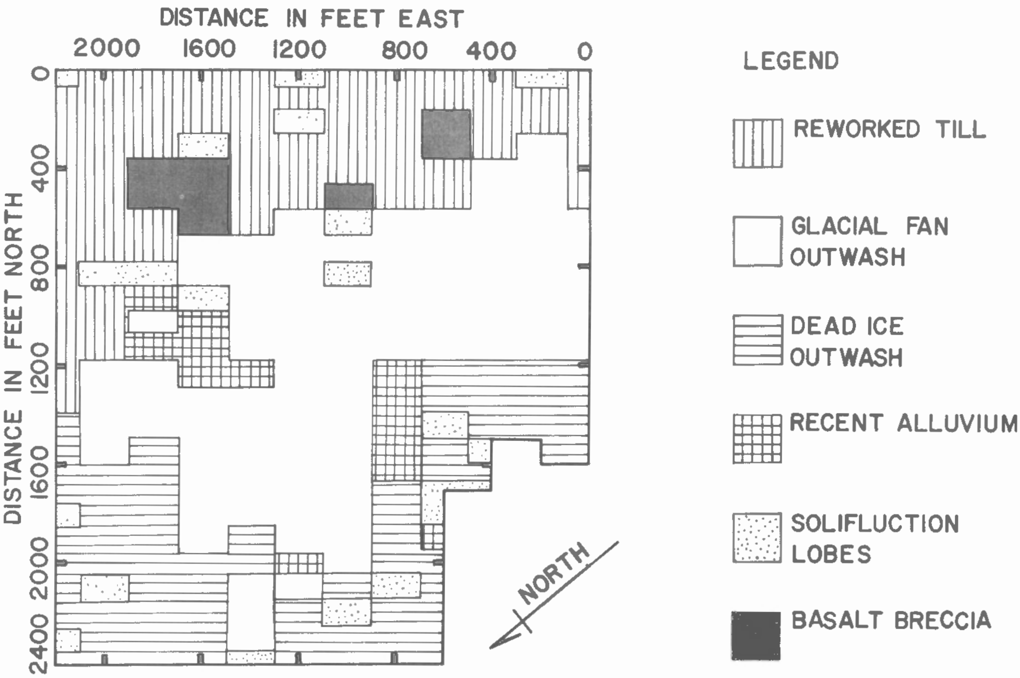

Figure 4. Glacial geology in the vicinity of the 47-Zone.

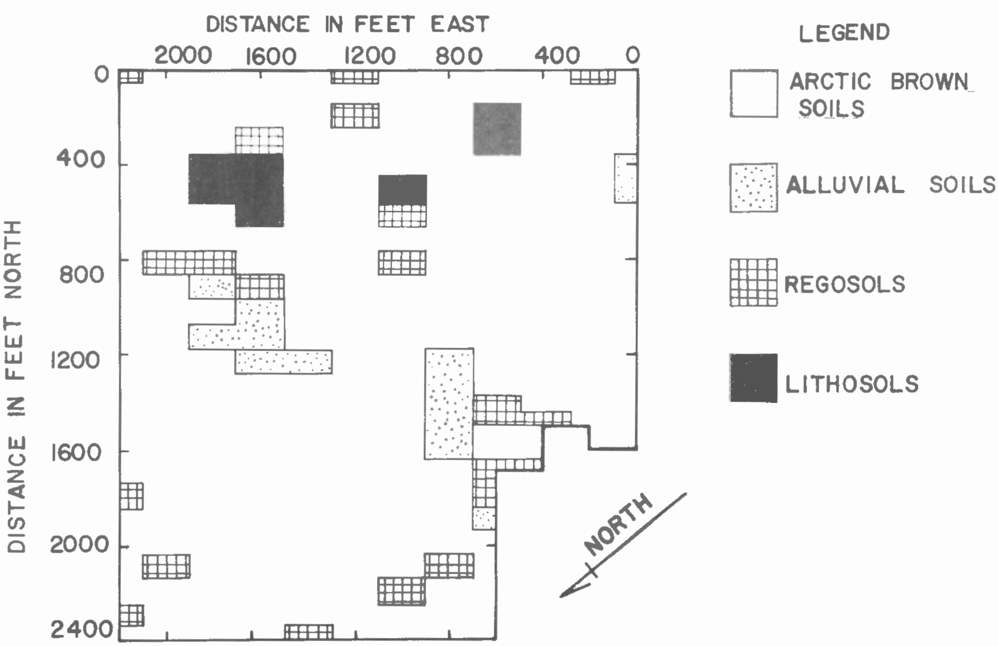

Figure 5. Soil distribution in the vicinity of the 47-Zone.

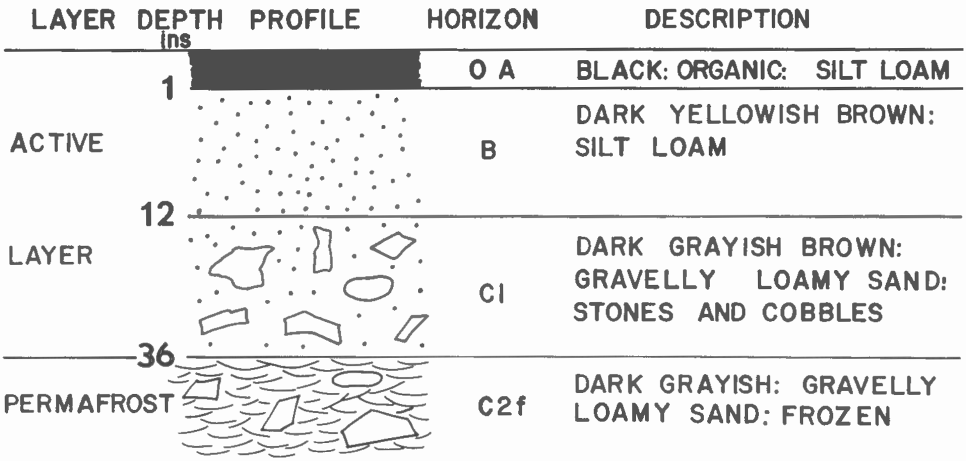

Figure 6. Idealized profile of Arctic Brown soil in the vicinity of the 47-Zone.

METHODS

Field Sampling Methods

Soils were sampled at the 47-Zone on a grid 2,200 feet east by 2,400 feet north (Fig. 2). O/A horizon samples were collected every 200 feet east and north on the grid. B horizon samples were collected every 200 feet east and every 100 feet north on the grid. Frost boil surface samples were collected approximately every 100 feet on the 1,000-foot east line (Fig. 2). There were slight variations in sample point location due to the presence of stone rivers, dense stone fields, solifluction lobes and recent drainage ways. The grid at the 13-Showing was of irregular dimensions (Fig. 3) and was controlled in size by drainage patterns and rock outcrops. Traverse lines at right angles to the strike of the vein were run every 300 feet for 2,100 feet of vein strike length. The longest traverse line was 1,600 feet. All samples collected came from the upper few inches of silty frost boils located along these lines at progressively increasing sample intervals away from the vein. On one line, samples were taken from both the surface of the boils and from just above bedrock. At this site permafrost was usually below the surface of the bedrock. Surface frost boil samples were also collected from two traverse lines crossing I.P. (Induced Polarization) anomalies in the Hope Lake area. Background O/A and B horizon samples came from near the 47-Zone and from the Hope Lake area. Background boil samples were collected from a wider area on a roughly linear 25-mile traverse from the Dismal Lakes to about 15 miles southwest of the village of Coppermine.

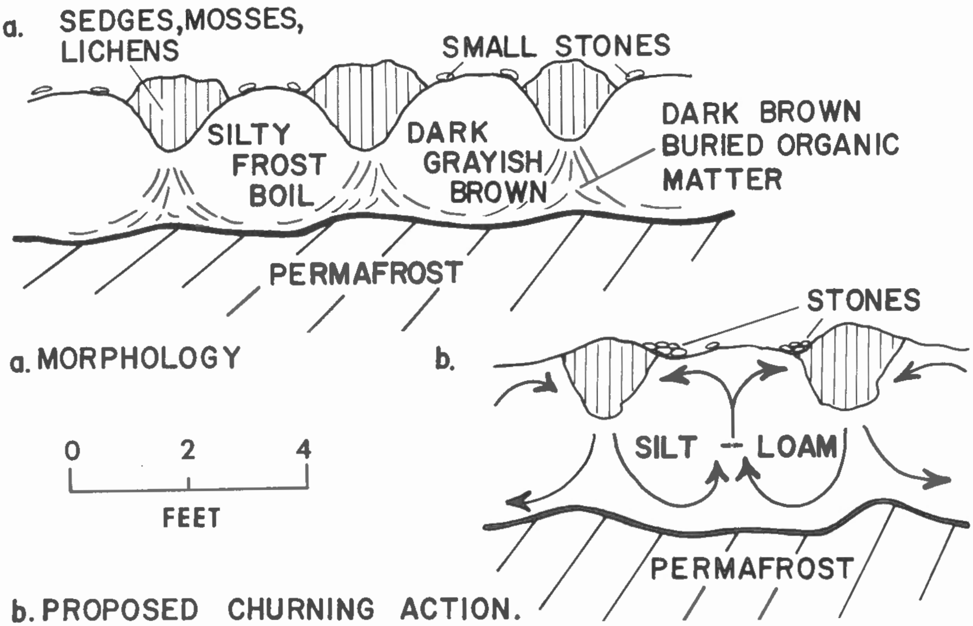

Figure 7. Idealized cross sections of silty frost boils.

Sampling of O/A horizons proved time consuming and maintaining uniformity of sample medium was difficult. The surface organic horizon of the Arctic Brown soils is discontinuous, very thin and stony and collection of this horizon, on this basis alone, is not recommended. Even at good locations, a large lateral area had to be 'scavenged' to produce a large enough sample for analyses. B horizons proved much easier than O/A horizons to sample, although they too are discontinuous and sometimes it required considerable lateral digging at a sample station to obtain an adequate sample. C horizons of the Arctic Brown soils are very coarse textured and usually difficult to collect. B horizons are recommended as the best Arctic Brown soil medium to collect in pedogeochemical exploration. However, as has been mentioned earlier, these soils at the 47-Zone are of limited extent and for sampling purposes silty frost boils can be found in sufficient quantities even where Arctic Brown soils predominate. Because of the mechanism of boil regeneration (Fig. 7) they homogenize the mineral soil horizons above the permafrost table producing a surface sample representative of the particular site to some depth. According to a recent Soviet investigation (Pitulko, 1969) the trace element (Cu, Zn, Ni, Pb, Nb and Y) content of frost boils is higher than that of soils in the same area and is in fact very close to that of the underlying permafrost. Because boils act as accummulators of fines in the bare central part of the boil, stones are pushed to the side and are found under the vegetation-covered rims of the boils and thus a small sample from the centre of the boil provides sufficient $<$ 80 mesh material for analysis. Silty frost boils provide the best sampling medium for pedogeochemical investigations in the Coppermine area and we recommend sampling them.

To obtain good silty stream sediment samples, as were collected near the 47-Zone, it was necessary to dig by hand in the stream bed for some time. In this area of continuous permafrost the water temperature is about 1°C and stream sediment sampling by hand becomes extremely unpleasant. It is recommended that some kind of sampling tool be used with, of course, the usual precautions concerning contamination. Because of the previously mentioned rapid fluctuations in water level in streams and small kettle lakes, sampling of water from these is not advised.

Lake water samples collected came from larger lakes that are relatively unaffected by rapid water fluctuations introduced by rainfall, runoff and movement through the active layer (a larger lake is distinguished as having one axis at least 1,000 feet long). The lake water samples were collected on two days with an intervening period of about two weeks. The uniformity of copper concentrations tends to support the hypothesis that the larger lakes are relatively unaffected by rainfall and subsequent rapid water fluctuations that affect small streams and kettle lakes. Lake water samples were collected in duplicate in polythene bottles previously washed three times in the lake water.

Biogeochemical sampling is relatively easy, although with the limited vegetation in frost boil areas and the general dwarf nature of plants, it takes some time to collect a sample large enough for analysis. Some of the pre-ashing separations for lichens tended to make them impractical sample media.

In permafrost regions, the ground is usually frozen from the surface down for most of the year (8 to 9 months) but during the summer, the surface layer or active layer thaws out. In the Coppermine region, depth of thaw in coarse gravels is 3 to 4 feet of mineral soil. However, as everywhere in the permafrost zone, latitude, elevation, air temperature, soil texture, vegetation cover, drainage position, moisture content, and length of snow cover causes variations in the depth of thaw (Brown, 1970). Soils with permafrost are distinguished as those which freeze from both the surface and from depth and thaw from the surface, as opposed to non-permafrost soils some of which freeze and thaw always from the surface. Because permafrost acts as an impermeable barrier to water movement, most of the soils are wet or poorly drained during the summer. Dispersion of cations from ores can occur in three main ways in glaciated permafrost environments: (1) glacial transport of particles of ore; (2) periglacial transport of particles of ore; (3) chemical transport of cations in some nonparticulate manner. The glacial and periglacial features which dominate the landscape in the Coppermine area indicate that the former two are extensive. The copper concentrations in the lake waters constitute evidence that significant chemical transport also occurs.

Laboratory Analysis Methods

The <10 and >80 mesh O/A horizon samples, the <80 mesh B horizon, frost boil and stream sediment samples were chemically analyzed as follows: 3 ml of 4 $\bar{N}$ HNO_3 is added to 200 mg of sample in a pyrex tube which is placed in a water bath for one hour, mixed, diluted to 10 ml with metal-free water, mixed again, centrifuged and analyzed by atomic absorption spectroscopy. The method of analysis used here gives a total metal content in mineral soil, boil and stream sediment samples. Methods of separating such Cu forms as that present as finely divided sulphides and that occluded in free iron hydroxides are not presently available. The plant material was ashed and 100 mg analyzed as above. The lake water samples were analyzed by atomic absorption spectroscopy following concentration procedures for certain of the cations. In lake waters, the content of all elements but copper was equal to or less than the detection limit of the method.

Expenditures

Field expenditures for the operation amounted to about $5,000. This included helicopter subcharter, accommodation, freight, and ground transportation but did not include staff salaries (3 men) and cost of laboratory analyses. The approximate cost for a company to conduct a similar study, depending on availability of facilities, could be as high as $10,000.

RESULTS AND DISCUSSION

Presentation of the Data

The metal concentrations in the soils, boils, stream sediments and plant ash are recorded in ppm. Lake water concentrations are in ppb. The lake water analytical results are presented on a location map of the lakes with black shading of anomalous concentration levels. The stream sediment analytical results are shown on a plan of the stream system with the thickness of the stream corresponding to copper concentrations. Computer drawn copper anomaly maps were constructed from the analytical results for the 47-Zone Arctic Brown soils and the 13-Showing frost boils. Copper profile plots for frost boil analytical results were also constructed for the 47-Zone, the 13-Showing, and for the showing defined by the I.P. anomalies. As common points of reference, the sampling grid and the outline of the ore body or position of the mineralized quartz vein are shown on the anomaly maps.

At the 47-Zone, sample traverse lines were 200 feet apart; the spacing between samples was 100 feet for the B horizon and 200 feet for the O/A horizon. At the 13-Showing, sample traverse lines were 600 feet apart and the spacing between samples decreased progressively toward the base line from 200 feet to less than 10 feet.

The contour plots were based on values calculated on a regular 10-foot grid for the 47-Zone plots and on a 20-foot grid for the 13-Showing frost boil plot. The grid values are weighted means of the neighbouring data points and the search area for these was chosen to be an ellipse containing 9 data points on the average with the major axis perpendicular to the sample traverse line. For the 47-Zone plots, f = major axis/minor axis = 2 and for the 13-Showing frost boil plot, f = 9 (D. Hobbs, Geological Survey of Canada; Personal Communication).

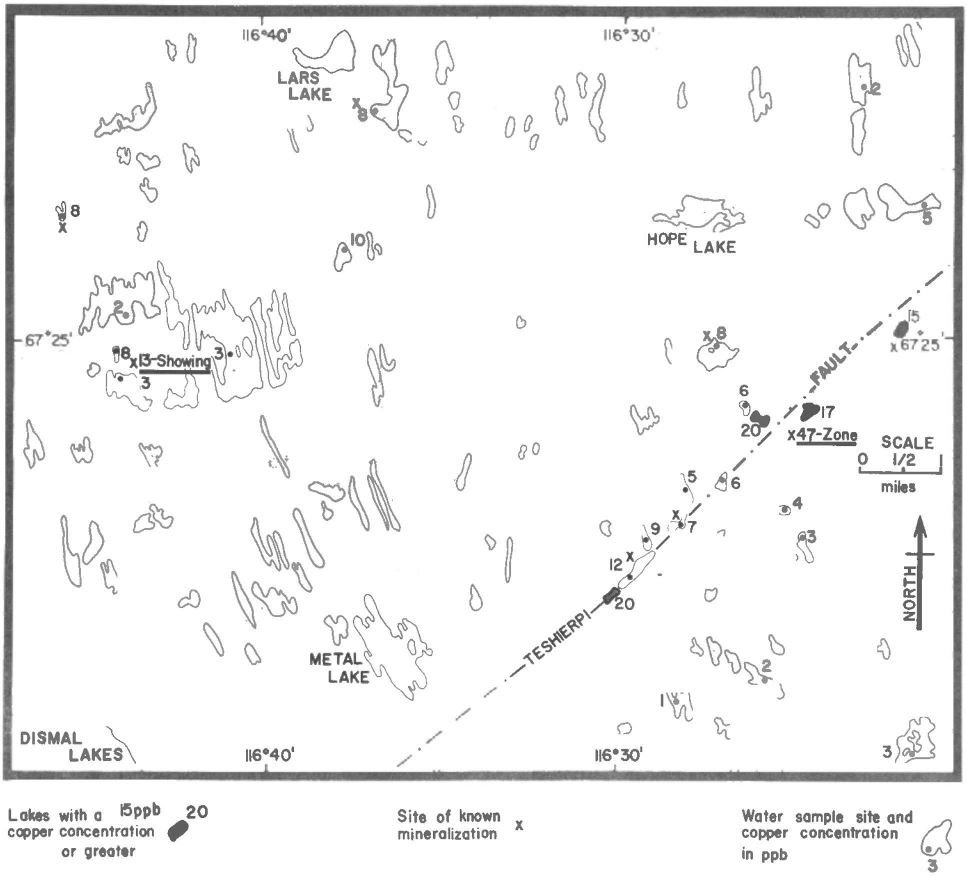

Figure 8. Location of lakes sampled and their copper concentrations in ppb.

Lake Water Results

A study of copper concentration in lake waters (Fig. 8) determined that background copper concentrations are 2 ppb, threshold concentrations are 8 ppb and anomalous concentrations are 15 ppb. The background concentrations were consistently associated with lakes that had no known nearby mineralized occurrences. Threshold concentrations were associated with lakes that received drainage from noneconomic mineralized occurrences. Of the 25 lakes analyzed, 4 had anomalous Cu concentrations and all of these are in the valley of Teshierpi Fault. Two of the lakes, immediately downslope from the 47-Zone, contained 15 and 20 ppb Cu. A third lake, northeast of the 47-Zone and on the Teshierpi Fault, has a concentration of 15 ppb Cu and can be related to the Cu mineralization in quartz carbonate float at the E-grid, a showing approximately 6,500 feet northeast of the 47-Zone. The fourth lake, southwest of the 47-Zone, in Teshierpi Fault valley, is at the end of a chain of connected lakes and its Cu content of 20 ppb could well be due to concentration at the end of the drainageway. When compared with lakes in the U.S.S.R. (3 to 31 ppb Cu) (Perel man and Borisenko, 1962) the

Cu concentrations in the lakes of the Coppermine River Basalt are relatively low. None of the Soviet lakes, however, are in permafrost regions, which by inhibiting leaching processes, could account for the corresponding lower values in the Coppermine area lakes.

However, the fact that lake waters do have measurable Cu contents that can be related to mineralization does indicate the chemical transport of copper in solution or active dispersion of copper from mineralized zones in other than particulate form.

None of the other cations analyzed for in lake water showed a relationship to known mineralization. Most concentrations for the other cations, Zn, Pb, Ni, Co and Mn were usually below detection level by the methods used. Based on the results of 25 lakes analyzed, only the two lakes downslope from the 47-Zone, and the lake 6,500 feet northeast of the 47-Zone would have merited further stream sediment analysis in their vicinity.

Stream Sediment Results at the 47-Zone

Permafrost acts as an impermeable barrier to downward movement of water in surficial deposits. Thus, drainage in permafrost areas is complex relative to areas without permafrost and all streams upslope from lakes with anomalous Cu concentrations should be sampled, rather than just those flowing directly into such lakes. At the 47-Zone, this procedure resulted in the determination of Cu concentrations in stream sediments from 4 streams.

Anomalous concentrations were found only in the 2 streams which traverse the mineralized zone (Fig. 9). For these anomalous streams, Cu concentrations upstream from the mineralized zone range from 800 to 1,000 ppm Cu. After crossing the ore body, Cu concentrations in the region of 3,000 ppm Cu are maintained approximately 1,500 feet downstream. These anomalous values may be expected to be traceable farther, but in this case, the streams join and end in a small kettle lake. The other two streams, one on each side of the 47-Zone had no concentrations greater than 2,000 ppm Cu with most in the region of 1,500 ppm Cu (Fig. 9). Mineralized breccia did outcrop on stream 3 close to the 1,287 ppm Cu concentration shown on Figure 9. This could be the cause of the slightly higher concentrations, up to 1,995 ppm Cu, downstream from this location.

Based on the above results, stream sediment sampling on 1,000-foot intervals or less will detect the presence of a deposit the size of the 47-Zone.

Comparison of Soil and Frost Boil Results At the 47-Zone

O/A horizons compared to B horizons

On the followup detailed level, the Cu concentration of O/A horizon samples from the 47-Zone grid produced a more diffuse and less effective anomaly map (Fig. 10) than either the 'total' or 'true' B horizon samples (Figs. 11 and 12, respectively). In part this was because the O/A horizon samples were collected at 200-foot intervals as opposed to 100-foot intervals

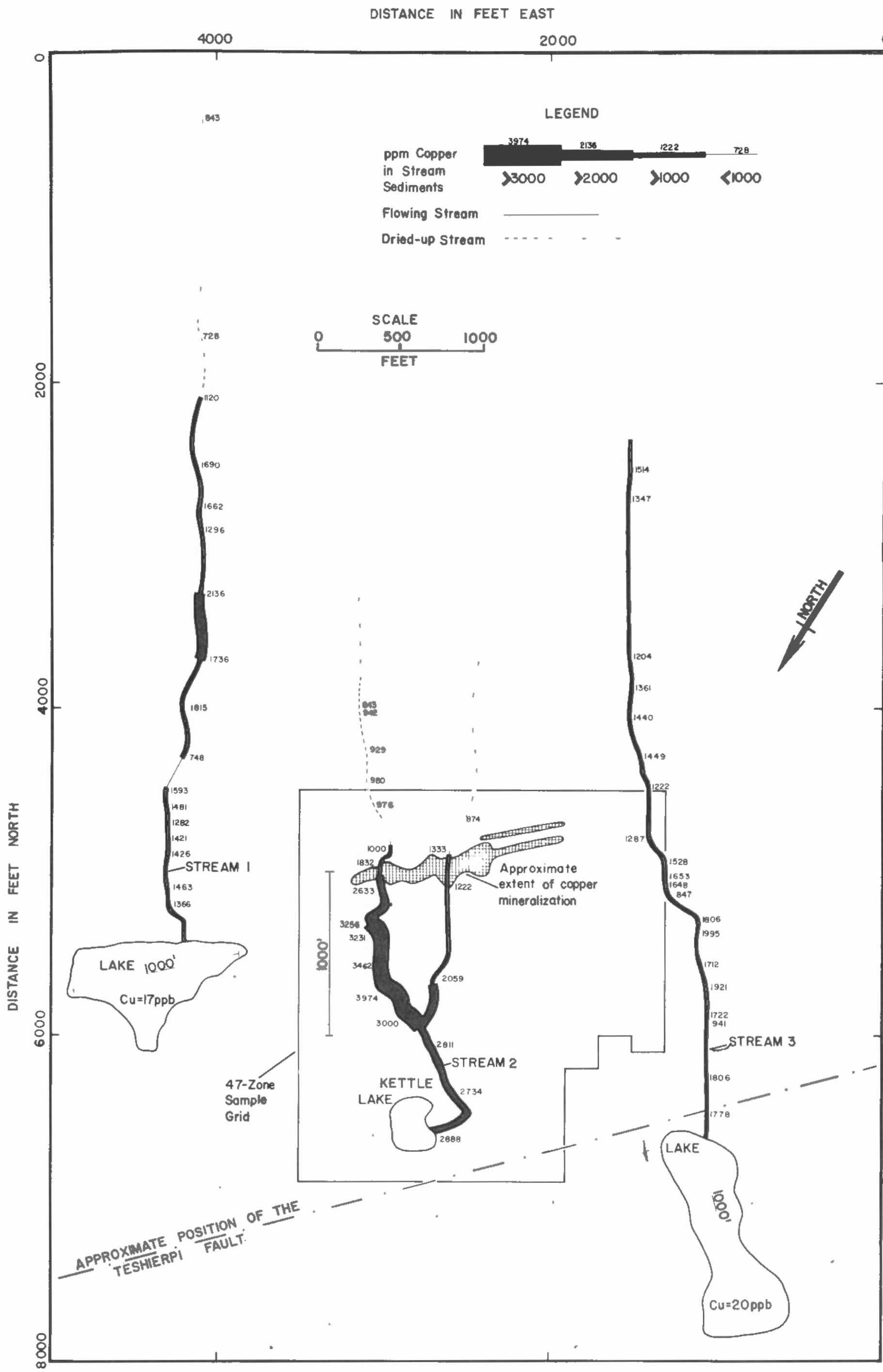

Figure 9. Copper concentrations in stream sediments in the vicinity of the 47-Zone.

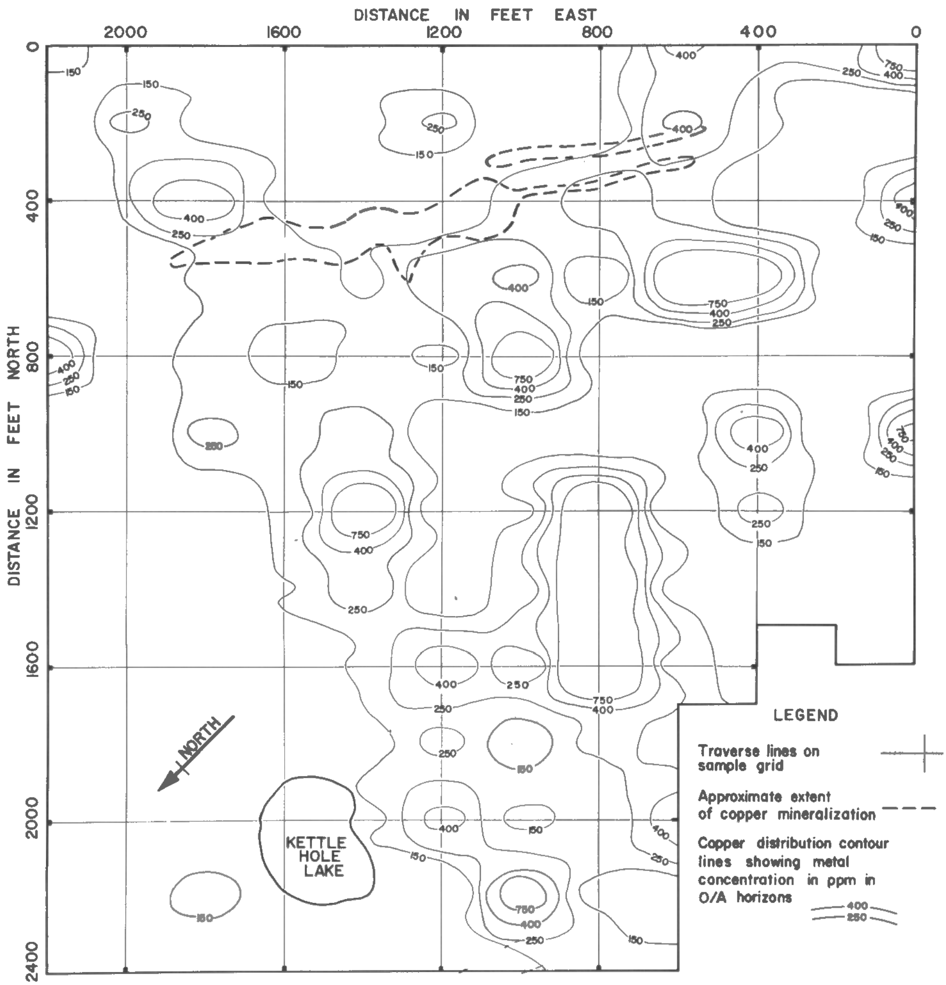

Figure 10. Geochemical anomaly map showing distribution of copper in O/A horizons in the vicinity of the 47-Zone.

for B horizons. However, at the semiregional level, samples of surface O/A horizon may be competitive with stream sediments. No attempt was made to separate O/A horizons into 'total' and 'true' types as for the B horizons. B horizons are suggested as a better sampling media than O/A horizons in areas of Arctic Brown soils because: (1) Cu distribution in the former most effectively defines the 47-Zone mineralization; and (2) soil B Horizon is more amenable to simple, rapid sample collection.

'Total' B horizons compared to 'true' B horizons

Two B horizon anomaly maps are presented (Figs. 11 and 12). During sampling, a B horizon was collected at each grid point but the soil

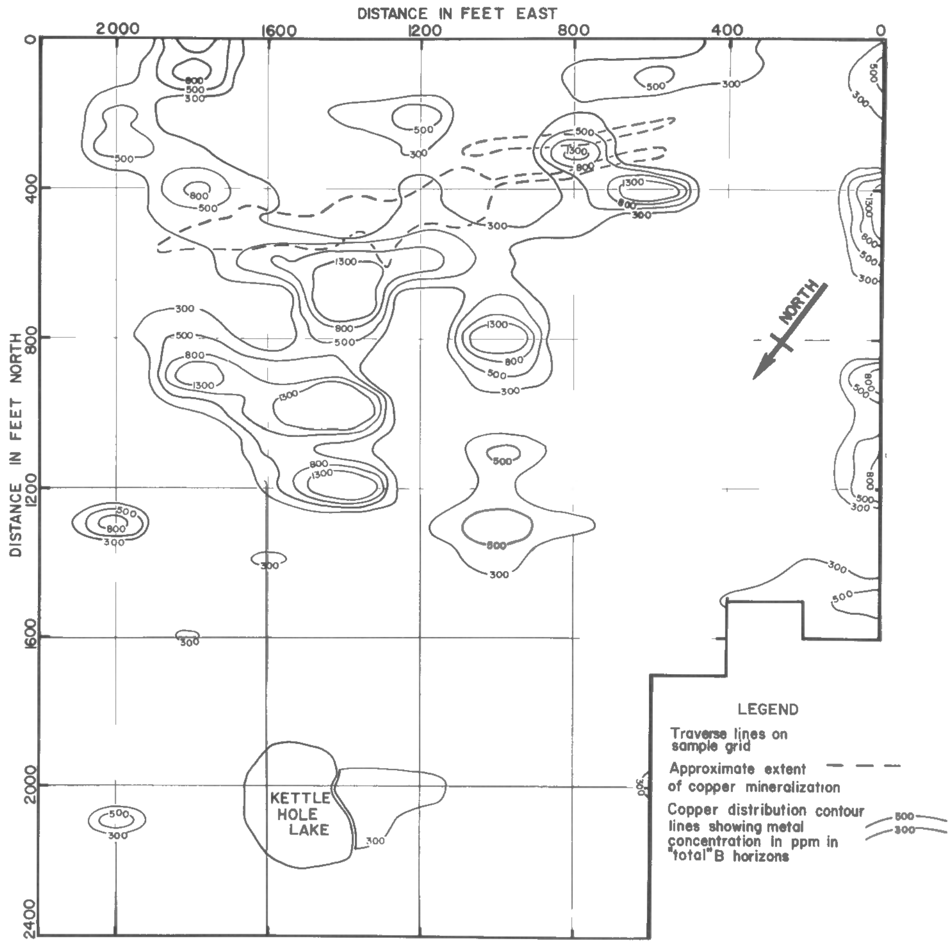

Figure 11. Geochemical anomaly map showing distribution of copper in 'total' B horizons in the vicinity of the 47-Zone.

distribution (Fig. 4) near the 47-Zone really makes this impossible, and in several cases the B horizon was actually a stream sediment, solifluction lobe, or an ore breccia sample. The anomaly map constructed using the results for samples at all the grid points is referred to as the 'total' B horizon anomaly map (Fig. 11). In the other case (Fig. 12), a geochemical anomaly map was constructed using only 'true' i.e. actual, Arctic Brown soil B horizon sample material results. The purpose of this operation was two-fold: (1) Figure 11 shows the type of anomaly map that would have resulted had the samples been collected by persons unfamiliar with the variations in soils and glacial geology near the 47-Zone, and who simply collected mineral soil samples from beneath the humus layer at every grid station. The resulting anomaly map along with the stream sediment analyses locates the zone of

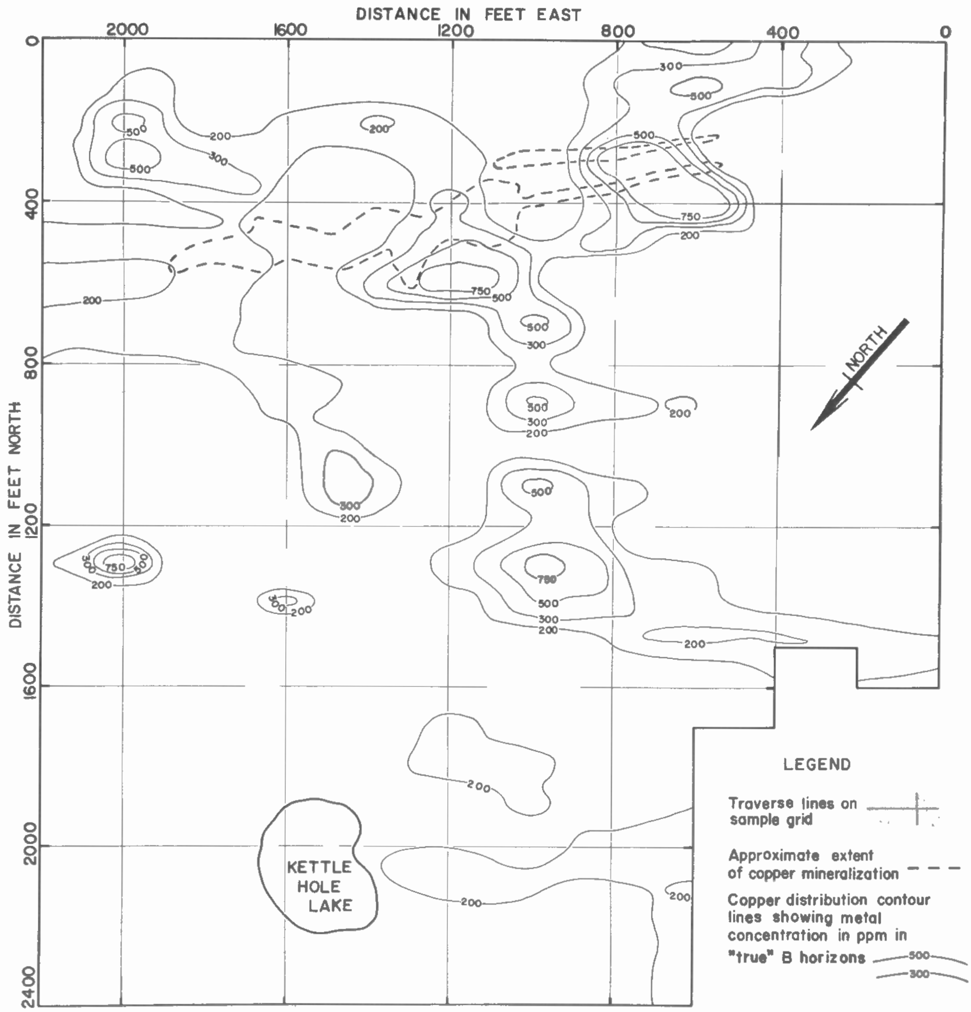

Figure 12. Geochemical anomaly map showing distribution of copper in 'true' B horizons in the vicinity of the 47-Zone.

mineralization and shows that at least for the 47-Zone this collection procedure would have been adequate; (2) Figure 12 shows that had the 47-Zone been completely covered by Arctic Brown soils i.e. had there been no visible surface expression of mineralization, collection and analysis of 'true' B horizons from these soils would also have located the 47-Zone mineralization. Figure 12 is thus of great value as it tends to predict the successful detection of mineralization even when mineralization is not visible at the surface.

<u>C horizons compared to B horizons</u>

Table 2 shows analytical results for Arctic Brown O/A, B and C horizons from soils collected at three sites located on representative types of 47-Zone area glacial deposits. It is evident that the copper content in C horizons is persistently highest. The C horizon is immediately above the permafrost and this may indicate, although not conclusively because only 3 sites were studied, that sampling of Arctic Brown soils is best done as close to the permafrost table as possible. However, because in permafrost regions, Arctic Brown soils only occur on very coarse gravelly deposits, C horizon sampling is extremely difficult and would probably only be justified as a very final stage in geochemical exploration.

TABLE II

Metal Concentrations in the Horizons of Three Arctic Brown Soils at the 47-Zone

Underlying Glacial Overburden	Horizons	Depth in cms	Cu	Zn	Mn	Ag
				in ppm		
Till[1]	O/A	0-5	85	65	1042	0.5
	B	5-25	54	38	453	n.d.[2]
	B/C1	25-45	146	57	860	n.d.
	C1	45-90	153	63	922	n.d.
	Permafrost	90+	n.s.[3]	n.s.	n.s.	n.s.
Outwash[4] (terrace or fan)	O/A	0-4	115	51	953	n.d.
	B	4-25	169	32	464	0.5
	C1	25-90	2935	51	1995	n.d.
	Permafrost	90+	n.s.	n.s.	n.s.	n.s.
Outwash[4] (dead ice)	O/A	0-2	132	44	736	n.d.
	B	2-30	149	32	420	n.d.
	C1	30-35	286	40	876	n.d.
	C2	35-90	415	57	1096	0.5
	Permafrost	90+	n.s.	n.s.	n.s.	n.s.

1 Appendix A, description (a).

2 n.d. = none detected.

3 n.s. = no sample.

4 Appendix A, description (b).

Silty frost boil surface samples compared to B horizons

At the 47-Zone, anomalous to background contrast for Cu concentration in silty frost boils was sixtyfold as opposed to about twenty-five fold for soil B horizons on the same line (Fig. 13). Silty frost boils constitute a uniform sampling medium as is often not the case with B horizon soils.

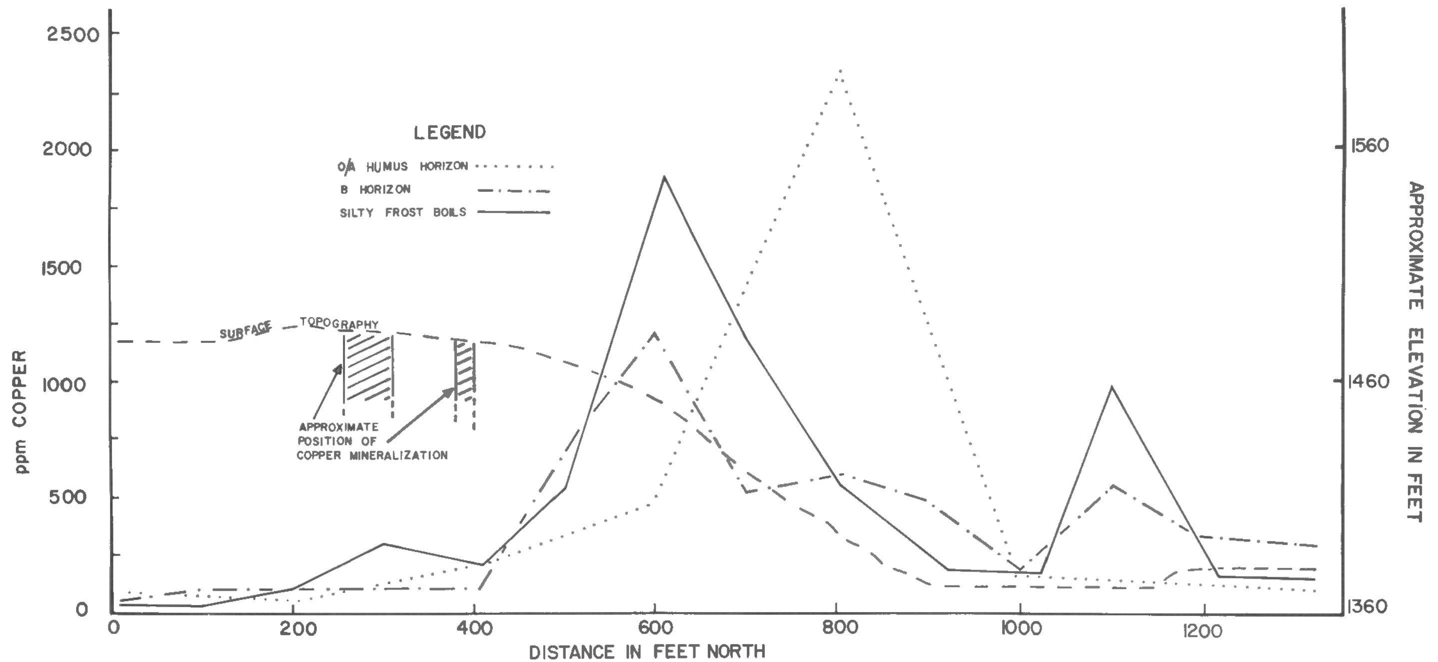

Figure 13. Frost boil and soil horizon anomaly profiles; comparison on a traverse line at the 47-Zone.

TABLE III

Biogeochemical Results of Plant Ash Analyses from the 47-Zone

Distances in feet, east and north on the 47-Zone sample grid	Expected value due to sample site location	PLANT TYPE				
		Dwarf lupin[1]	Heather[2]	Lichen(1)	Lichen(2)	Lichen(3)
		ppm Cu in Plant Ash				
1600E:300N 47-Zone	Background	50	217	174	217	117
1500E:500N 47-Zone	Anomalous	100	250	443	242	583
975E:1150N 47-Zone	Threshold	58	308	n.s.[3]	367	133
1700E:2430N 47-Zone	Background	50	233	125	174	83
Vicinity of Hope Lake airstrip	Background	58	158	108	108	125

[1] Leaves only.

[2] Combined foliage.

[3] n.s. = no sample.

Vegetation Results at the 47-Zone

Cu results for analyses of lupins, heather and three types of lichens are given in Table 3. The Cu concentration in the samples shows some correlation to anomalous and background copper distribution in the soils. Further study would be required to confirm the relationship. Such a study is not warranted at this time because other sampling media are more effective for determining Cu distribution in the Coppermine River Basalt region.

Potentilla twigs and leaves collected from streams 1 and 3 (Fig. 9) at the 47-Zone, were analyzed for Cu, Zn, Ag and Mn. Cu was found to be preferentially concentrated in the twigs. However, Potentilla only grows adjacent to water courses or lake edges, and its effectiveness as a sampling media for geochemical exploration is in direct competition with lakes, water and stream sediments. The Potentilla results for Cu were somewhat erratic and less useful than stream sediment results at the same sites.

Frost Boil Results at the 13-Showing

The frost boil copper anomaly map (Fig. 14) showed that Cu was significantly dispersed only 200 feet as a maximum, downslope from the mineralized quartz vein. Copper concentrations here were lower than in the frost boils at the 47-Zone. Only a few concentrations of >1,000 ppm Cu were recorded. The anomaly map (Fig. 14) indicates the position of the vein even in the 6N to 3S part where it is concealed by 2 to 3 feet of silty surface colluvium. The lowest copper concentration values were obtained where the vein is visible as surface mineralized float between the 6S and 12S lines. Usually less than 20 feet upslope from the vein there is a very sudden concentration decrease of Cu in the frost boils. The large anomaly near the 6N line could well be due to contamination from surface drilling and blasting. Conversely, similar exploration activities between the 6S and 12S lines should have, but did not, produce anomalously high copper concentrations in frost boil surface samples collected near the vein. An 8 ppb Cu concentration in the lake at the foot of the slope (Figs. 14 and 8) can be related to the noneconomic copper mineralization at this showing.

Copper analysis of silty soil from tops and bottoms of frost boils on the 1S line (Fig. 3) at the 13-Showing revealed certain concentration differences. These differences, about twofold as a maximum (Fig. 15), were only significant close to the mineralized vein. Farther from the vein, top and bottom samples have a similar Cu content. Thus, although surface samples of frost boils give a good representation of Cu concentration in the entire thawed active layer, it may be better when bedrock is shallow to sample frost boils as close to the permafrost table as possible. With silty frost boils, this can be rapidly done by means of a conventional posthole soil auger.

Frost Boil Results at Two Known I.P. Anomalies

(1) Cu concentrations in frost boils from two traverse lines over a known I.P. anomaly in the Coppermine River Basalt area, revealed a sixteenfold anomaly: about 800 ppm Cu relative to a local background of about 50 ppm Cu (Fig. 16(1)). The Cu anomaly was developed on the two traverse

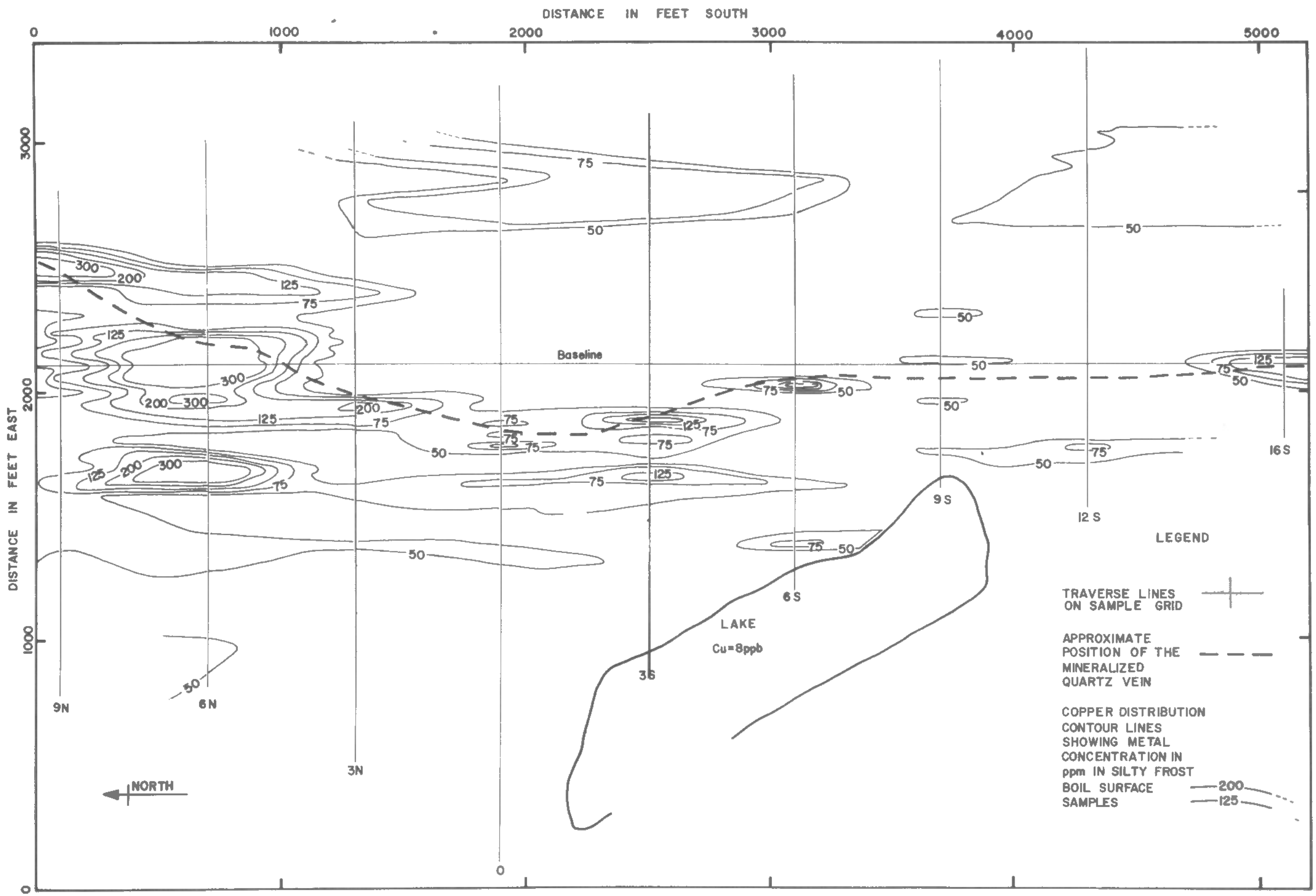

Figure 14. Geochemical anomaly map showing distribution of copper in silty frost boil surface samples in the vicinity of the 13-Showing

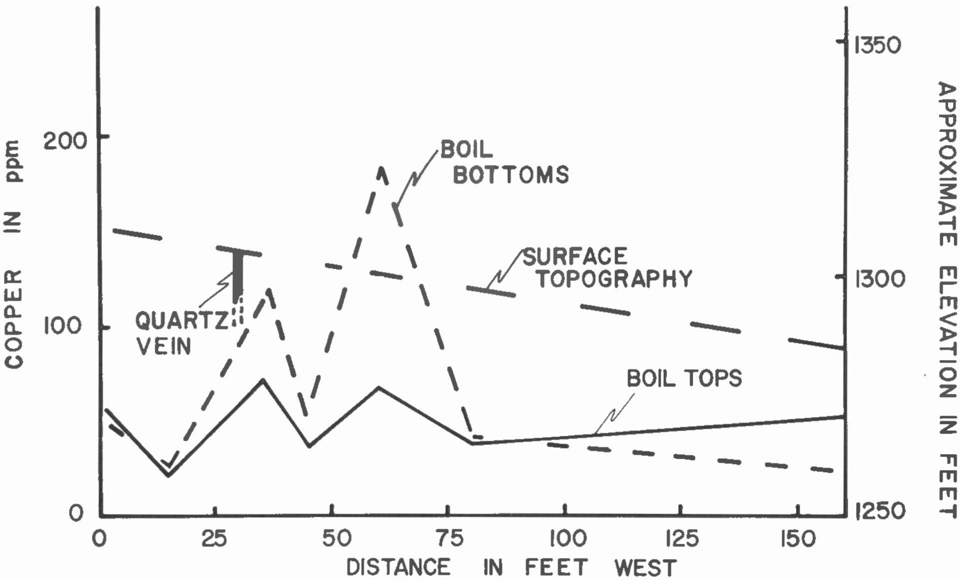

Figure 15. Frost boil anomaly profiles: comparison of copper concentrations at the 13-Showing.

lines located at right angles to and crossing the elongated I.P. anomaly. At this I.P. anomaly overlapping geochemical and geophysical anomalies occur in a geological situation which may be analogous to the 47-Zone fault breccia system.

(2) No significant Cu concentrations were found on the third traverse line at right angles to the second elongated I.P. anomaly (Fig. 16(2)). Only two high Cu concentrations out of thirty-six samples were obtained and these were on a steep hillslope, with much scree, remote from the I.P. anomaly and were disregarded. The remaining 34 values had consistently low Cu concentrations over the 1,600-foot-long traverse line including over the centre of the known I.P. anomaly.

Regional Background, Frost Boil Results

Surface frost boil samples (9) from a 25-mile traverse crossing the dolomites, basalts and sediments in the Coppermine River area (Fig. 1) had very uniform total Cu concentrations. Average Cu content was 45 ppm with a range of 20 ppm to 71 ppm and a standard deviation of 16 ppm. Cu content in frost boils from the regional traverse, 13-Showing, and 47-Zone, suggests that any concentration in excess of 100 ppm Cu in a surface frost boil is associated with some type of mineralization, mineralized float, or hydrogeochemical anomaly.

The mineralogy in the fine sediment fraction (<5μ) was very uniform. X-ray diffraction of the <5μ fraction of the 9 frost boils showed their composition to be mainly mica and kaolinite with smaller quantities of

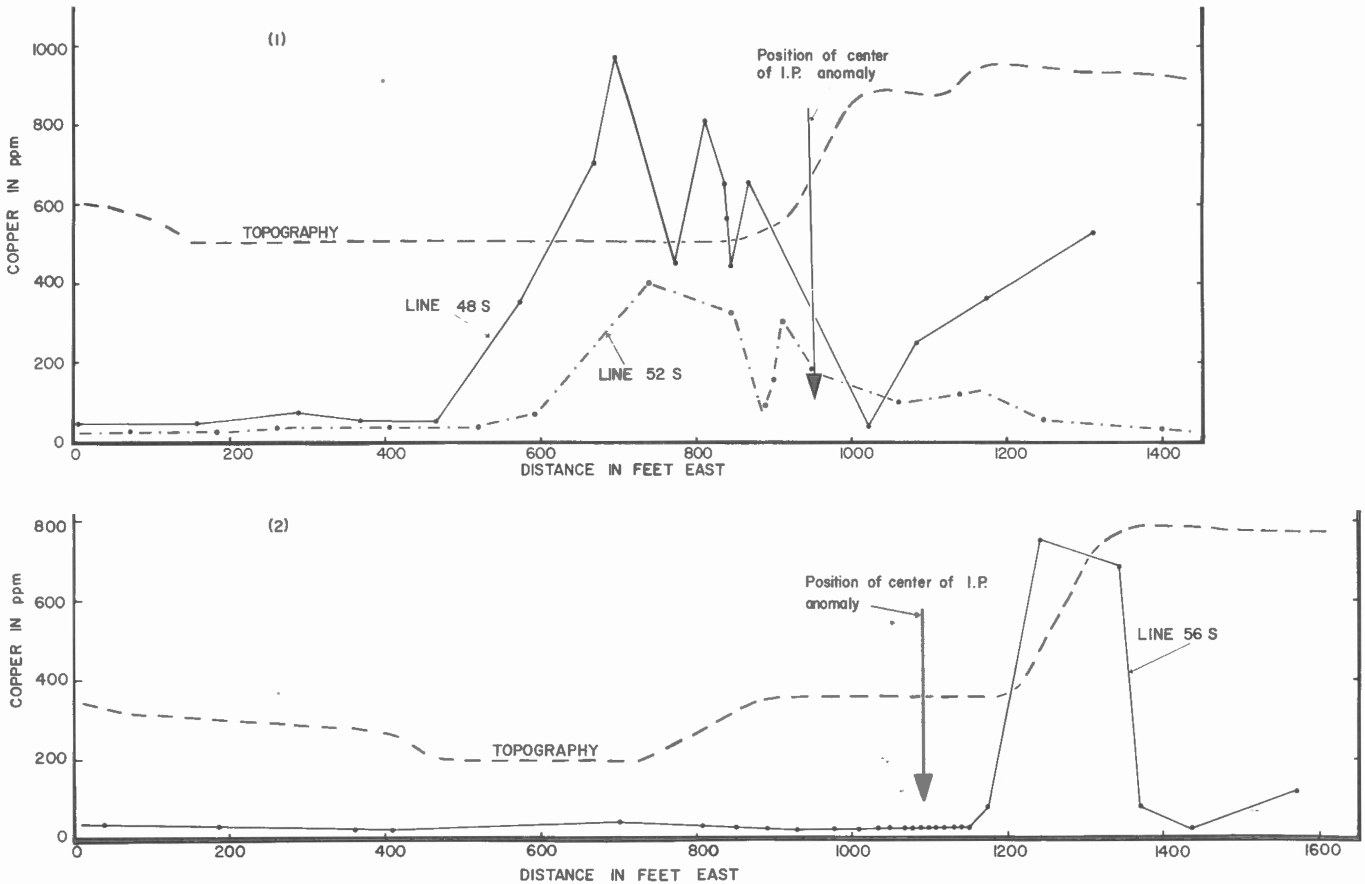

Figure 16. Frost boil anomaly profiles: copper concentrations over two known I.P. anomalies.

TABLE IV

Means and standard deviation for Cu, Ni, and Ag concentrations in the different materials sampled in the Hope Lake area.

Type of Sample Media	Number of Samples	Copper		Nickel		Silver	
		Mean	1SD	Mean	1SD	Mean	1SD
		ppm	ppm	ppm	ppm	ppm	ppm
O/A horizon	132	337	725	64	21	0.52	0.17
'Total' B horizon[1]	275	346	704	43	16	0.39	0.15
'True' B horizon[1]	202	206	290	38	11	0.36	0.09
13-Showing frost boil[1]	211	93	196	39	12	0.37	0.09
Background frost boil[1, 2]	9	44	16	47	11	0.75	0.37
Total frost boil[1, 3]	301	128	245	42	17	0.38	0.13
Stream sediment	65	1661	693	110	22	1.02	0.21

1 Note the similarity in Ni and Ag means and standard deviations in the different pedogeochemical mineral soil sample media.

2 Only 9 samples were collected which makes the means and standard deviation doubtful. However, Ni and Ag values are still very similar to those at the 47-Zone and 13-Showing.

3 Includes the frost boils collected over the two I.P. anomalies.

chlorite and vermiculite. A similar mineralogical composition has been found for silty frost boils underlain by permafrost in Alaska (Allan et al., 1969). From these results it appears that the ubiquitous silty frost boils are of unusually uniform composition in the mineralogy of their fine size fractions and, at least in the Coppermine River Basalt region, also in their trace element concentration. These two factors make silty frost boils an excellent regional pedogeochemical sample media.

General Comparison of the Analytical Data

Because this was a feasibility study, many sample media were tested and some that now appear to be unfavourable were given more attention than others. The range of Cu concentrations in various sampling media is: stream sediments in the thousands up to about 4,000 ppm Cu; soil horizons or silty frost boils, in the hundreds up to about 1,000 ppm Cu; lake waters, in ppb up to about 20 ppb Cu. This study shows that Cu is the most effective element to use in geochemical prospecting in the Coppermine Basalt belt. This is not surprising because Cu is the dominant element in the ores of the region. In the lake waters no other element (Zn, Pb, Ni, Co and Mn) but Cu could be correlated with mineralization. Similarly this relationship seemed to apply to all of the soil and stream sediment materials, which were analyzed for Cu, Ni, Ag and Mn. Concentrations of Ni at both the 47-Zone and 13-Showing were statistically very similar. The mean Ni concentration at the 47-Zone was 40 ppm, the standard deviation 11 ppm, as compared to 39 ppm and 12 ppm respectively at the 13-Showing, and 47 ppm and 11 ppm respectively for background frost boils. The same pattern is followed by Ag. This indicates that neither Ni nor Ag are of use as geochemical indicators of mineralization, because the variations at the 47-Zone should have been greater than for background samples. The means, standard deviations and parameters defining the normality of the distribution of these trace elements in the different sample media are presented in Table 4. Cu is the best trace element for use in geochemical exploration in the Coppermine River Basalt area. The great diversity of Cu:Mn ratios in soil 'total' B horizons at the 47-Zone and silty frost boil surface samples at the 13-Showing imply that Mn in permafrost areas may not act as a preferential absorber of other metal cations, at least of Cu in the Coppermine River Basalt belt.

CONCLUSIONS

The following conclusions on geochemical prospecting in the Coppermine River Basalt belt can be drawn:-

(1) Geochemical exploration can be used in permafrost regions.

(2) Copper is actively dispersed both as particles and in solution from known occurrences of mineralization.

(3) Copper is the most effective indicator element for tracing mineralization.

(4) Lake water is a very effective sampling media for regional geochemical exploration where one axis of the lake is at least 1,000 feet.

(5) Stream sediments are the best semiregional sampling media where samples are taken at a maximum interval of 1,000 feet.

(6) Detailed geochemistry at sites of favourable stream sediment anomalies, geophysical anomalies and geological structures, is best done by collecting surface samples taken at a maximum interval of 100 feet from silty frost boils.

(7) Frost boils are a better sample media than B horizons, due to the homogeneity of sample material at one site, uniformity of sample media among sites, and widespread occurrence.

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APPENDIX A

(a) Arctic Brown Soil on Till at the 47-Zone

Site Description: 30 feet northwest of post 00W, 00N at the 47-Zone; elevation 1,480 feet; relief about 50 feet; Caribou Moss, Arctostaphyllus, fern-like plants, several varieties of arctic lichen; on a 3 to 4 per cent B slope; aspect northwest; freely drained but wet due to thaw of active layer; possibly

Figure A1. Arctic Brown soil on till. (GSC photo 156836) two story with silty colluvium over coarse gravelly and cobbly reworked till; surface area is a medium densely stone field with stones up to 20 feet in diameter; usual stone size is about 2 feet in diameter; soil is a member of a coarse loamy, mixed, nonacid family of Pergelic Cryumbrepts.

Horizon	Depth cm	Description (all colours moist)
01	2-0	Black decomposing organic mat of mosses and lichens.
01/A	0-5	Black to very dark brown (10YR2/1) greasy silt loam; texture mainly due to organic matter; weak very fine platy to very weak very fine crumb; very friable; irregular to wavy clear boundary.
[B]	5-25	Dark yellowish brown (10YR4/4) gravelly silt loam; very weak fine platy breaking to very weak very fine crumb; very friable; few large frost shattered stones; irregular clear boundary.
[B]/C1	25-45	Dark brown (10YR3/3) gravelly silt loam between stones in indurated till; loose; structureless; many cobbles and boulders; wet diffuse irregular boundary.
C1	45-120	Dark greyish brown (10YR4/2) gravelly silt loam; loose; structureless; somewhat indurated till as only recently thawed; numerous frost shattered stones; clear smooth boundary.
C2f	120+	Permafrost; as C1; ice as veins between gravel and stones.

Notes: All the stones have cutans on their upper surface; stones are somewhat vertically orientated in the upper part of the profile; layer of organic-stained pebbles occurs beneath the 01; roots go down to the C1 but most of the young roots are in the [B]; beneath the [B] the material has a gravelly washed appearance; stones are mainly angular basalt or dolerite with very few rounded quartzite and dolomite cobbles; pH values were, O/A=6.5, [B]= 6.5, [B]/C1=8.0, C1=8.0.

(b) Arctic Brown Soil on outwash at the 47-Zone

Site Description: At post 200W, 2100N at the 47-Zone; elevation 1,380 feet; relief about 40 feet; vegetation as for (a) but with dwarf lupins; on a 4 per cent B slope; aspect northwest; freely to imperfectly drained, [B] is moist, C is wet; silty colluvium over poorly sorted 'dirty' outwash; flat outwash area in dead ice topography; few surface stones of 1- to 2-foot diameter; very few, very large stone pits; outwash consists of large 1- to 2-foot diameter boulders with interstitial pebbles and clean washed gravel; all angular stones are basalt or dolerite with a very few very rounded cobbles of quartzite and dolomite; soil is a member of a coarse loamy, mixed, nonacid family of Pergelic Cryumbrepts.

Figure A2. Arctic Brown soil on outwash. (GSC photo 156834)

Horizon	Depth cm	Description (all colours moist)
01	2-0	Surface organic mat of lichens; continuous cover underlain by a layer of organic-stained stones with no cutans; clear smooth boundary.
O/A	0-2	Very dark brown (10YR2/2) discontinuous gravelly silt loam, weak coarse crumb; very friable; few organic-stained pebbles; 0 to 2 cm thick; clear smooth boundary.
[B]	2-30	Dark yellowish brown (10YR4/4) silt loam; very weak very fine platy to medium fine crumb; very friable; few coarse faint dark brown (10YR3/3) mottles; pebbles have silty cutans; 10 to 25 cm thick; gradual wavy boundary.
[B]/Cl	30-35	Dark brown (10YR3/3) gravelly loamy sand; many medium pebbles 1- to 2-inch diameter; well developed cutans on stones; organic stains on lower surface of stones; loose; a few roots reach this horizon; 0 to 10 cm thick; gradual wavy boundary.
Cl	35-90	Outwash as described above; very small, clean, washed gravel; very dark greyish brown (10YR3/2); wet.
C2f	90+	Permafrost; as Cl but with ice veins and lenses in gravel.

Notes: pH values were, O/A=6.5, [B]=6.0, [B]/Cl=6.0, Cl=7.0.

(c) Soil on ore zone breccia at 47-Zone

Figure A3. Breccia soil. (GSC photo 156835)

Site Description: 20 feet south of post 1200W, 300N at the 47-Zone; elevation 1,470 feet; relief 30 feet; caribou moss, varieties of Arctic lichen (all have a greenish coloration probably due to Fe chlorosis); on a 10 per cent C slope; aspect northwest; freely drained; same topographic position on a till upland as for the Arctic Brown on till; hematized breccia appears at the surface as extremely frost shattered boulders, and stripes and frost boils composed of breccia fragments; soil is a member of Lithic Pergelic Cryorthents.

Horizon	Depth cm	Description (all colours moist)
01	2-0	Mat of lichens; black (10YR2/1) greasy organic silt loam; much breccia and hematized angular fragments 2-3 inches in diameter.

A/Cl	0-4	Discontinuous very dark brown (10YR2/2) organic rich silt loam; occurs in cracks in rocks and in more brecciated pockets; coatings of fines on breccia may go down for 30 cm.
Cl(R)		Brecciated basalt bedrock; wet on excavation; weak red (2.5YR4/2) dries to weak red (2.5YR5/2); fragments are usually 2- to 4-inch diameter angular blocks.
C2(R)f		Frozen bedrock at depth; permafrost.

Notes: pH values were, 01=6.0; A/C=6.5.

APPENDIX B

Description of frost boil profile at the 13-Showing

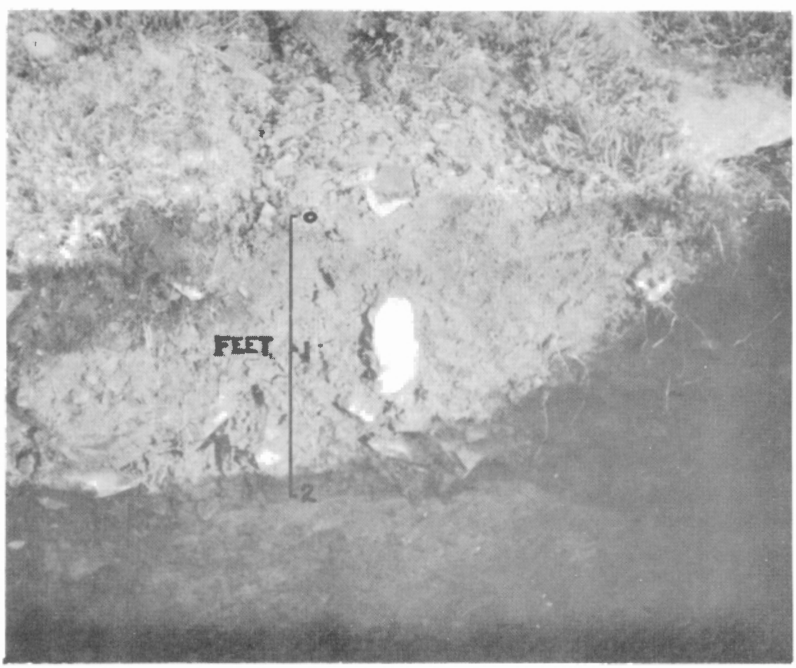

Figure B1. Frost boil profile. (GSC photo 156833)

Site Description: at post 100W, 100S at the 13-Showing; smooth, till covered or silty colluvium covered B/C slope; bedrock often at 2 feet; basalt bedrock;

vegetation is heather, dwarf lupin, potentilla; boils and stripes are bare with clean washed pebbles on their surface; hummocks surround boils; usually heather, dwarf lupins, yellow Caribou Moss on hummocks; vegetation between the boils is mainly sedges, sphagnum, dwarf birch in wetter areas; practically no surface stones; aspect west; many rounded cobbles in the till; stones are mainly beneath the organic matter areas between the boils; organic staining here extends to bedrock; roots extend to bedrock in boils and between.

Horizon	Description (all colours moist)
Boil	Gravelly light silt loam; weak fine platy; friable; stones have poor cutans; smaller stones look washed as in permafrost; some organic staining above the basalt bedrock at the base of the boils; dark brown (10YR4/3); many large faint (10YR3/2) mottles; few large faint very dark brown (10YR2/2) organic stains.
Between Boils	Beneath the tongues of organic matter, the mineral soil to bedrock is the same as above; many stones with good cutans; black to dark reddish brown (5YR2/1-2/2) 02 organic decomposing sphagnum layer; buried organic matter occurs as many large prominent mottles, black to very dark brown (10YR2/1-2/2).

Notes: No evidence of gleying in the boils of this pit but the gray reduced iron gley was seen at many other locations on the same hillslope; pH values are the same at the top and bottom, about pH 8.0.