Exploration Geochemistry Evaluation Study in a Region of Continuous Permafrost, Northwest Territories, Canada

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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 orebody (the 47-Zone of Coppermine River Ltd.) and a mineralized quartz vein (the 13-Showing of Coppermine River Ltd.). Lake waters were sampled in twenty-five 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 twenty-five lakes revealed that four were anomalous, seven were threshold and fourteen were background. Anomalous concentrations were greater than 15 ppb Cu, threshold about 8 ppb and background about 2 ppb. Significantly, two of the four 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, immediately downstream from the orebody, concentrations of copper determined by a hot HNO_3 leach were three- to four-fold (about 3,000 ppm Cu) those upstream from the orebody (about 800 ppm Cu) in a background area. Downstream from the orebody, copper concentrations determined by a cold HCl leach were two- to three-fold (about 1,200 ppm Cu) those upstream from the orebody (about 500 ppm Cu).

Samples of the materials of the O/A horizons were not entirely satisfactory for exploration purposes because of the prolonged time and effort required for their 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 orebody. Samples of silty frost boils were collected on only one line across this orebody. A comparison of the anomalous to background ratios for materials from silty frost boils, the B horizon and the 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 phenomenon 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 close to the mineralized quartz vein.

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

Results of biochemical studies (seventy-six 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 multi-stage approach for geochemical mineral exploration in the Coppermine Basalt Belt appears 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.)

INTRODUCTION

THE 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 (Hornbrook and Allan, 1970) to develop geochemical exploration techniques for permafrost regions, and this report describes a preliminary study involving the 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 (*Figure 1*). Two principal sites were examined, the 47-Zone and the 13-Showing. Both are mineralized copper showings on ground held by 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. Furthermore, the cold desert 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.

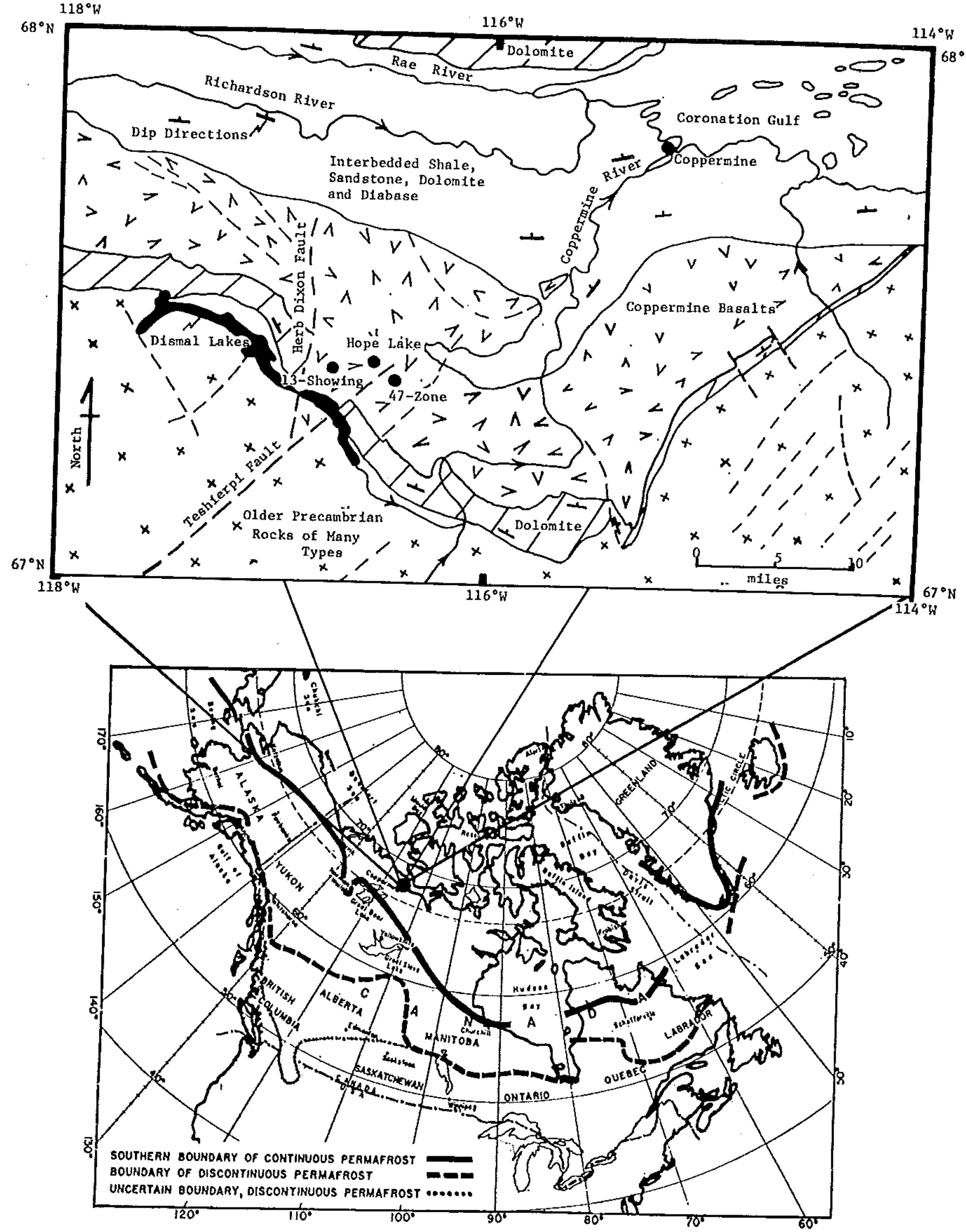


FIGURE 1 — Location map of study area, showing distribution of permafrost in Canada, general geology of the Hope Lake area and location of the 47-Zone and 13-Showing, Coppermine Basalt Belt, N.W.T.

Permafrost in Canada

Permafrost or perennially frozen ground is defined exclusively on the basis of temperature and refers to the thermal condition of earth materials such as soil and rock when their temperature remains below 0°C continuously for a number of years. Almost 50 per cent of Canada's land surface is underlain by permafrost. This area includes most of the Yukon, the Northwest Territories mainland and all of the Arctic Islands. Most of the Canadian Shield and its unknown mineral resources are thus located in the permafrost region.

There are two permafrost zones outlined in Canada (Brown, 1970): (1) continuous permafrost and (2) discontinuous permafrost. In the continuous zone, permafrost is supposedly found everywhere at depth. However, several hundred feet of thawed ground have been detected in this continuous zone beneath even shallow lakes both in Alaska (Brewer, 1958) and in Canada (Brown *et al.*, 1964). This situation will also exist beneath the larger rivers, which implies that permafrost in areas with numerous lakes and rivers, such as most of the Canadian Shield, is by no means "continuous" even in the continuous zone. There is also a strong possibility that permafrost is thawed out completely beneath larger (1000-ft diameter) lakes, providing a permeable connection of thawed ground among adjacent lakes and rivers. In the discontinuous permafrost zone, permafrost is found around "island areas" that have no permafrost at depth.

The depth of summer thaw of surficial materials in the permafrost zone is governed by a variety of factors, including vegetation cover, texture of the mineral soil, slope, aspect and distance north as it affects air temperatures. Very coarse gravel will thaw to much greater depths than fine silt, and in many cases the permafrost in coarse deposits is "dry", i.e. no ice formation is visible although the temperature is below 0°C continuously. Understanding the factors affecting depth of thaw, the distribution of thawed zones in the permafrost and therefore the existence of zones conducive to active leaching processes in permafrost regions could be very important in the interpretation of the degree and extent of geochemical dispersion halos which may be expected to be produced at a particular site.

Previous Exploration Geochemistry in Permafrost Regions of North America

To the best of our knowledge, previous geochemical investigations, of any size and extent, in areas of continuous permafrost in North America are non-existent. However, some geochemical exploration has been conducted by a few of the smaller companies active in the Northwest Territories. Even for the discontinuous permafrost zone in Canada, only very few geochemical studies, usually in the Yukon, are reported in the literature, such as at Keno Hill - Galena Hill (Boyle *et al.*, 1954, 1955, 1956; Boyle and Cragg, 1957; Boyle, 1965) and Casino (Archer and Main, 1970). These parts of the Yukon are also unglaciated or only slightly glaciated. In the discontinuous permafrost region of southern and central Alaska, also fortunately almost unglaciated, geochemical prospecting has been mainly limited to stream-sediment sampling using the available road system (Burand, 1966, 1968; Burand and Saunders, 1966). Exploration geochemistry has been used in the permafrost zone of the U.S.S.R. for some years (Stremyakov, 1958; Shvartsev, 1963).

This limited activity in Canada stands in contrast to the fact that 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 is underlain by permafrost.

Will Geochemistry Work in the Zone of Continuous Permafrost?

Most of Canada's permafrost regions (Brown, 1967) have also been glaciated (Prest *et al.*, 1967). This means that exploration geochemistry is apparently confronted with two problems: (1) glaciation and its associated surficial deposits, often unrelated to local bedrock, and (2) permafrost and its supposed lack of weathering and leaching. The former problem also exists over most of southern Canada (south of latitude 60°N), where it has been shown that the disadvantages of glaciation can often be overcome by pedogeochemical, hydrogeochemical or biogeochemical techniques. The concept of permafrost as a "dead" environment retarding chemical weathering is rapidly becoming historical. That rocks and therefore mineralized zones do weather and leach in zones of permafrost and that soils leach and clays weather and absorb cations has been demonstrated even in Antarctica (Claridge, 1965) and in Alaska (Allan *et al.*, 1969). Even in the continuous permafrost zone, as mentioned previously, there are probably many thawed areas which may be interconnected, associated with larger bodies of water. This could result in the formation of dispersion halos in the water and sediment of lakes and rivers in the continuous permafrost zone.

The formation of anomalous metal concentration halos in the vicinity of mineralization occurs by weathering and leaching. In the permafrost zone, a halo can also be produced by physical dispersion of particles due to periglacial processes such as cryoturbation (frost heaving) and solifluction (mass movement of soils). These periglacial processes bring material from depth to the surface. In the Arctic, rock formations buried by colluvium are often detected by looking at the frost-shattered rock fragments in, or on the surface of, frost boils. The nature of cryoturbation (Washburn, 1967) is such that it tends, by processes not yet fully understood, to homogenize the active layer, the layer which lies above the permafrost table and which thaws each summer. This homogenation allows the surface sampling of frost boils to replace the classical B-horizon sampling of soils south of the permafrost zone. Also, soils with B horizons (Arctic Brown soils) are extremely rare in the permafrost zone.

One major unknown factor which could have a considerable effect on the formation of geochemical halos in frozen surficial materials which lie over mineralized zones warrants discussion. This is the possibility of ionic transfer in frozen overburden, a process at present only beginning to be researched. If this, or some similar process, does not occur, then it is unlikely that mineralized bedrock which qualifies as permafrost and is hidden by overburden will produce an anomalous surface-detectable metal halo via this overburden. Mineral deposits that can be located by geochemical techniques in permafrost will then be those that: (1) project into the active (summer-thawed) layer; (2) are intersected by such features as streams, lakes and glacial erosion channels; and (3) intersect thawed zones at depth beneath lakes and rivers. This implies that regional geochemical exploration should concentrate on the sampling of some media associated either with thaw zones in the permafrost or a physiographic feature which dissects the landscape. Samples from beneath the permafrost table of perennially frozen glacial deposits, including glacial tills, outwash, kames, terraces and eskers, may prove useful in regional surficial geochemistry when used in conjunction with a knowledge of the glacial history. Nevertheless, considering the number of mineral deposits originally located by their surface showing, there must be many more in northern Canada that are only shallowly buried by glacial materials. The latter are the mineral deposits that surficial geochemical exploration methods in permafrost regions should be designed to locate.

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 rock only. The basalts are underlain by the Hornby Bay Dolomites (*Figure 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 western portion of the belt is a gently dipping anticline with a northeast-trending axis; the central and eastern portion is 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 (see *Figure 2* for location) was discovered by Coppermine River Ltd. in 1967. As outlined, it is a 4.1-million-ton body averaging 2.96 per cent copper, allowing 10 per cent dilution, with 0.6 per cent copper 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 the right lateral shear type.

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 flow. 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 zones have an average width of between 60 and 190 feet; the top is horizontal, whereas 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 *Figure 2* for location). 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 mountonées 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, Arctic Brown soils cover most of the 47-Zone and are developed on both till and outwash. There are, however, a few areas where the 'soil' consists of little more than the vegetation-covered shear-zone breccia. Based on the frost-boil traverse line across the Basalt Belt, the distribution of Arctic Brown soils 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 and have cobbles covered on their lower

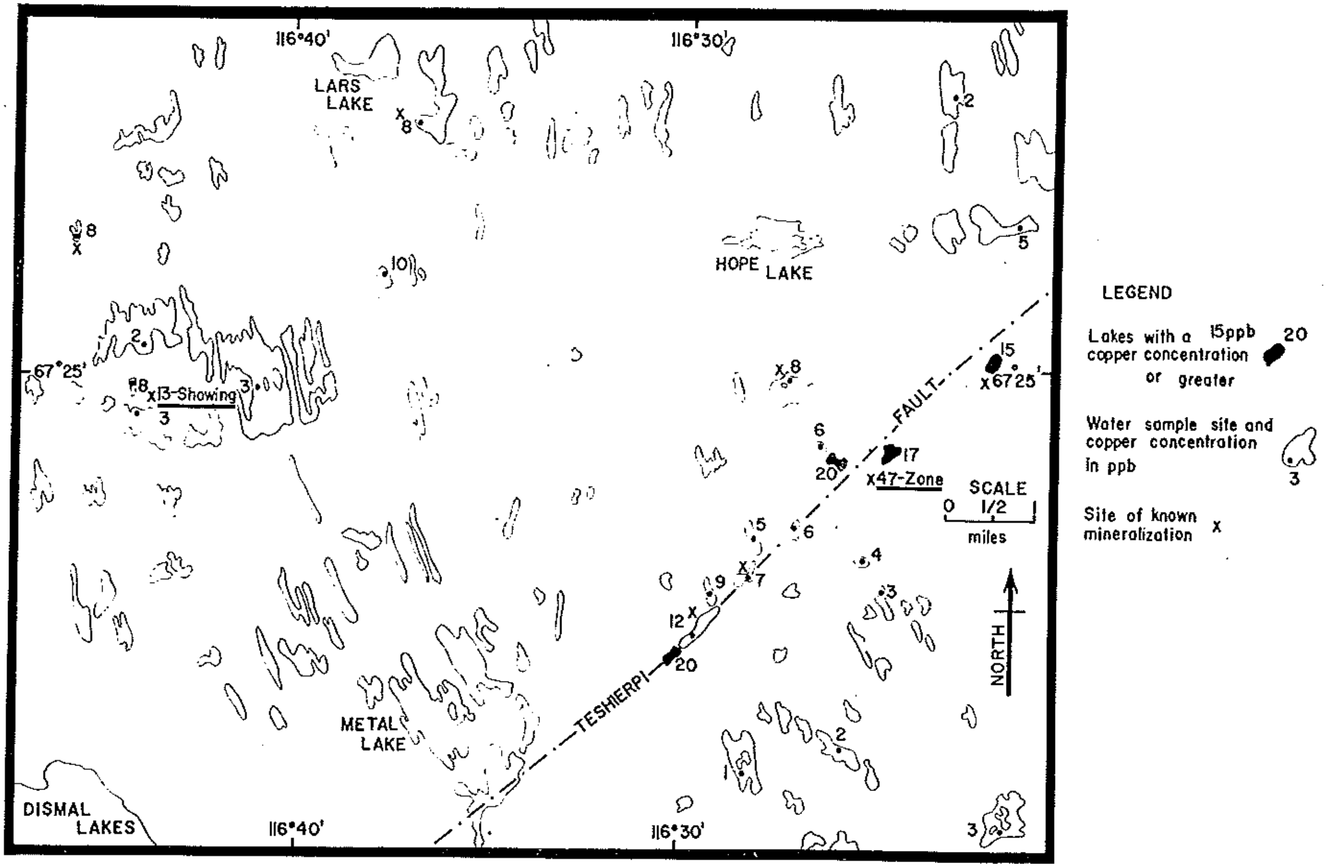


FIGURE 2 — Location of lakes sampled and their copper concentrations in ppb, Coppermine Basalt Belt, N.W.T.

side by 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 associated upward migration of water in the soils. This 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. The movement of water above the permafrost and through the active layer is both rapid and complex. During a 24-hour period, small kettles at the 47-Zone fill rapidly, and then drain, and the smaller streams flow and then quickly dry up after only slight rainfall.

In general, however, the Coppermine region is characterized more by silty colluvium with numerous frost boils, as at the 13-Showing. This showing is a smooth hillslope 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, the 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.

METHODS

Field Sampling Methods

Soils were sampled at the 47-Zone on a grid 2,200 feet east by 2,400 feet north. 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. There were slight variations in sample point location due to the presence of stone rivers, dense stone fields, solifluction lobes and recent drainageways. The grid at the 13-Showing was of irregular dimensions 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. Background O/A- and B-horizon samples came from the vicinity of 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.

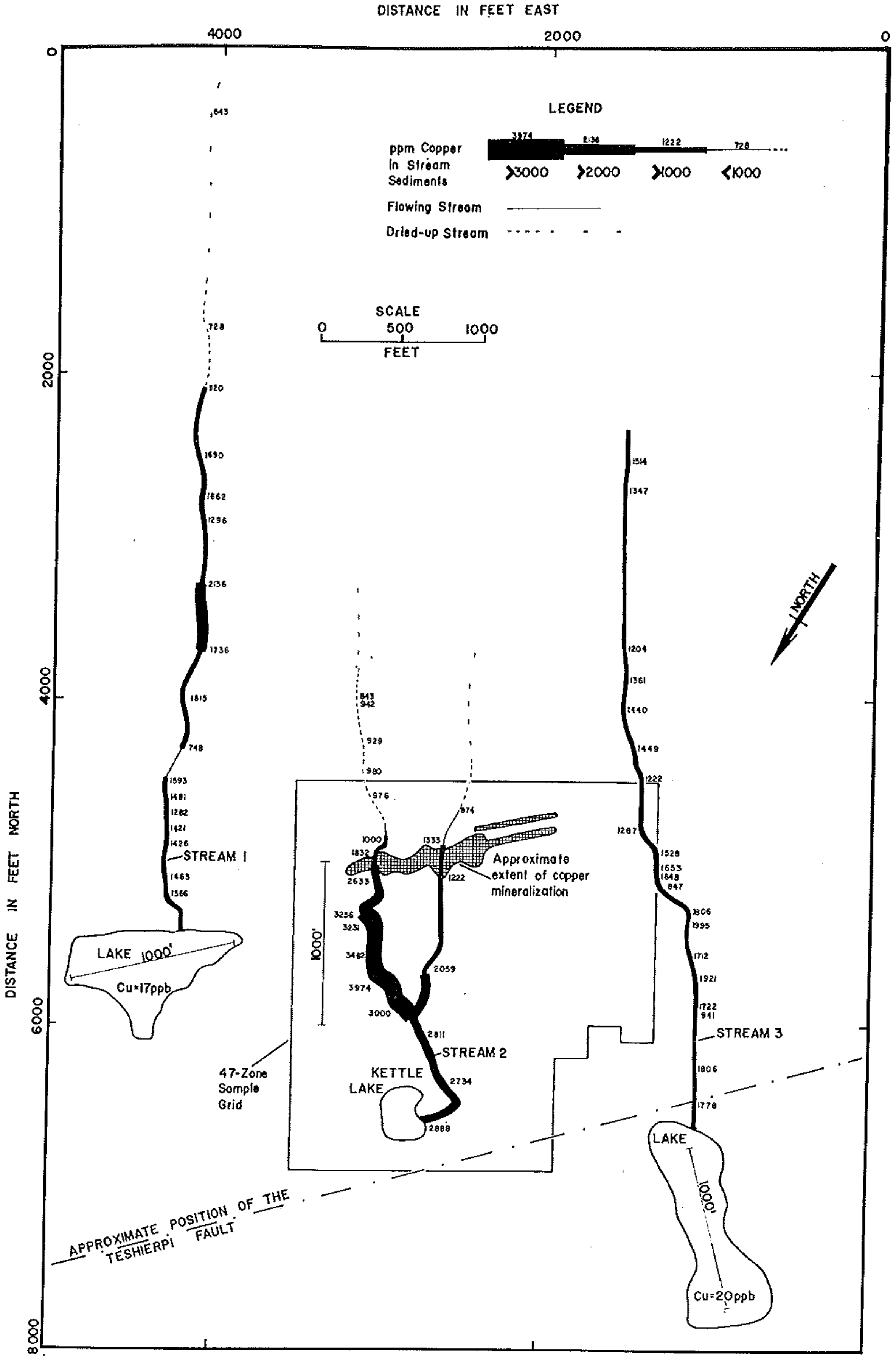
Sampling of O/A horizons proved to be time-consuming, and maintaining sample uniformity was difficult. The surface organic horizon of the Arctic Brown soils is discontinuous, very thin and stony, and collection of this horizon, on this basis alone, is not recommended. Even at good locations, a large lateral area had to be 'scavenged' to produce a large enough sample for analysis. B horizons proved much easier than O/A horizons to sample, although they too are discontinuous, requiring in places considerable lateral digging at a 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 pedogeochemical medium to collect. 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. The mechanism of boil regeneration homogenizes the mineral soil horizons above the permafrost table, producing a surface sample that is representative of the particular site to some depth. Boils also act as accumulators of fines in the bare central part of the boil, where stones are pushed to the side and are found under the vegetation-covered rims of the boils. Thus, a small sample from the center of the boil provides sufficient minus-80-mesh material for analysis. Also, 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. Silty frost boils, therefore, provide the best sampling medium for pedogeochemical investigations in the Coppermine area, and we recommend sampling them.

To obtain good silty stream-sediment samples, such 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 precaution 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.

The 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 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.

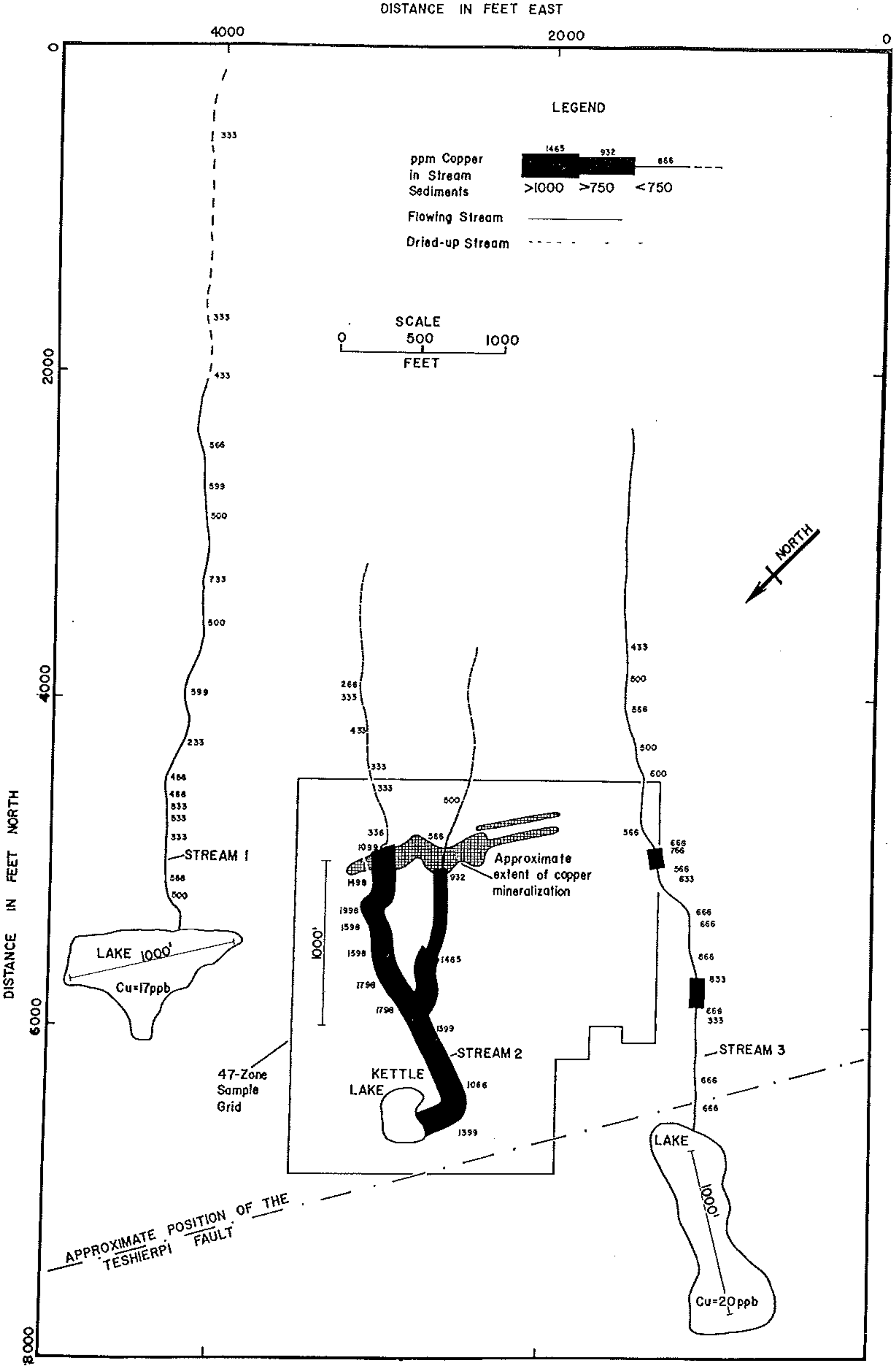
Biogeochemical sampling is relatively easy, although with the limited vegetation in frost-boil areas and the general dwarfed nature of the plants, it takes some time to collect a sample large enough for analysis. The difficulties in the separation of lichen samples into individual species prior to ashing 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; and (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 first two are extensive. The copper concentrations in the lake waters constitute evidence that significant chemical transport also occurs.



(a)
Hot HNO_3

FIGURE 3 — Copper concentrations in stream sediments in the vicinity of the 47-Zone, Coppermine Basalt Belt, N.W.T.: (a) hot-extractable copper.



(b)

Cold HCl

FIGURE 3 — Copper concentrations in stream sediments in the vicinity of the 47-Zone, Coppermine Basalt Belt, N.W.T.: (b) cold-extractable copper.

Laboratory Analysis Methods

The minus-10-mesh and plus-80-mesh fraction of the O/A horizon, the minus-80-mesh fraction of the B horizon, and frost-boil and stream-sediment samples were chemically analyzed as follows: 3 ml of 4N 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, frost-boil and stream-sediment samples. Methods of completely separating such copper forms as finely divided sulphides and those occluded in free iron hydroxides are not currently available. The plant material was ashed, and 100 mg analyzed as above. The stream-sediment samples were also analyzed by a cold HCl leach method, as described by Ward *et al.* (1966). The copper is determined colorimetrically as a 2-2′ biquinoline complex. It is thought that this method removes the copper which has been moved chemically and subsequently sorbed and precipitated; it may not significantly attack copper in the form of copper sulphide particles. The lake-water samples were analyzed by atomic absorption spectroscopy following concentration procedures for certain of the cations.

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 analytical results of the lake water are presented on a location map of the lakes, with black shading representing 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. As common points of reference, the sampling grid and the outline of the orebody or position of the mineralized quartz vein are shown on the anomaly maps. Copper profile plots for frost-boil analytical results were also constructed for the 47-Zone and the 13-Showing.

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 300 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 nine data points, on the average, with the major axis perpendicular to the sample traverse line.

Lake-Water Results

A study of copper concentration in lake waters (*Figure 2*) 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 non-economic mineralized occurrences. Of the twenty-five lakes analyzed, four had anomalous copper concentrations, and all of these are in the valley underlain by the 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 copper 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 the Teshierpi Fault valley, is at the end of a chain of connected lakes, and its content of 20 ppb Cu 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 copper concentrations in the lakes of the Coppermine River Basalt are relatively low. None of the Soviet lakes, however, are in permafrost regions.

However, the fact that lake waters do have measurable copper 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 the detection level of the method used. Based on the results of twenty-five 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 copper concentrations should be sampled, rather than just those flowing directly into such lakes. At the 47-Zone, this procedure resulted in the determination of copper concentrations in stream sediments from four streams.

(1) Hot-HNO_3-Extractable Copper

Anomalous concentrations were found only in the two streams which traverse the mineralized zone (*Figure 3a*). For these anomalous streams, copper concentrations upstream from the mineralized zone range from 800 to 1,000 ppm. After crossing the orebody, copper-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 (*Figure 3a*). Mineralized breccia did outcrop on stream 3, close to the 1,287-ppm-Cu concentration shown on *Figure 3a*. This could be the cause of the slightly higher concentrations, up to 1,995 ppm Cu, downstream from this location.

(2) Cold-HCl-Extractable Copper

With this method, a similar distribution of copper concentrations (*Figure 3b*) was noted in the stream sediments. The copper removed from any particular sample was consistently less than (usually about 1/3) that removed by the hot leach. The cold-extractable copper concentrations detected the presence of the mineralized zone at least as well as the hot method. Also, this cold HCl method is ideal for use in the field.

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, employing either of the analysis methods described.

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

O/A horizons compared to B horizons

On the follow-up detailed level, the copper concentration of O/A-horizon samples from the 47-Zone grid produced a more diffuse and less effective anomaly map (*Figure 4*) than either the 'total' or 'true' B-horizon samples (*Figures 5* and *6*, respectively). In part, this may be because the O/A-horizon samples were collected at 200-foot intervals as opposed to 100-foot intervals for B horizons. Conversely, however, at the semi-regional level, samples of the 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 was done 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) the copper distribution in the former most effectively defines the 47-Zone mineralization; and (2) B horizons, as mentioned previously, are more amenable to simple, rapid sample collection.

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

Two B-horizon anomaly maps are presented (*Figures 5* and *6*). During sampling, a sample from the B horizon was collected at each grid point, but the soil distribution near the 47-Zone really makes this impossible, and in several cases the B-horizon sample was actually a stream-sediment, solifluction-lobe or 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 (*Figure 5*). In the other case (*Figure 6*), a geochemical anomaly map was constructed using results for only the 'true', i.e. actual, Arctic Brown soil B horizon.

The purpose of this operation was two-fold. (1) *Figure 5* shows the type of anomaly map that would have resulted had the samples been collected by persons unfamiliar with

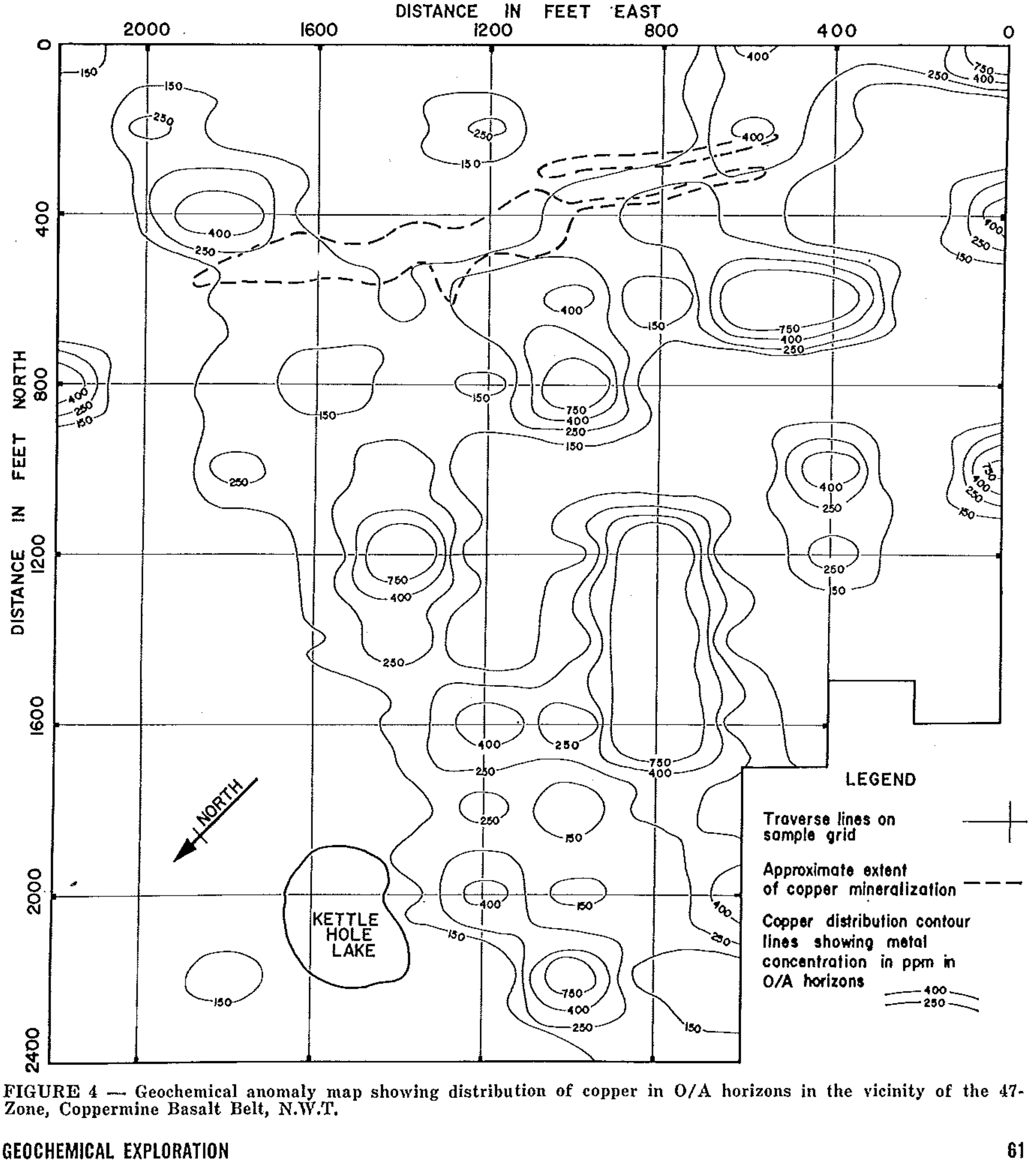


FIGURE 4 — Geochemical anomaly map showing distribution of copper in O/A horizons in the vicinity of the 47-Zone, Coppermine Basalt Belt, N.W.T.

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

Underlying Glacial Overburden	Horizons	Depth in cms	Cu(1)	Zn	Mn	Ag
			in ppm			
Till	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 (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 (dead ice)	O/A	0—2	132	44	736	n.d.
	B	2—30	149	32	420	n.d.
	C1	30—25	286	40	876	n.d.
	C2	35—90	415	57	1096	0.5
	Permafrost	90+	n.s.	n.s.	n.s.	n.s.

(1)None of the B horizons of these three soils had anomalous Cu concentrations; (2)n.d. = none detected; (3)n.s. = no sample

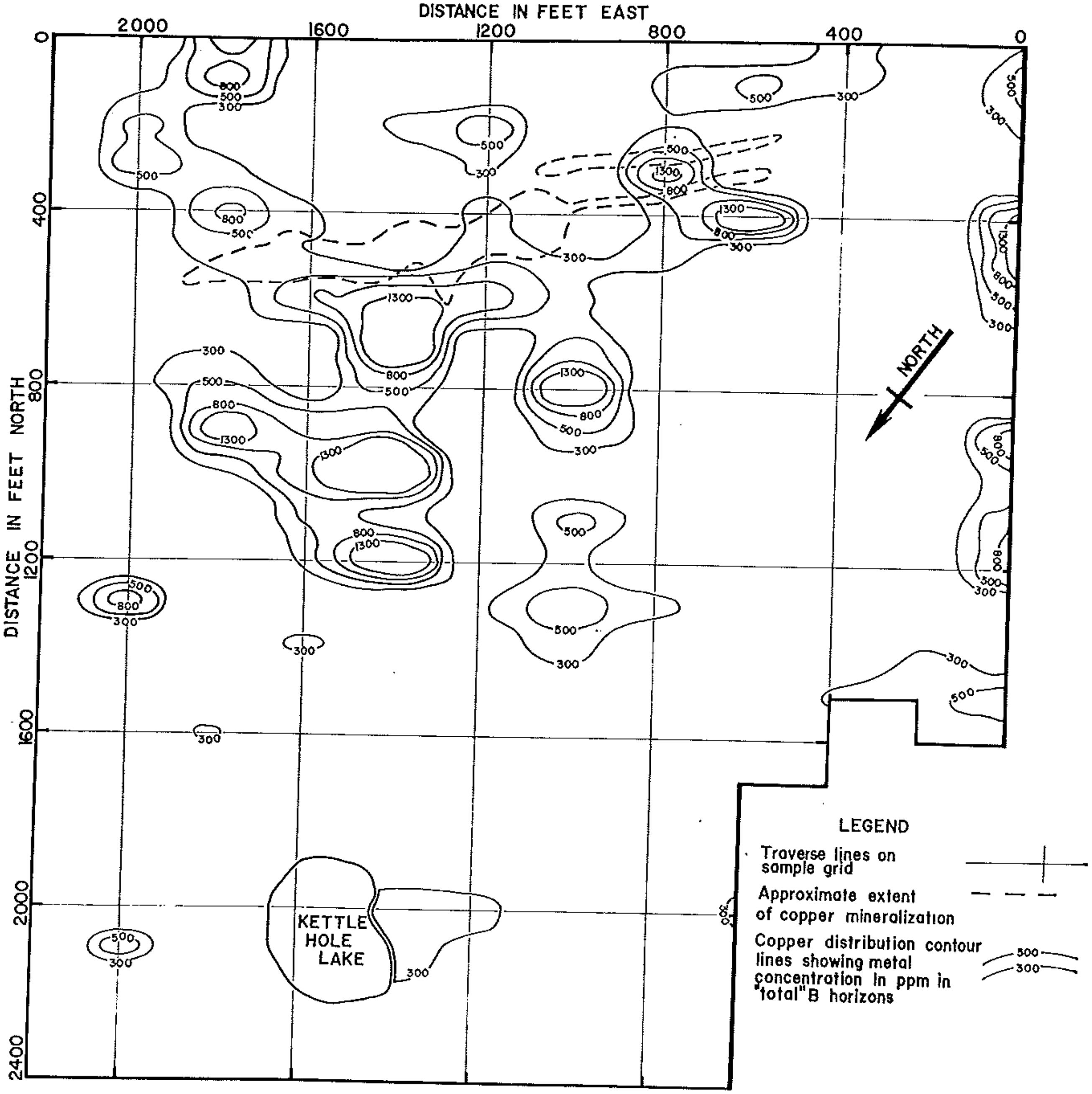


FIGURE 5 — Geochemical anomaly map showing distribution of copper in 'total' B horizons in the vicinity of the 47-Zone, Coppermine Basalt Belt, N.W.T.

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 mineralization and shows that, at least for the 47-Zone, this collection procedure would have been adequate. (2) *Figure 6* shows that had the 47-Zone been completely covered by Arctic Brown soils, i.e. had there been no visible surface expression of mineralization, the collection and analysis of 'true' B horizons from these soils would also have located the 47-Zone mineralization. *Figure 6* is thus of great value, as it tends to predict the successful detection of mineralization even when not visible at the surface in areas with continuous permafrost.

C horizons compared to B horizons

Table I 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 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 three sites were studied, that sampling of Arctic Brown soils is best done as close to the permafrost table as possible. In permafrost regions, however, because Arctic Brown soils only occur on very coarse gravelly deposits, C-horizon sampling is extremely difficult and would probably only be justified as a final stage in geochemical exploration.

At the 47-Zone, the anomalous to background contrast for copper concentrations in silty frost boils was sixty-fold, as opposed to about twenty-five-fold for B-horizon soils on the same line (*Figure 7*). This implies that even at the 47-Zone, where there were relatively few frost boils, they may still have been better sampling media than the horizons collected from Arctic Brown soils.

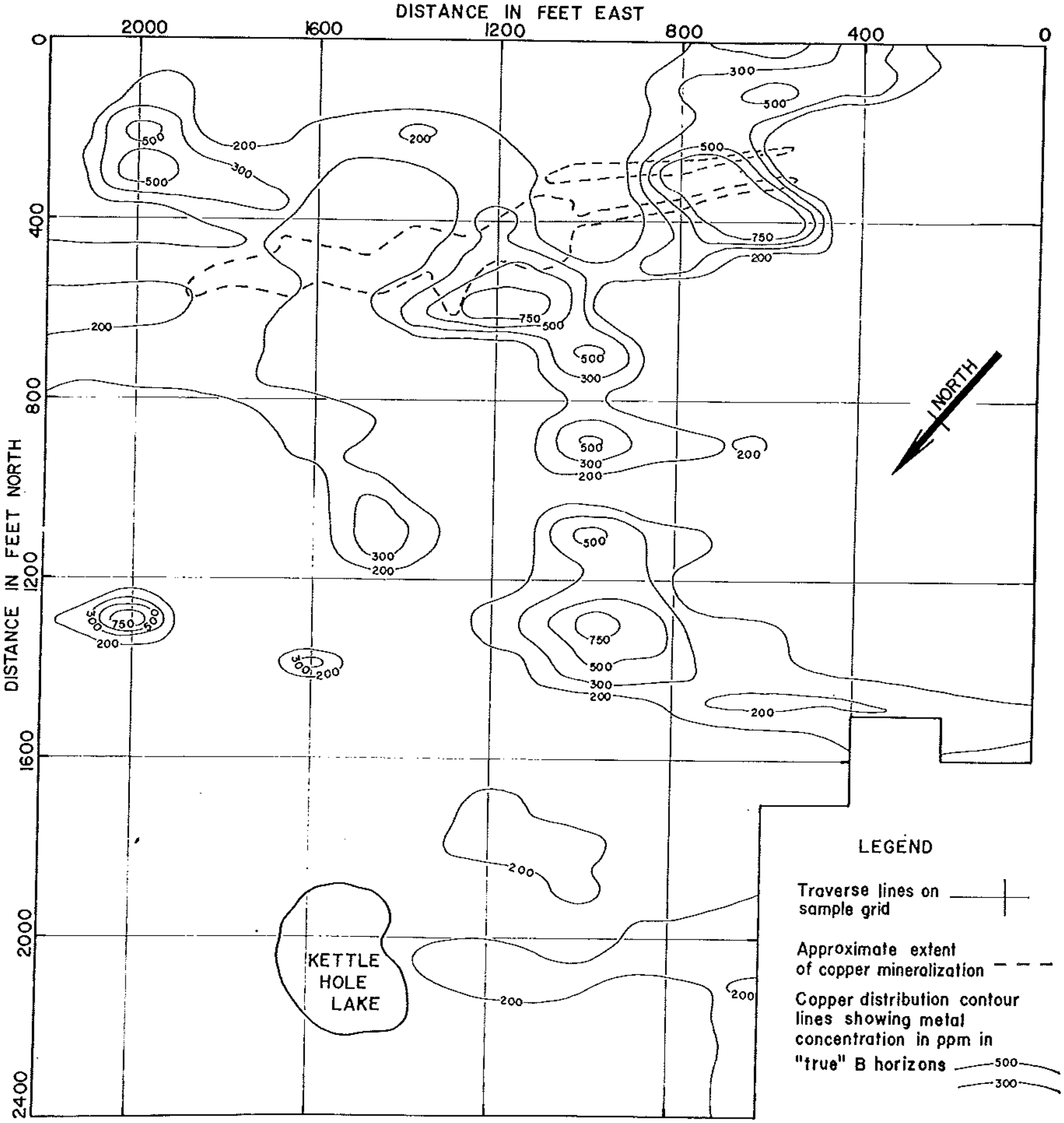


FIGURE 6 — Geochemical anomaly map showing distribution of copper in 'true' B horizons in the vicinity of the 47-Zone, Coppermine Basalt Belt, N.W.T.

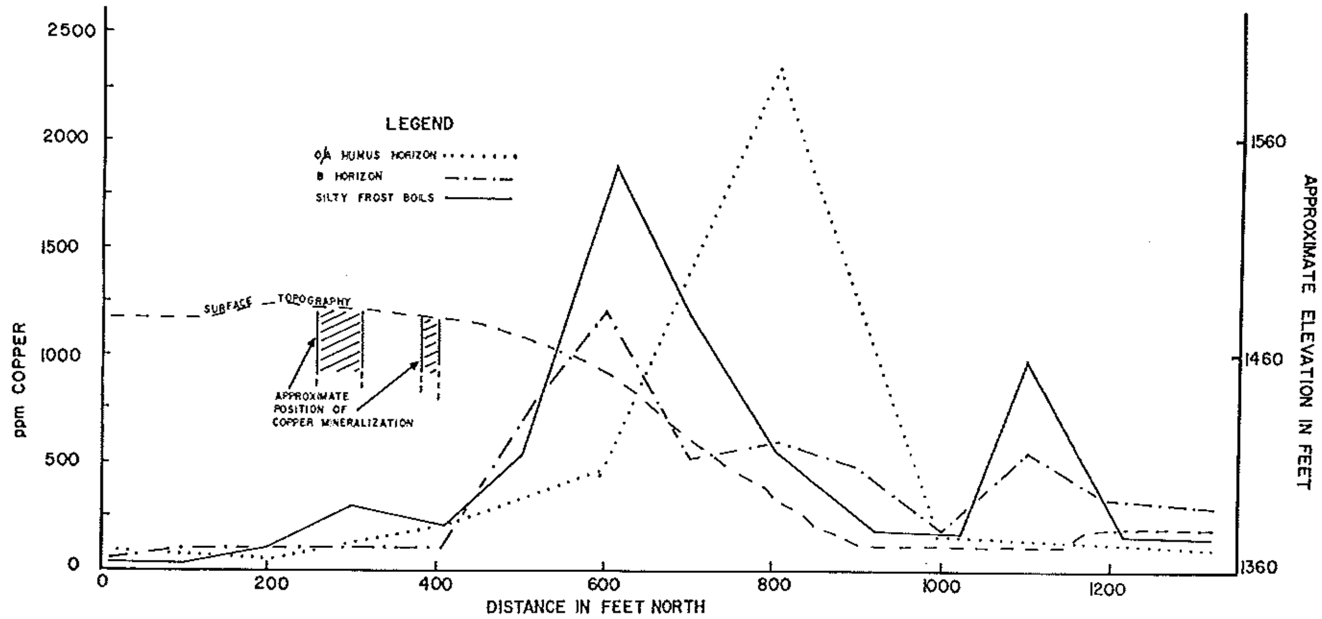


FIGURE 7 — Frost-boil and soil anomaly profiles; comparison on a traverse line at the 47-Zone.

TABLE II — Biogeochemical Results of Plant Ash Analyses from the 47-Zone

Distance, in feet, east and north on the 47-Zone sample grid	Expected value due to sample site location	PLANT TYPE				
		Dwarf(1) lupin	Heather(2)	Lichen(1)	Lichen(2)	Lichen(2)
		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
Near Hope Lake airstrip	Background	58	158	108	108	125

(1)Leaves only (2)Combined foliage (3)n.s. = no sample

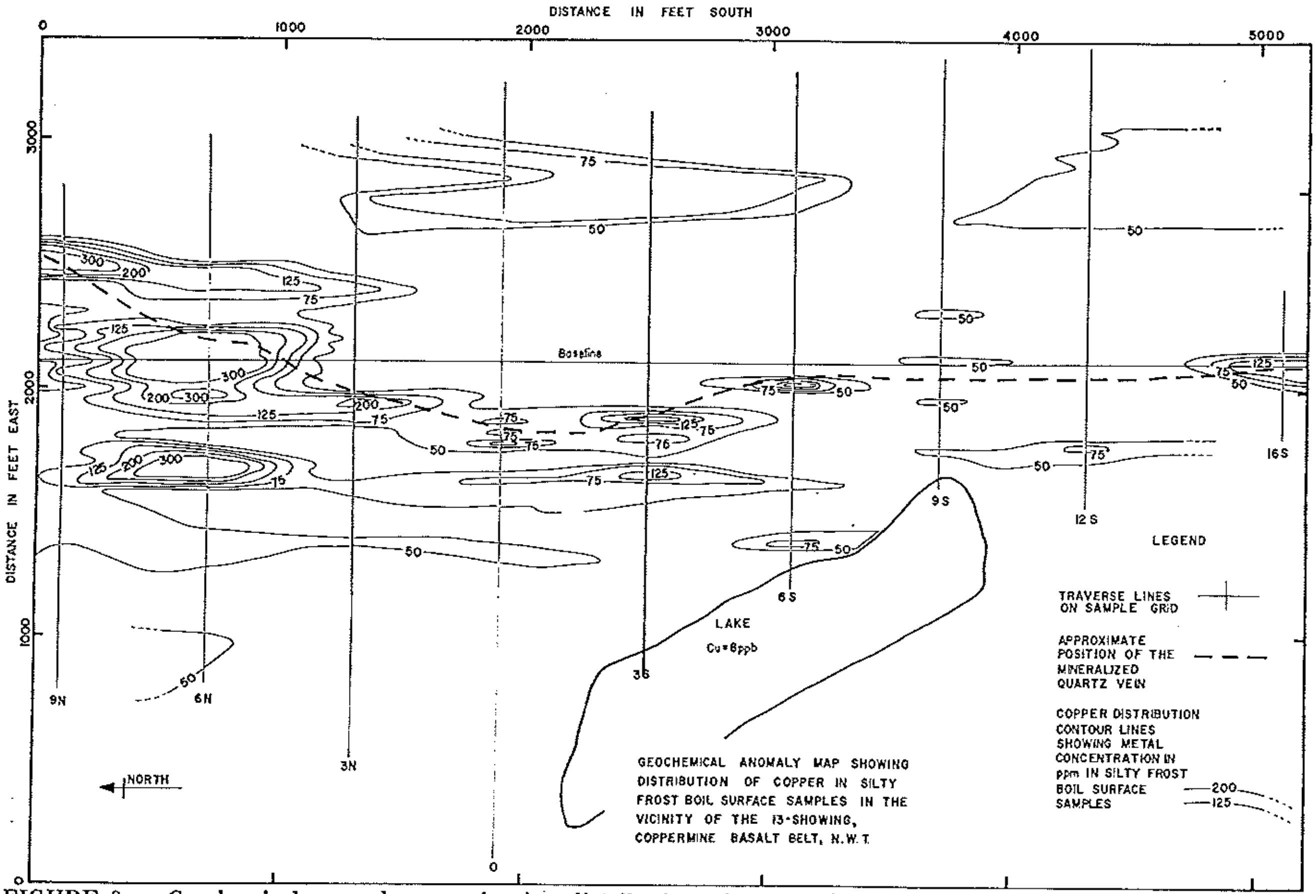


FIGURE 8 — Geochemical anomaly map showing distribution of copper in silty frost-boil surface samples in the vicinity of the 13-Showing, Coppermine Basalt Belt, N.W.T.

Vegetation Results at the 47-Zone

Copper results for analyses of lupins, heather and three types of lichens are given in Table II. The copper 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 the copper distribution in the Coppermine River Basalt region.

Potentilla twigs and leaves collected from stream 1 and 3 (*Figure 3*) at the 47-Zone were analyzed for Cu, Zn, Ag and Mn. Copper 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 sample medium for geochemical exploration is in direct competition with lake, water and stream sediments. The Potentilla results for copper 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 (*Figure 8*) showed that copper was significantly dispersed, probably by solifluction, only for a maximum of 200 feet 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 (*Figure 8*) 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 copper 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 did not produce anomalously high copper concentrations in frost-boil surface samples collected near the vein between the 6S and 12S lines. An 8-ppb Cu concentration in the lake at the foot of the slope (*Figures 8* and *2*) can be related to the non-economic copper mineralization at this showing.

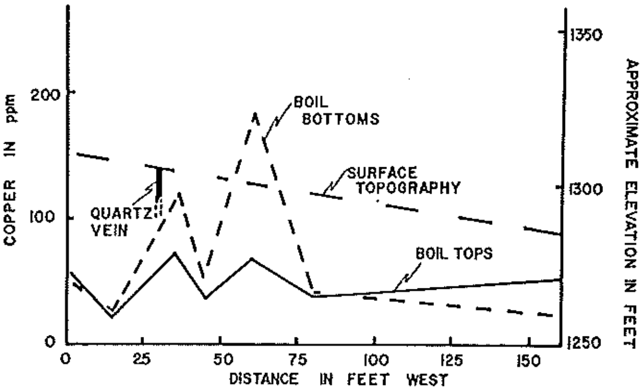


FIGURE 9 — Frost-boil anomaly profiles; comparison of copper concentrations at the 13-Showing, Coppermine Basalt Belt, N.W.T.

Copper analysis of silty soil from the tops and bottoms of frost boils on the 1S line at the 13-Showing revealed certain concentration differences. These differences, about two-fold as a maximum (*Figure 9*), were only significant close to the mineralized vein. Farther from the vein, top and bottom samples have a similar copper content. Thus, although surface samples of frost boils give a good representation of the copper concentration in the entire thawed active layer (*Figures 7* and *8*), 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 post-hole soil auger.

Regional Background Frost-Boil Results

Nine surface frost-boil samples from a 25-mile traverse crossing the dolomites, basalts and sediments in the Coppermine River area (*Figure 1*) had very uniform total copper concentrations. The average copper content was 45 ppm, with a range of 20 to 71 ppm and a standard deviation of 16 ppm. The copper content in frost boils from the regional traverse suggests that any concentration in excess of 100 ppm hot-HNO_3-extractable copper or 50 ppm cold-HCl-extractable copper in a surface frost boil is associated with some type of mineralization, mineralized float or hydrogeochemical anomaly.

The mineralogy in the fine sediment fraction ($<5\mu$) was very uniform. X-ray diffraction of the $<5\mu$ fraction of the nine frost boils showed their composition to be mainly mica and kaolinite, with smaller quantities of chlorite and vermiculite. A similar mineralogical composition has been noted 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 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 copper concentrations in various sampling media is: stream

TABLE III — Means and Standard Deviations 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	ISD(3)	Mean	ISD	Mean	ISD
		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(12)	9	44	16	47	11	0.75	0.37
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 nine samples were collected, which makes the means and standard deviations doubtful. However, Ni and Ag values are still very similar to those at the 47-Zone and 13-Showing.
(3)One standard deviation.

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 copper is the most effective element to use in geochemical prospecting in the Coppermine Basalt Belt. This is not surprising, because copper is the dominant element in the ores of the region. In the lake waters, no other element (Zn, Pb, Ni, Co and Mn) but copper could be correlated with mineralization. Similarly, this relationship seemed to apply to all of the soil and stream-sediment materials, which were analyzed for copper, silver, nickel and manganese. Concentrations of nickel at both the 47-Zone and 13-Showing were statistically very similar. The mean nickel concentration at the 47-Zone was 40 ppm and 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 silver. This indicates that neither nickel nor silver are useful 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 III. The great diversity of copper:manganese ratios in 'total' B-horizon soil samples at the 47-Zone and silty frost-boil surface samples at the 13-Showing imply that manganese in permafrost areas may not act as a preferential absorber of other metal cations, at least of copper, in the Coppermine River Basalt Belt.

CONCLUSIONS

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

(1) Copper is actively dispersed both as particles and in solution from known occurrences of mineralization.
(2) Copper is the most effective indicator element for tracing mineralization.
(3) Lake water is a very effective sampling medium for regional geochemical exploration where one axis of the lake is at least 1,000 feet.
(4) Stream sediments are the best semi-regional sampling media where samples are taken at a maximum interval of 1,000 feet.
(5) Detailed geochemical sampling 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.
(6) Frost boils are better sample media than B horizons, due to the homogeneity of sample material at an individual site, the uniformity of sample media among sites and their widespread occurrence.

These conclusions are specific for the Coppermine River Basalt Belt. However, they have broader implications with respect to the use of exploration geochemistry in areas of permafrost in general. With due consideration of the problems caused by the existence of glacial deposits and the limitations imposed on the source of geochemical dispersion by the existence of permafrost, geochemistry can be expected to work as well in the zone of permafrost as in any other surficial environment.

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