GEOLOGICAL
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DEPARTMENT OF ENERGY,
MINES AND RESOURCES

PAPER 69-49

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E. H. W. Hornbrook
(with a contribution by G. D. Hobson)

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# ABSTRACT

A biogeochemical prospecting program was conducted during the late summer of 1967 at a copper-molybdenum deposit, to determine the distribution of copper, molybdenum and associated elements in plant organs and soils, and to evaluate the effectiveness of plant prospecting techniques for detecting this and similar deposits.

New and modified methods for the collection and preparation of soil and vegetation samples, and the spectrographic analysis of organic material in mobile laboratories (separately developed during earlier work), were simultaneously used under field operating conditions. A sample grid of 96 stations was established over the deposit and the following materials were collected where possible at each station: B horizon, $A_h$ horizon, bark (collected at breast height, 4 feet 6 inches from the ground), second year twig and needle. Alpine fir, Abies lasiocarpa, was sampled at all stations and lodgepole pine, Pinus contorta, only at certain stations on the main baseline. Shallow seismic determinations of the depth and nature of surficial material were carried out simultaneously with field operations.

Organic samples were analyzed spectrographically for Ba, Sr, Mn, Ti, Ag, Cr, and Co and soil and vegetation samples were analyzed colorimetrically at the Geological Survey of Canada, Ottawa, for Mo, Cu, Zn, Pb, and Ni.

Significant conclusions, among the several determined, in research on biogeochemical prospecting techniques are: (1) Biogeochemical twig and needle results are as equally effective as geochemical soil results in detecting mineralized zones. (2) The behaviour of molybdenum in alpine fir second-year needles demonstrates the phenomenon of the breakdown of a partial exclusion mechanism, and how this can be advantageously used to obtain an accentuated distribution contrast over mineralized areas. (3) Copper and molybdenum were the only elements whose distribution showed a persistent relationship to the mineralized zones of the deposit, and the latter, in needles, is particularly useful as a pathfinder element for copper-molybdenum deposits.

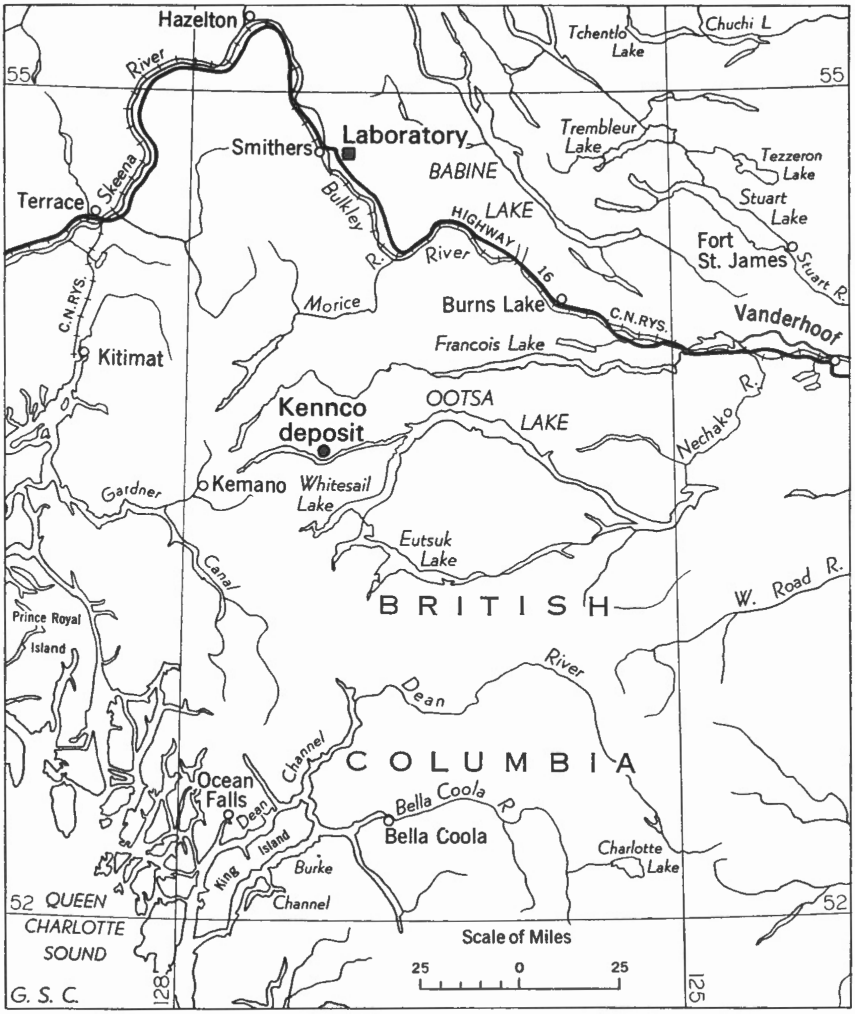

Figure 1. Index map of west-central British Columbia, showing the location of the Kennco deposit and the trailer laboratory site near Smithers.

# BIOGEOCHEMICAL PROSPECTING FOR COPPER IN WEST-CENTRAL BRITISH COLUMBIA

## INTRODUCTION

A biogeochemical and geochemical prospecting program was conducted at the Huckleberry Mountain copper-molybdenum deposit of Kennco Explorations (Western) Limited, in west-central British Columbia during the late summer of 1967. The program was conducted to determine the content and distribution of copper, molybdenum and associated elements in plant organs and soils of the landscape, in order to evaluate the effectiveness of plant prospecting techniques for detecting buried mineral deposits.

The Huckleberry Mountain Property is situated between Tahtsa Reach and Sweeney Lake, at 53° 40'N and 127° 10'W, about a knoll on the south slope of Huckleberry Mountain (Fig. 1). Access is provided from either Burns Lake or Houston, south via the Tahtsa Lake Mining Access Road 110 or 130 miles respectively to the property. The final three-mile section of the road into the property was constructed by Kennco.

The landscape containing this deposit was chosen for biogeochemical investigation partly because it has many features similar to that of the Lucky Ship Property of Amax Explorations Incorporated. The Lucky Ship molybdenum deposit is situated 28 miles to the northwest on the east side of Morice Lake. Biogeochemical investigations conducted during the earlier part of the summer at the Lucky Ship Property have been described by Hornbrook (1969b). Included among the similarities that would permit a meaningful comparison between each property's exploration results are the following significant features: altitude – 3,000 to 4,000 feet above sea level, forest cover type species – alpine fir and lodgepole pine dominant, soil types – podozolic, host rock – Hazelton Group, intrusive – central granitoid stock with associated mineralization. Also, a favourable recommendation was given by Fortescue and Usik (1969), who briefly examined the vegetation on the property in 1965.

The Huckleberry Mountain Property has been dormant since 1964 when Kennco finished their drilling program. Geochemical stream sediment and geophysical surveys were also carried out by Kennco on the property. Results of this exploration indicated that the quartz diorite intrusive stock contained some subgrade copper mineralization, but that higher grade mineralization was present in the host Hazelton Group rocks adjacent to the stock.

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Ottawa 4, Ontario.

During August, 1967, soil and vegetation samples were collected from 96 stations of a sample grid established over the deposit. Samples were prepared and analyzed spectrographically in two mobile trailer laboratories stationed at Smithers, British Columbia. Colorimetric analyses of the same samples were completed in Ottawa at the Geological Survey of Canada.

Shallow seismic determinations of the depth and nature of the surficial material were carried out by a two-man crew under the direction of G. D. Hobson of the Geological Survey. A report describing their work and the results is found as a contribution by G. D. Hobson in Appendix D.

## Acknowledgments

The writer was aided in his field and laboratory work by D. M. V. Coombes, R. E. Cranston, F. P. Horan, W. F. Tuer and K. D. Wollin to whom he is indebted for their able assistance and excellent companionship. Thanks are due to P. T. Black and other officials of Kennco Explorations (Western) Limited, who gave permission to carry out biogeochemical investigations at their property. Information concerning the property in this report has been reviewed by staff of the company. Thanks are also due to J. J. Lynch of the Geological Survey, under whose direction the colorimetric analyses were done in Ottawa.

## GENERAL DESCRIPTION OF THE LANDSCAPE

Geology of the region has been described by Duffell (1959). A generalized geological map of west-central British Columbia is shown in Figure 2. The Huckleberry Mountain Property is situated in a transitonal zone between the Coast Mountains and the interior Nechako Plateau. Volcanic and sedimentary rocks of this zone are part of the main belt of Hazelton Group rocks which trend northwest along the eastern contact of the main body of the Coast Range Intrusions. This belt is composed of interbedded breccia, tuff, dacite, rhyolite, basalt, argillite, greywacke, chert, conglomerate and minor limestone which are intruded in places by stocks of granitoid rocks. The property is underlain by Hazelton Group greywacke, tuff, argillite and andesite host rocks which have been intruded by the quartz diorite porphyry stock that forms the small knoll south of the western ridge extension of Huckleberry Mountain. The geology of the property has been described in detail by J. M. Carr (1964) as follows:

"The stock and adjacent dykes are emplaced into altered tuffs and tuffaceous sedimentary rocks assigned to the Hazelton Group, which is mainly of Middle Jurassic age. According to evidence obtained from vertical drill-holes and rare outcrops, bedding and foliation in the Hazelton rocks are generally inclined at low to moderate angles, partly in a south-southwesterly direction.

"The quartz diorite porphyry is a grey to pinkish rock of dacitic composition which weathers buff coloured. It contains closely spaced phenocrysts of white plagioclase as much as 1 centimetre long, and smaller ones of biotite, quartz, and, in places, pink orthoclase. The groundmass has a fine

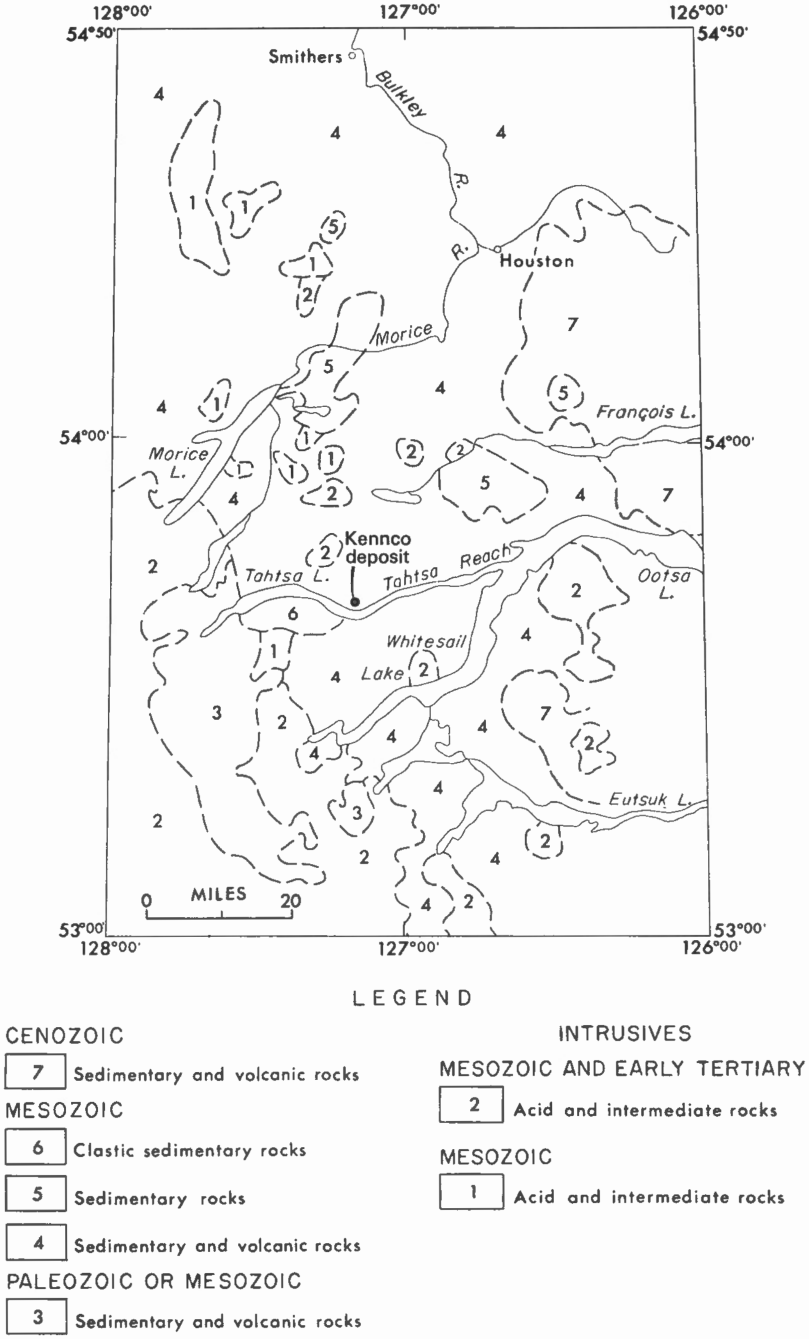

Figure 2. General geology of the transitional zone between the Coast Mountains and the Interior Nechako Plateau.

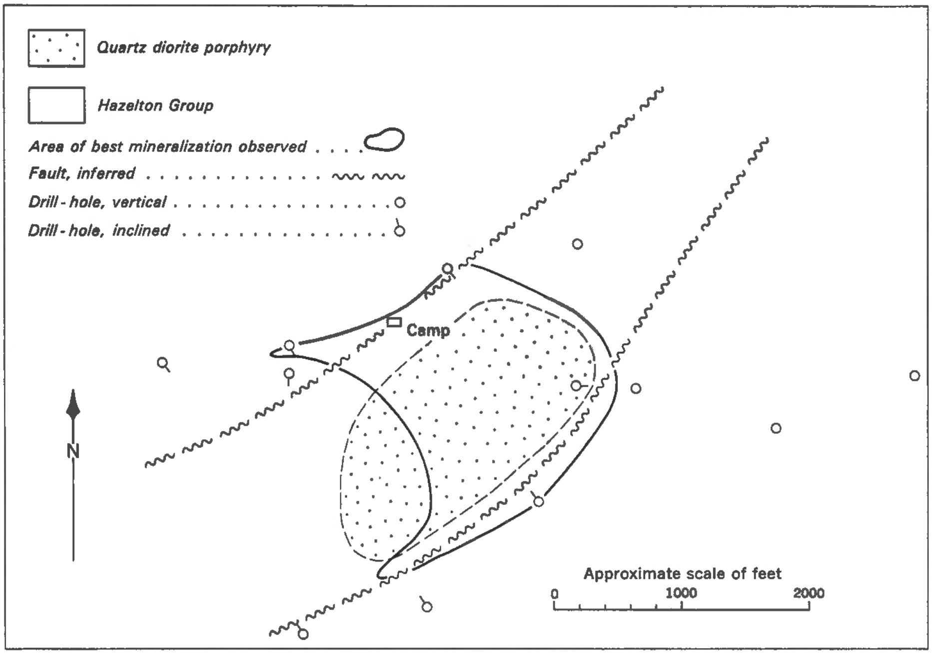

Figure 3. Len group claims, Huckleberry Mountain (modified from Carr, 1964).

granitic texture and consists mainly of the same four minerals. Dykes and sheets of this rock occur with unknown attitudes and in apparently diminishing numbers away from the stock.

"Hornblende feldspar porphyry forms dykes and sheets cutting the stock and adjacent rocks. It is a rock of dacitic composition which differs in appearance from the quartz diorite porphyry mainly in the presence of numerous aligned hornblende phenocrysts and the scarcity of quartz phenocrysts. The groundmass is aphanitic, pinkish, and consists mainly of quartz and plagioclase. The attitudes of the dykes and sheets are unknown, except that most are steep.

"The above-described rocks are altered most strongly where they are fractured and veined, chiefly in and around the stock. Quartz veins up to 1 inch wide and partly vuggy are numerous in parts of the stock, where they tend partly to form sets of sub-parallel veins in various directions. In the Hazelton rocks, veins are slender and less conspicuous. Rock adjoining the quartz veins is marginally bleached, or is pink because of orthoclase, or is otherwise altered. Mineral in veins partly containing quartz include orthoclase, actinolite, calcite, fluorite, and epidote. Veins of the orange-brown zeolite, stilbite are plentiful, and heulandite is possibly also present. Gypsum veins occur, and disseminated anhydrite was recognized in drill core from a depth of about 600 feet below the surface. Biotite formed by alteration is partly in veinlets, but is chiefly finely aggregated in porphyry and abundantly disseminated in hornfelsed strata adjoining the stock. Chlorite and sericite alteration is strongest near faults, in sheared rock containing abundant calcite veins that are mostly post-mineral in age.

"All outcrops and drill-holes contain pyrite occurring as disseminations and fracture-fillings, and in quartz veins. Copper and molybdenum mineralization is earlier than some, if not all, of the pyrite, and is concentrated chiefly near the stock, where it is apparently best in the zone indicated on Figure 3. Chalcopyrite is the principal copper mineral and is locally accompanied by traces of bornite. Limited surface oxidation has in places produced small quantities of copper carbonates. Chalcopyrite, which is generally accompanied by pyrite, occurs partly disseminated in altered rocks and partly as coarsely crystalline coatings, nests, and blebs in quartz veins. Molybdenite occurs in smaller amounts as fine particles and streaks, in or near quartz veins, generally in the vicinity of chalcopyrite but in places accompanied only by pyrite. Magnetite in veins and other local concentrations apparently formed before the sulphides."

Company geological, geophysical, geochemical and diamond-drill data suggests that better copper-molybdenum mineralization would be found adjacent to the stock in the fractured zones, whereas the stock contains copper mineralization only (Black, P. T., pers. comm.).

Podzolic soils of the area are similar to those described by Farstad and Laird (1954), in the Nechako, Françoise Lake and Bulkley-Terrace areas. The typical podzol soil is developed on a sandy gravelly parent till, of low lime content, under an alpine fir and lodgepole pine type of vegetation. A soil profile typical of that observed at most stations is shown in Figure 4. B horizon in soil sample pits shows much variation in colour and thickness. The most common colours were orange-yellow over a yellow subhorizon. Occasionally the upper B horizon had a reddish cast. Thicknesses of the B horizon less than 8 inches or more than 15 inches were rare. At certain stations the developed soil was modified by local drainage conditions or by the forest fire, which burned through the area about 50 years ago. In the stream valley, north and west of the knoll, a grey to chocolate brown stony

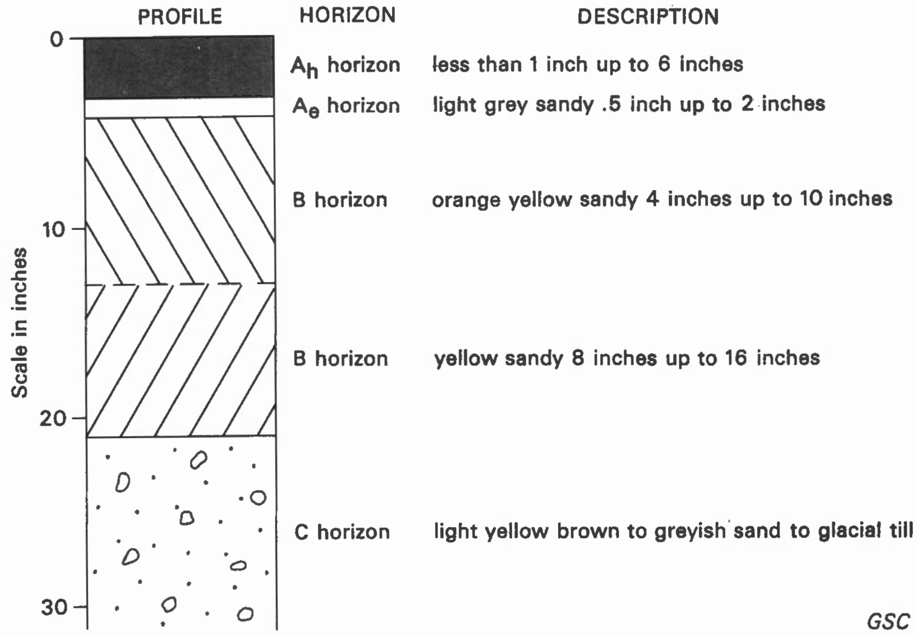

Figure 4. Sketch representing a typical podzol soil profile occurring in the vicinity of the Huckleberry Mountain copper-molybdenum deposit.

soil was sampled. On the top of the knoll many charred fragments were observed in the upper B horizon, in the poorly developed $A_e$ horizon and in the thin humus horizon.

Rowe (1959), has described the forest vegetation as being in the Montane transition section of the Montane Forest Region as follows:

"The forests of the relatively low-lying land on the northern half of the Nechako plateau are transitional in composition between the Montane and the Subalpine. Relationship to the latter Region is most apparent, as the characteristic forest type consists of spruce (Picea glauca, P. engelmanni and their intergrades) and alpine fir (Abies lasiocarpa). However, blue Douglas fir (Pseudotsuga taxifolia var. glauca) is also scattered throughout, and its presence has led to the inclusion of this Section in the Montane Forest Region.

"The widely distributed spruce-fir forest has been decimated by fires, resulting in an expansion of associations of aspen (Populus tremuloides), western white birch (Betula papyrifera var. commutata) and lodgepole pine (Pinus contorta var. latifolia). Under the present conditions of environment, Douglas fir appears to be losing the position of prominence that it formerly had in the vegetation pattern, except perhaps in the drier, open forest types. On the eastern side of the Section, there is a gradation into the northern Columbia forest with the appearance of mixed stands of Engelmann spruce, western red cedar (Thuja plicata) and western hemlock (Tsuga heterophylla) and of Engelmann spruce with Douglas fir. Westward, the hemlock appears again in the foothills of the Coast range. Along the rivers and lakes, black cottonwood (Populus trichocarpa) is commonly found. Numerous grassy openings and parklands with groves of aspen occur, particularly in the western half of the Section.

"The major part of the northern interior plateau is a rolling upland at about 2,500 feet altitude, and only a few hills and low mountains exceed 5,000 feet. The underlying bedrock is of rather flat-lying Palaeozoic and Mesozoic sediments, with some local Tertiary sediments and lavas. Large sections were flooded by post-glacial lakes, remnants of which still remain in the comparatively broad, flat valleys, and there has been a thick deposition of lacustrine deposits. Upper slopes and highlands are covered with glacial drift. The soils are grey wooded or podzolic under coniferous stands, and grey-black or immature under the more open mixed and hardwood forests of the lowlands."

Locally, alpine fir Abies lasiocarpa and lodgepole pine Pinus contorta are the dominant species, and the latter is only more common in the sandy soil on the top of the knoll. An occasional white spruce Picea glauca, western hemlock Tsuga heterophylla and black cottonwood Populus trichocarpa were observed in the valleys and slopes surrounding the knoll. Other species indigenous to the area and the complex bog site east of the knoll are described by Usik (1969).

Alpine glaciation in small cirque glaciers among the higher mountains is still active. Drumlins, and crag and tail effect on ridges and hanging valleys are among the common features of glaciation. Surficial material overlying the ridges and plateaus is till; thick fluvioglacial deposits occur in the valleys.

The relief of the region is similar to that described in Hornbrook (1969b), for the Lucky Ship Property of Amax Explorations Incorporated. It is not as rugged as the Coast Range, but more so than the interior Nechako

Plateau. The main mountain ranges of the region, Tahtsa, Kasalka, and the Sibola trend northeasterly, transverse to the general trend of the Coast Range. At their western extremities they are characterized by peaks up to 7,000 feet elevation. On the east, plateau-like areas, common at about 4,500 feet elevation, eventually merge into the main interior Nechako Plateau. Drainage is into long narrow lakes such as Morice, Nanika, Tahtsa and Whitesail lakes, that are situated between transitional mountain ranges. These lakes occupy valleys that are erosional rather than orogenic in origin according to Duffell (1959).

Climatic data for the area are not available, but at Telkwa, on Highway 17, 70 miles north of the property, monthly, seasonal and mean annual temperatures are reported, and are shown in Table 1. Rainfall in the region may vary considerably locally but total precipitation is similar to that of the central interior of British Columbia.

Table 1

Monthly, seasonal, and mean annual temperatures in degrees Fahrenheit, at Telkwa, British Columbia, 70 miles north of the Huckleberry Mountain copper-molybdenum deposit

| Month | Temperature | Month | Temperature |
|---|---|---|---|
| December | 18 | June | 53 |
| January | 16 | July | 56 |
| February | 21 | August | 56 |
| Mean Winter | 18 | Mean Summer | 55 |
| March | 30 | September | 49 |
| April | 38 | October | 39 |
| May | 47 | November | 28 |
| Mean Spring | 38 | Mean Fall | 39 |

Mean annual temperature 38

The main feature of the local topography shown in Figure 5 is the nearly circular knoll formed by the intrusive stock. Relief about the knoll varies between 100 and 200 feet above the stream valleys. Drainage from the swamps and streams almost completely circumfluent the knoll. On the south slope of Huckleberry Mountain, and on the north slope of the knoll, close to the stream valley, several small swampy seepage basins occur which were avoided during sample collection. Most of the spring run-off from the south slope of Huckleberry Mountain drains around the west side of the knoll but some flows east into the complex bog and area of small ponds before draining around the south side of the knoll. There it joins the stream from the west and eventually flows south to Tahtsa Reach. These streams are only full during spring run-off and flow intermittently throughout the remainder of the year. The small ponds in the complex bog area east of the knoll have very slow drainage.

Contamination from trenches, roads or the old campsite was possible, and great care was taken near them during sample collection. The

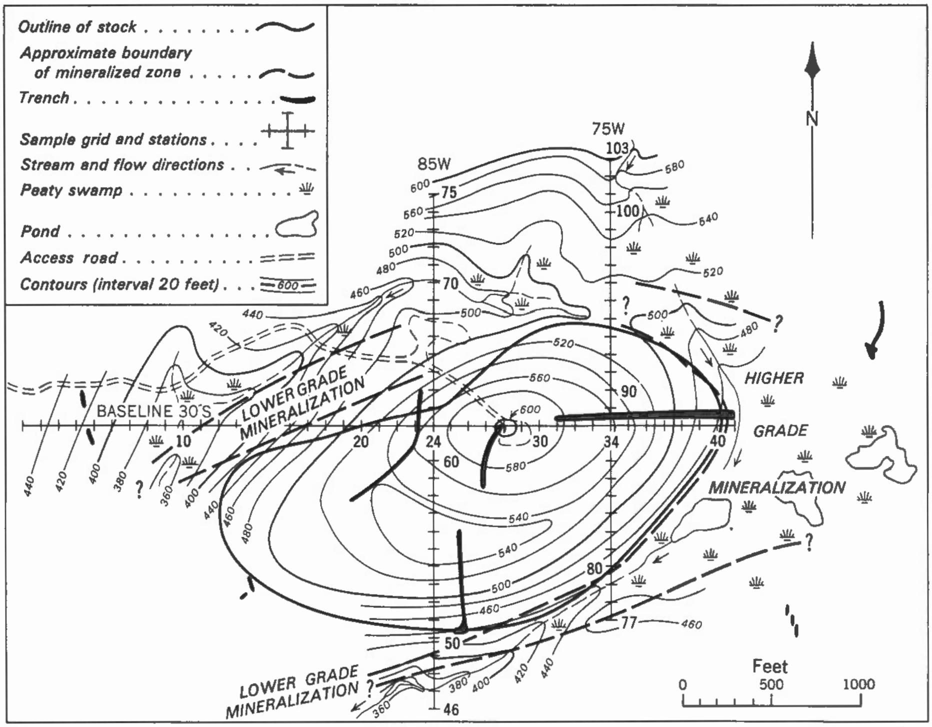

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Figure 5. Plan map of the property.

seepage basins and complex bog area were metal accumulating, and an attempt was made to avoid taking samples at sites where enrichment was an obvious possibility.

## DISCUSSION OF METHODS

### Methods of Establishing the Sample Grid over the Deposit

Two north-south lines and the main east-west baseline on the property were selected to comprise the sample grid over the mineral deposit (Fig. 5).

Methods of establishing biogeochemical traverse lines over this mineral deposit, utilizing a minimum number of traverses, involved compromises among the following factors:

1. Orientation and length of each traverse line were established so that the lines covered enough of the zone of mineralization to provide effective coverage of the anomalous areas, and extended sufficiently to provide coverage of background areas remote from mineralization.

2. As far as possible, each traverse line was chosen so that its forest cover was of uniform density, and the association of plant species allowed equal availability of the same sample tree species for sample collection at each station.
3. Information on the depth and lithology of the surficial material obtained from the shallow seismic survey (Appendix D), was used as a control; so that, as much as possible, traverse lines were established over surficial material of uniform thickness.
4. Consideration was given to avoiding open areas, swamps, boulder trains, peaty soil and seepages.
5. To avoid unnecessary duplication of the types of sample sites, and to reduce the number of sites in stream valleys, all traverses selected were oriented to bisect perpendicularly contour lines and stream valleys.
6. Establishment of suitable traverse lines was facilitated because several previously cut lines on the property were available.
7. A total of 96 stations were established at 100-foot intervals on 9,600 feet of traverse lines.

## Methods of Collection and Preparation of Sample Material

Alpine fir grew in sufficient abundance and uniform density that it was possible to sample it routinely at all 96 stations in the sample grid. Lodgepole pine was only sampled at certain stations on the main baseline for the purpose of selecting the sample species, and species organ, to collect in the biogeochemical survey. The following sample materials were collected at each station: B horizon (mineral soil), $A_h$ horizon (organic soil, humus), bark (collected at breast height, 4 feet 6 inches off the ground), second-year twigs and second-year needles. Previous experience had shown that it is only necessary to collect the above sample tree organs for chemical analyses to obtain effective data on the distribution of metal elements in sample trees (see Hornbrook, 1969b).

After collection, all samples were taken to Smithers, British Columbia, for processing in the sample preparation trailer laboratory. Collection and preparation techniques have been described in detail by Fortescue and Hornbrook (1967), and are briefly reviewed in Appendix A. During a three-week period, 288 samples of vegetation and 192 samples of soil were collected and prepared for analyses.

Measurements of height, age and breast height diameter were recorded for each alpine fir and lodgepole pine sampled. Results of the previous biogeochemical investigation, conducted earlier in the summer, at the Lucky Ship Property (Hornbrook, 1969b), showed that there was no relationship between the distribution or absolute concentration of an element and the above parameters. This observation was confirmed at the Huckleberry Mountain Property, and therefore details of these parameters are not tabled in this report. A relationship would only be developed if there was a large variation in the parameters of the sample trees. Alpine fir and lodgepole pine trees were commonly 40 feet high, 7 inches thick at breast height and about 45 years old.

## Colorimetric Method of Analyses

Plant ash, humus ash and mineral soil were analyzed colorimetrically for molybdenum, copper, nickel, zinc and lead after decomposition with HF, $HNO_3$ and $HClO_4$ in the laboratories of the Geological Survey of Canada, Ottawa. Standard methods for the colorimetric determinations were used for each element as described briefly in Appendix B.

## Scan Spectrographic Method of Analyses

The scan spectrographic method of analyses was used to provide semiquantitative results for the determination of barium, strontium, manganese, titanium, chromium, cobalt and silver in plant ash and humus ash material. These results, which are precise but not necessarily absolute, were examined mainly to determine if the distribution of the above elements could be significantly related to the copper-molybdenum distribution in the vicinity of the mineral deposit.

Previous work by Hornbrook (1969c), has shown that the spectrographic method, relative to the colorimetric method described previously, was precise enough to produce satisfactory results for biogeochemical investigations of this type. The method was described in detail in Fortescue and Hornbrook (1967) and a brief review is given in Appendix C.

## Presentation of Data

A great deal of confusion has arisen concerning the problem of whether to interpret organic material data on an ash or oven-dry basis (Hornbrook, 1969a). A comparison of the molybdenum profiles for ash and oven-dry needles in Figure 6 reveals that the profiles are almost identical. The ash percentage of most bark and foliage organs is between 2 and 5 per cent, but for any individual organ, the ash percentage can be remarkably uniform. Because the ash percentages are uniform, the plant material data can be examined with equal confidence on either an ash or oven-dry basis.

In the case of organic soil material data, the molybdenum profiles do not show complete agreement in Figure 7, because the composition of humus samples varies from station to station along a traverse line. Physical and chemical variations may create an extreme range in ash percentages among several humus samples. Variations from 5 per cent to 50 per cent are common unless great care is practiced during sample collection and preparation. Ash percentage variations in a plot of humus ash data are manifested in apparent contrasts in element concentration. A plot of this nature is not a valid representation of the actual element distribution. Therefore it is necessary to examine and report organic soil material data only on an oven-dry basis.

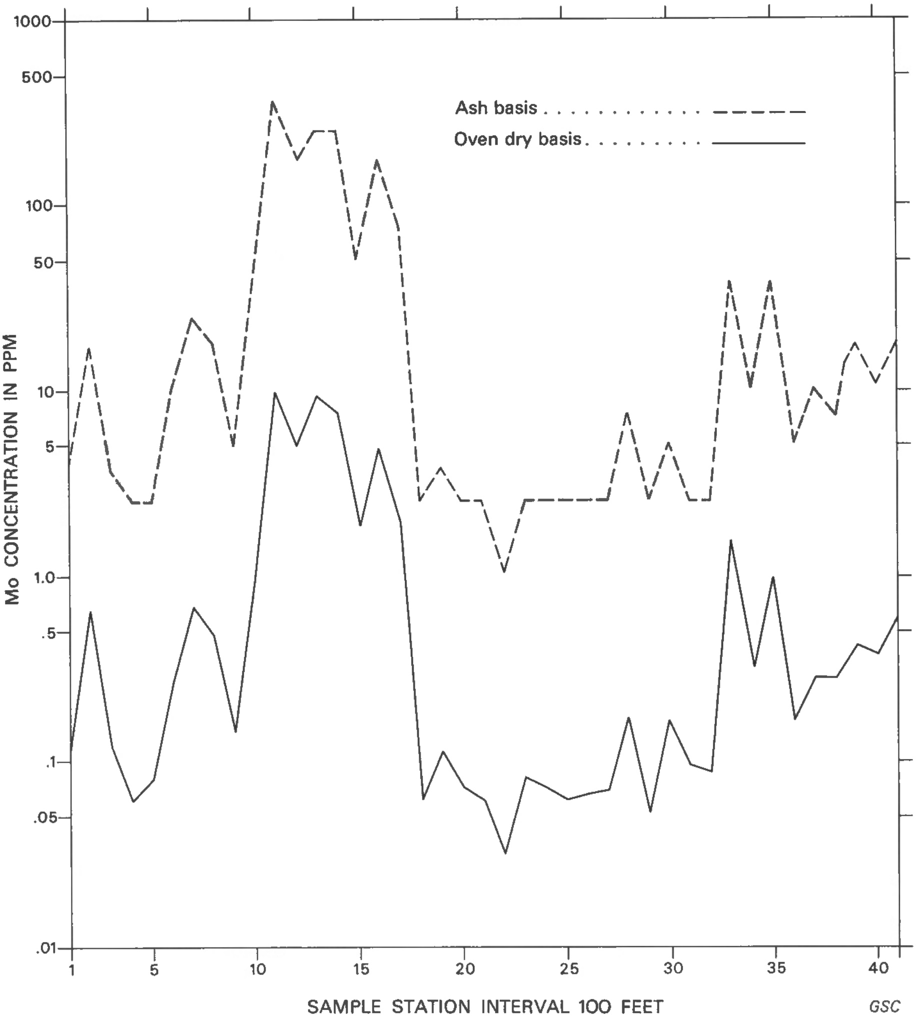

**Figure 6.** Comparison between molybdenum content in alpine fir, second year needle ash and oven-dry needles.

## DISCUSSION OF RESULTS

### Selection of Species and Organ of Species for Sampling

To determine the distribution of a given element in vegetation, it is necessary to collect the same plant organ, from the same species of plant, at every station, throughout the area investigated. Frequently more than one type of plant organ must be collected for analyses of two or more elements. Individuals among the various metal elements determined, are preferentially concentrated, not only in different species of plants, but in different organs, or ages of the same organ in one selected species of plant. Further, Warren

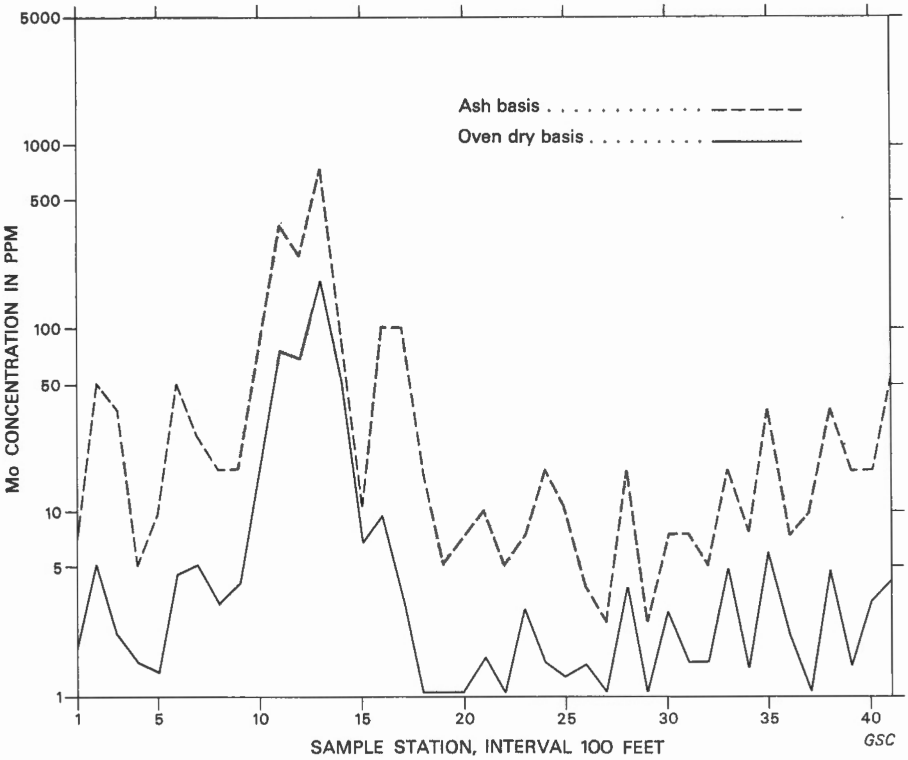

**Figure 7.** **Comparison between molybdenum content in humus ash and oven-dry humus.**

and Delavault (1955), established that systematic and uniform sampling was essential from all parts of a sample tree's foliage to obtain a truly representative twig, needle or leaf sample.

The following demonstrates the steps involved in the selection of the sample species that will provide the most meaningful results for each element determined. Preliminary sampling and analyses of bark, twig and needles of the dominant species, alpine fir and lodgepole pine, at stations on the baseline, was carried out. Profile plots were constructed from the analytical results to allow a comparison and evaluation of the behaviour of copper and molybdenum in each organ.

The profiles in Figures 8 and 9 show copper is preferentially concentrated in the second year twigs of both species to approximately the same degree. The profiles in Figures 10 and 11 show molybdenum is preferentially concentrated in the needles of both species, but there is considerably more molybdenum in alpine fir than in lodgepole pine. A more detailed comparison of the behaviour of molybdenum in the needles of both species is warranted. Background and local threshold levels are approximately the same, but near stations 12 and 33, in anomalous zones, the content of molybdenum in alpine fir has increased enormously relative to lodgepole pine. Brooks (1968), has described the cause of this phenomenon in a similar case with molybdenum in a different species, and it applies here as follows: This is a

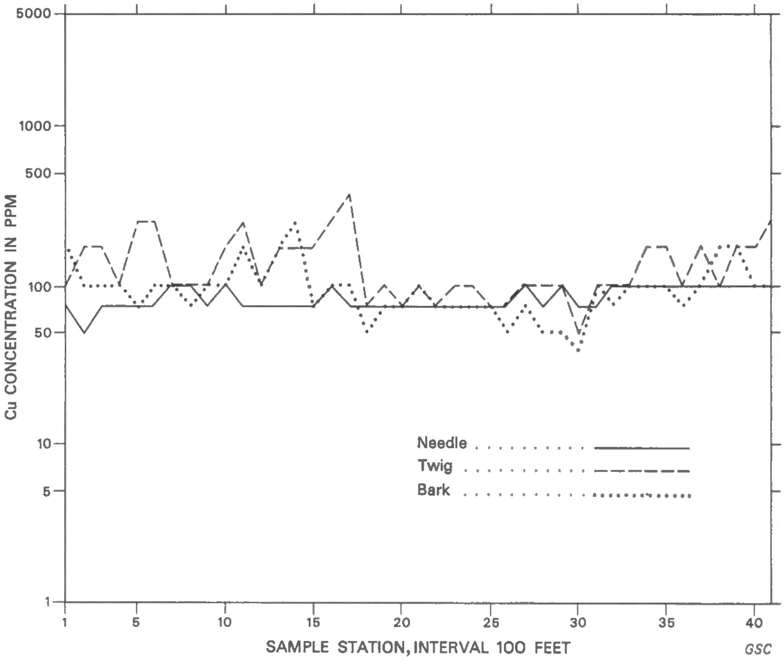

Figure 8. Comparison among copper content in the ash of alpine fir bark, second year twigs and needles.

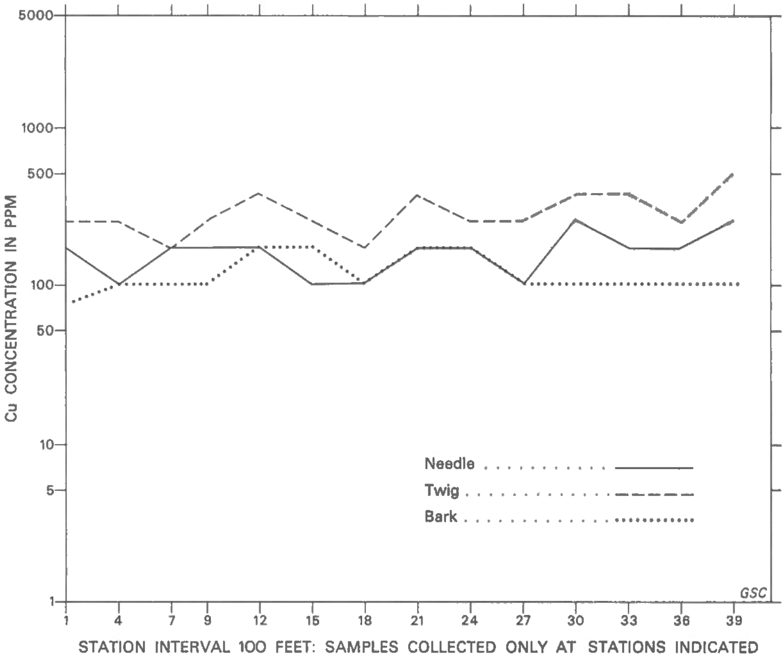

Figure 9. Comparison among copper content in the ash of lodgepole pine bark, second year twigs and needles.

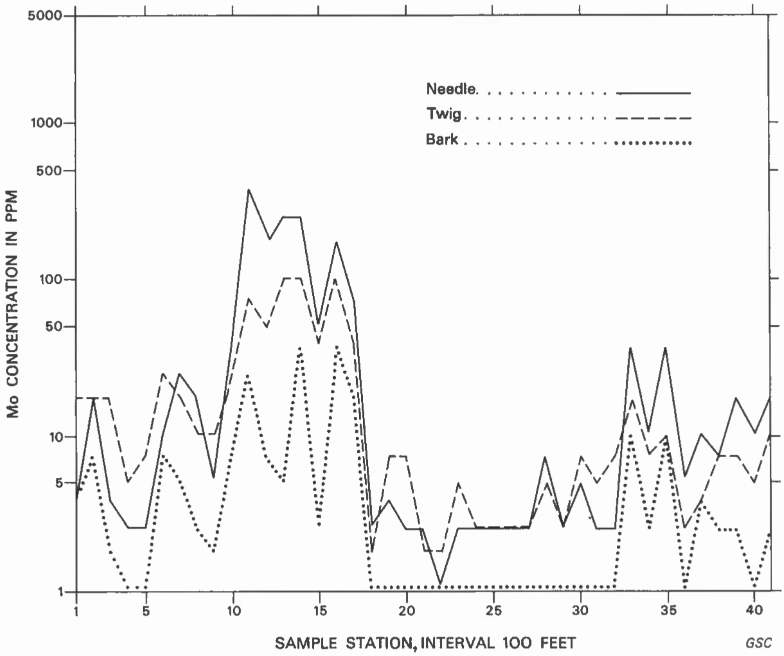

Figure 10. Comparison among molybdenum content in the ash of alpine fir bark, second year twigs and needles.

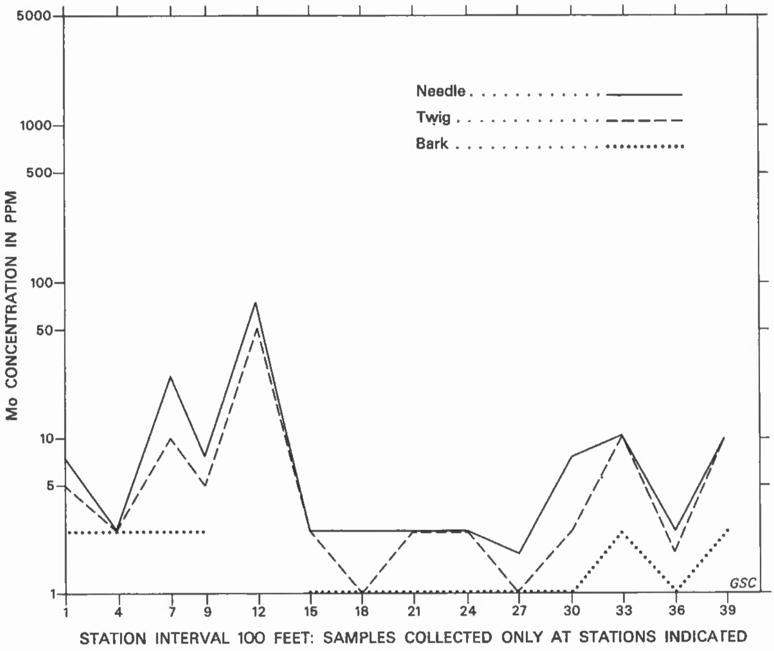

Figure 11. Comparison among molybdenum content in the ash of lodgepole pine bark, second year twigs and needles.

case of a plant showing a partial exclusion mechanism, where the uptake of molybdenum by the plant, shows a regular, though restricted increase, with an increasing content of molybdenum in the soil. At a certain threshold concentration, the partial exclusion mechanism breaks down, and the plant reflects even more strikingly the increasing molybdenum content in the soil. The breakdown has evidently occurred in alpine fir and not in lodgepole pine. Therefore, alpine fir is admirably suitable for biogeochemical plant prospecting because its molybdenum response is accentuated over anomalous zones. Hornbrook (1969b), found that the molybdenum anomaly obtained by its use not only offered more contrast than that of lodgepole pine, but frequently more than the equivalent anomaly obtained by soil analyses.

Although the prospect was considered to be a copper-molybdenum deposit, the molybdenum profile results in alpine fir second year needles more effectively defined its mineralized zones than did copper profile results in either alpine fir or lodgepole pine second year twigs. Frequency distribution curves in Figure 12 demonstrate why the copper profile in twigs (Fig. 8) has much less contrast than the molybdenum profile (Fig. 9). Copper results in twig ash have only a single population while molybdenum results in needle ash have three contrasting populations. Further, the range of copper concentrations in twig ash (50 ppm to 500 ppm, 1:10), is considerably less than molybdenum in needle ash (1 ppm to 375 ppm, 1:375). Evidently there was no breakdown of the exclusion mechanism operating for copper in the twigs of either species. The nature of the molybdenum response in needle ash simplifies the determination of regional background, local threshold and anomalous molybdenum population levels. This simplification facilitates plotting, examination and interpretation of complex analytical plant results. As Warren (1962), pointed out, frequency distribution curves provide the opportunity to carry out the essential determination, of what the normal element pattern in the area is, before establishing what concentration levels may be considered anomalous. The normal distribution pattern of molybdenum in needles is: regional background values - 2.5 ppm, local threshold values in the vicinity of the deposit - 10 ppm, and anomalous values - in excess of 50 ppm. The excellent discrimination among the contrasting molybdenum populations in alpine fir second year needles was also found in a previous biogeochemical study of a similar deposit (Hornbrook, 1969b). It is more difficult but the single copper population curve for twigs (Fig. 12) will yield statistically copper concentration levels that can be used for plotting anomaly maps.

Therefore, throughout the area investigated, alpine fir second year twigs and needles should be sampled and analyzed for copper and molybdenum respectively.

## Copper and Molybdenum in B Horizon Soil and Humus

Geochemical soil sampling of the $A_h$ horizon (organic soil, humus) and the B horizon (mineral soil) was carried out at each station in conjunction with the plant sampling program. The soil program was conducted to obtain results from an established geochemical prospecting method. These results were required in order to permit a comparative evaluation between biogeochemical plant prospecting methods and geochemical soil sampling methods in detecting buried metallic mineral deposits.

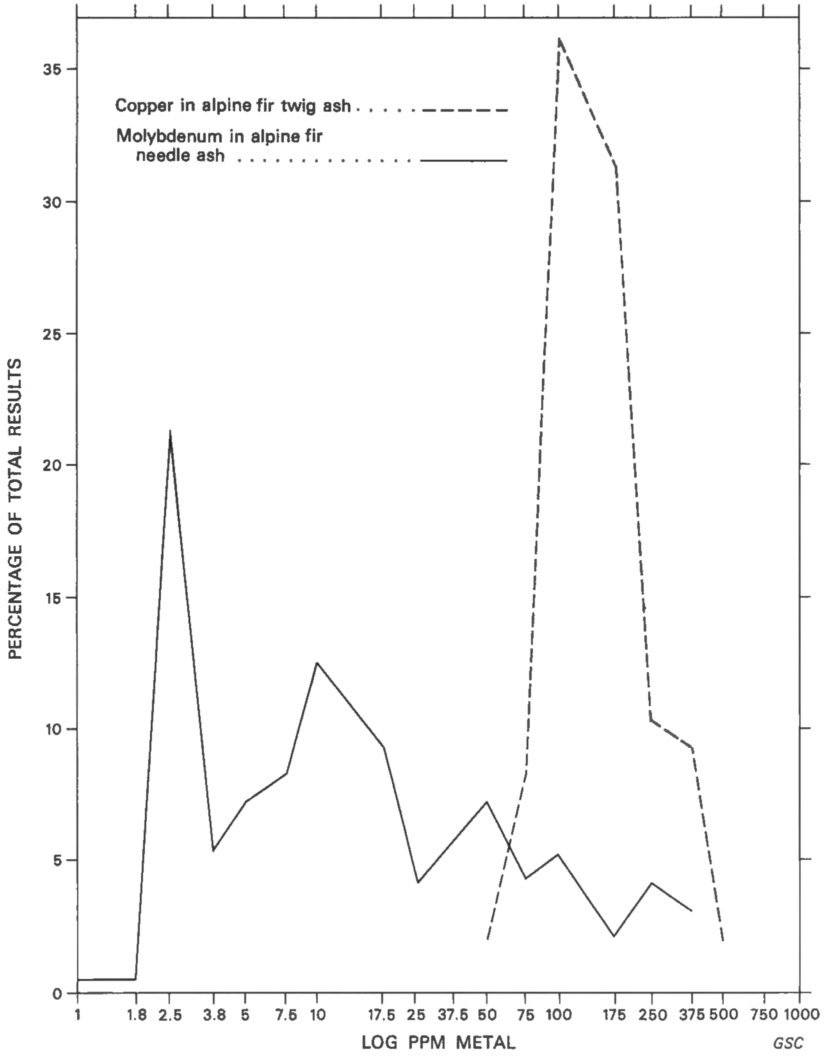

**Figure 12.** Frequency distribution of copper and molybdenum respectively in alpine fir twig and needle ash; calculated from the colorimetric analyses of 96 samples of each material.

Figure 13 shows the copper and molybdenum profiles in oven-dry humus and Figure 14 shows their profiles in B horizon soil. Copper and molybdenum profiles show similar distribution in both materials although there is more copper present in every sample. Both element profiles have very good contrast and they accurately define the location of mineralized zones on the baseline. In profile plots of second year alpine fir twig and needle ash (Figs. 8, 10), only the molybdenum in needles is as effective in defining the mineralized zones as the copper and molybdenum in organic and mineral soils (Figs. 13, 14).

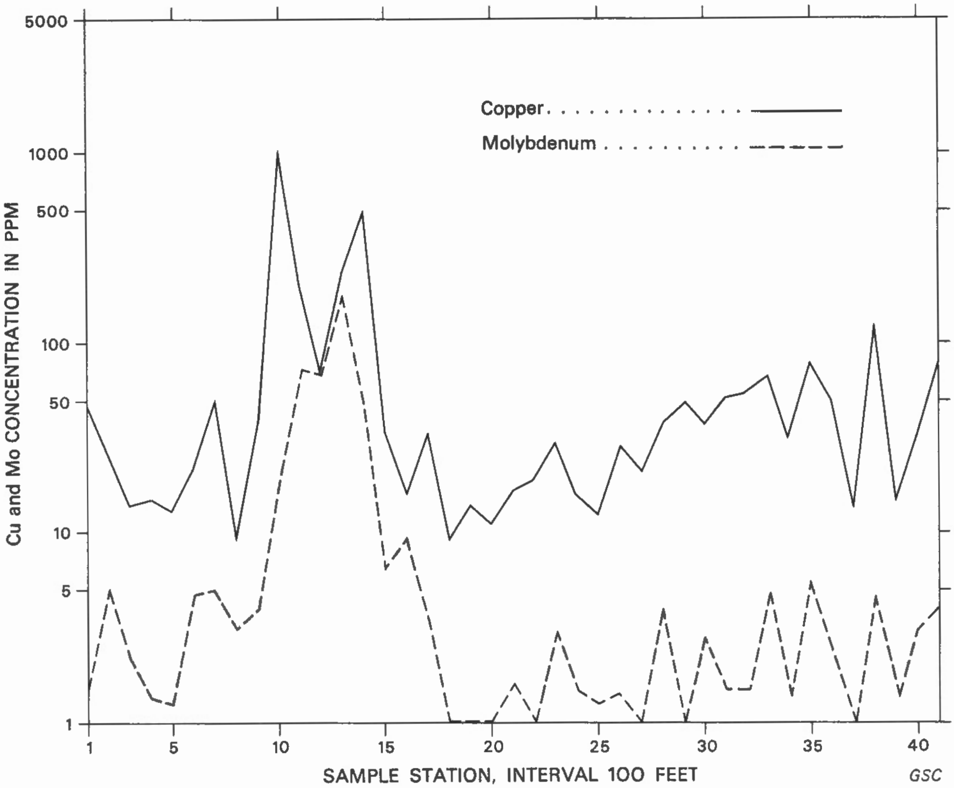

**Figure 13. Comparison between copper and molybdenum content in oven-dry humus.**

## Anomaly Maps

Six anomaly maps (Figs. 15 to 20) have been constructed to determine and compare the distribution of copper and molybdenum in each material sampled. The anomaly maps are: Figure 15 - copper in B horizon soil; Figure 16 - molybdenum in B horizon soil; Figure 17 - copper in oven-dry humus; Figure 18 - molybdenum in oven-dry humus; Figure 19 - copper in oven-dry second-year alpine fir twigs; Figure 20 - molybdenum in oven-dry second-year alpine fir needles. The anomaly maps permit a comparison of the effectiveness in defining mineralized zones of biogeochemical plant prospecting results and standard soil geochemical results. Isograds were arbitrarily restricted to two concentration levels on each element's map in order to avoid unnecessary detail and complications in the comparison. Two concentration levels were chosen for each element that best exhibited their distribution in the area in each sample material. Small highly anomalous areas about one or two stations in stream valleys were not included on the maps because they may be produced by metal-accumulating processes in peaty soils associated with the drainage system. All anomaly maps, and the plan of the property in Figure 5 have the sampling grid, and an outline of the stock in common, to facilitate reference among them.

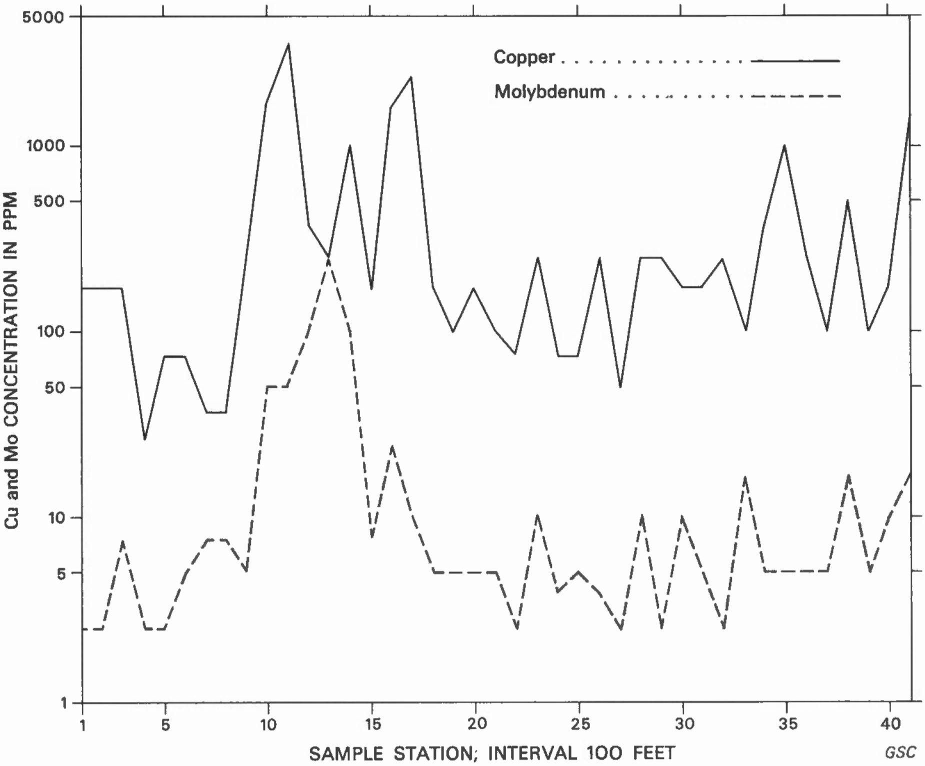

**Figure 14.** **Comparison between copper and molybdenum content in B horizon soil.**

The following observations are warranted after a study and comparison among the six anomaly maps.

1. The distribution of copper and molybdenum compared together in, or separately among, B horizon soil, oven-dry humus and oven-dry plant material, are remarkably similar.
2. Each anomaly map clearly defines the location of the copper-molybdenum mineralized zones peripheral to the stock as shown in Figure 5.
3. The distribution of copper and molybdenum in twigs and needles respectively produces a pattern equivalent to that produced for those elements in B horizon soil and oven-dry humus.
4. The boundaries of the anomalous zones of interest outline the peripheral mineralization about the stock and exclude most of the chalcopyrite mineralization within the stock.
5. The obvious relationship of copper in twigs to the mineralized zone shown in the anomaly map (Fig. 19), is not evident when part of the same copper results are plotted in profile as shown in Figure 8.
6. The possibility must be considered that the anomalous zones, which coincide with the circumfluent drainage pattern about the knoll (Fig. 5), may be partly or entirely produced by the soils associated with the streams and the swamps.

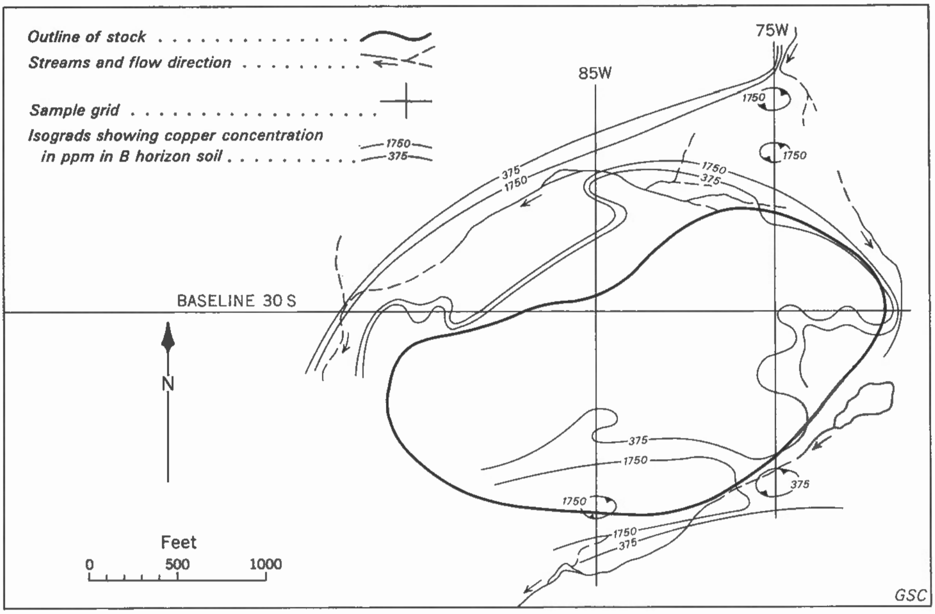

Figure 15. Geochemical anomaly map showing distribution of copper in B horizon soil.

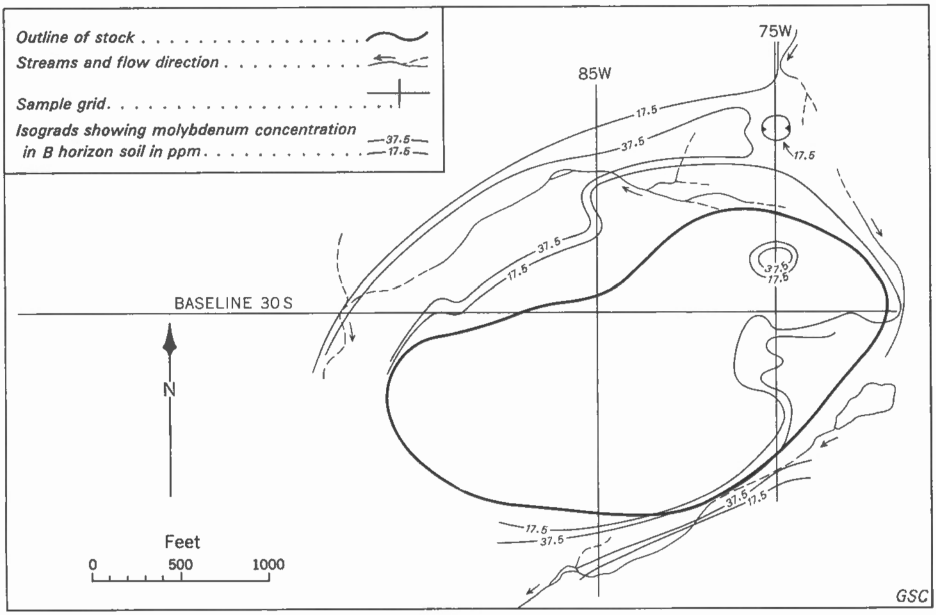

Figure 16. Geochemical anomaly map showing distribution of molybdenum in B horizon soil.

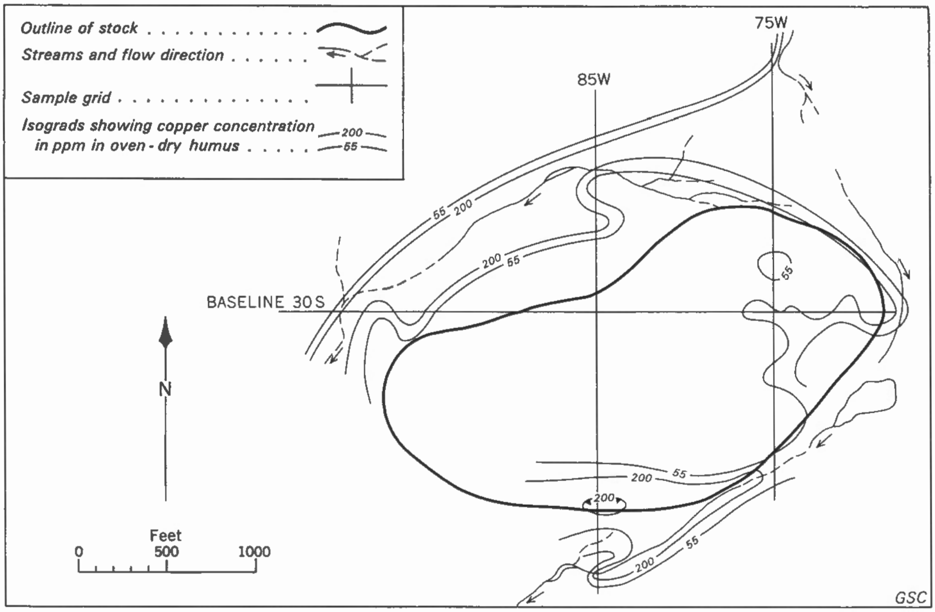

Figure 17. Geochemical anomaly map showing distribution of copper in oven-dry humus.

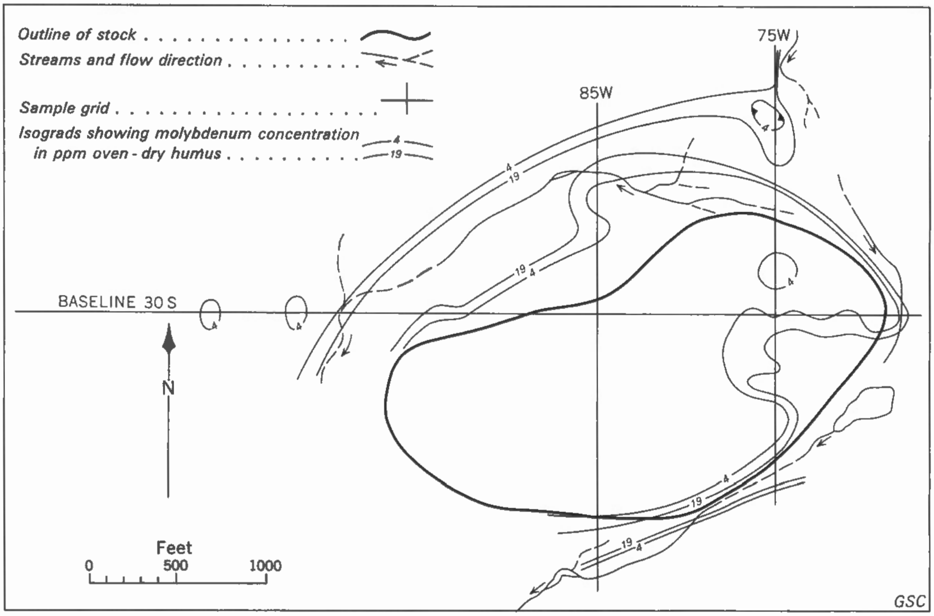

Figure 18. Geochemical anomaly map showing distribution of molybdenum in oven-dry humus.

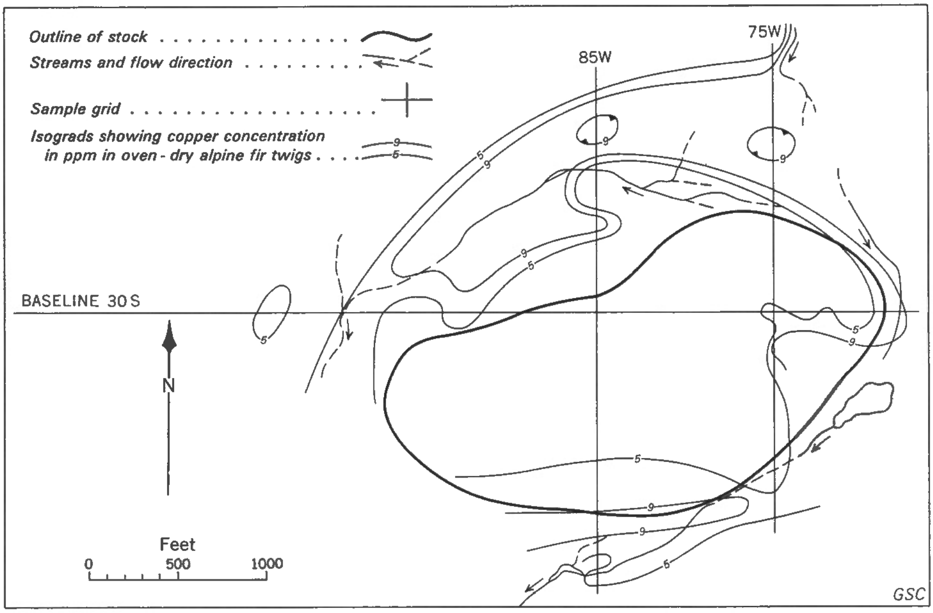

Figure 19. Biogeochemical anomaly map showing distribution of copper in oven-dry alpine fir second year twigs.

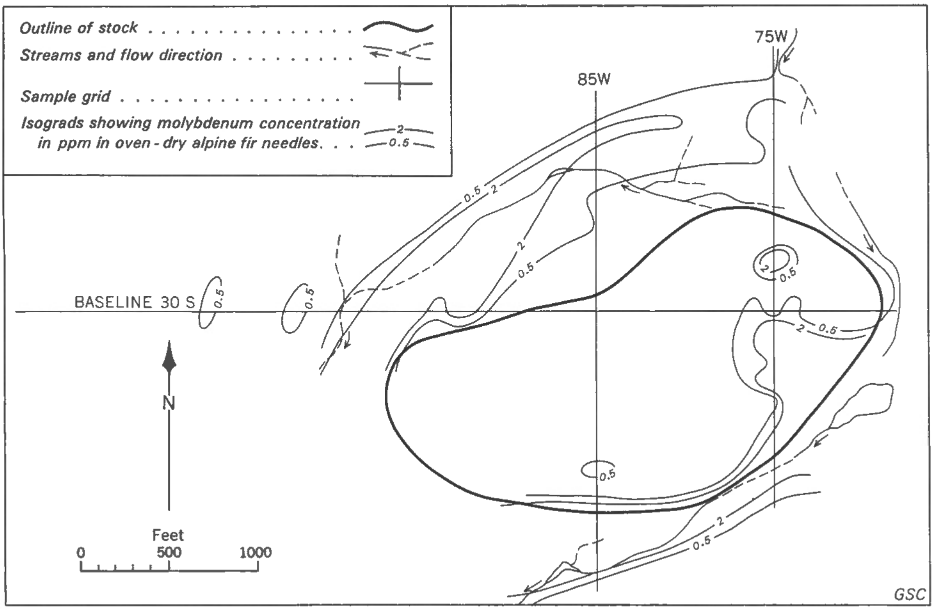

Figure 20. Biogeochemical anomaly map showing distribution of molybdenum in oven-dry alpine fir second year needles.

## General Observations of the Analytical Results

A study of the semiquantitative spectrographic results and the colorimetric results for lead, nickel and zinc was carried out to determine if there was any significant pattern in their distribution. No persistent relationship was found between their distribution and that of molybdenum or copper in the vicinity of mineralized zones. However at certain places on the sample grid, lead and zinc occasionally exhibited a partial relationship to the distribution of copper and molybdenum. It would appear that none of the above elements studied has a future potential as a geochemical pathfinder element in exploration for the Huckleberry Mountain type of deposit.

Lead and nickel are preferentially concentrated in the twigs, manganese in needles, barium and strontium in bark and zinc is uniformly distributed throughout the organs of alpine fir and lodgepole pine.

## SUMMARY AND CONCLUSIONS

Research on biogeochemical plant prospecting techniques at the Huckleberry Mountain copper molybdenum deposit shows the following:

1. All copper and molybdenum anomaly maps clearly define the location of known copper and molybdenum mineralized zones located peripheral to the stock.
2. Biogeochemical twig and needle results are as equally effective as geochemical soil results in detecting the peripheral mineralized zones of the deposit.
3. Metal accumulating conditions in peaty soils, associated with the drainage system, possibly contribute to the intensity of the copper and molybdenum anomalies, but these conditions are not the cause of the anomalies. On each anomaly map, anomalous zones of interest extend beyond the possible influence of either the complex bog or the stream system. Further, suspected strongly anomalous zones coincident with the streams or bog, were purposely excluded from each anomaly map. Thus the anomalous zones remaining provide a valid expression of copper and molybdenum distribution over the deposit.
4. A comparison of the content and contrast of copper and molybdenum in bark, twig and needle organs of the two sample tree species indicated that second year alpine fir twigs and needles should be sampled and analyzed for copper and molybdenum respectively.
5. At a single sample station, the different concentrations found for molybdenum in each of bark, twig or needle samples of both species illustrates the necessity for maintaining consistency in collecting the same organ from the same species of tree at every sample station.
6. The specific behaviour of elements in plant organs is demonstrated by the frequency distribution curves for copper and molybdenum in twigs and needles respectively. The essential study of these curves permits identification of contrasting populations, and a choice of plotting methods, that will produce the most meaningful results for interpretation.

7. The method used to plot plant results is as important as which element is analytically determined because the obvious relationship of copper in twigs to the mineralized zones in anomaly maps is not evident when the same results are plotted in profile.
8. The behaviour of molybdenum in alpine fir second year needles demonstrates the phenomenon of the breakdown of a partial exclusion mechanism, and how this can be advantageously used to obtain an accentuated distribution contrast over mineralized zones.
9. Copper and molybdenum were the only elements whose distribution showed a persistent relationship to the mineralized zones of the deposit.
10. The determination of molybdenum in alpine fir needles has considerable potential as a biogeochemical pathfinder element for copper-molybdenum deposits.

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## APPENDIX A

### Plant and Soil Collection and Preparation Techniques

At each station, a humus sample was collected from the $A_h$ horizon as close to the previously selected sample tree as possible. Next, the sample tree was cut down, and the foliage sampled using steel secateurs. Bark samples were stripped off 1-inch-thick wood discs, that were sawed off the main stem of the tree at breast height. The discs were used for growth ring count to determine the age of the sample tree. The soil pit was dug with a mattock where the humus was sampled, and a representative sample of the B horizon was collected using hand tools. All samples were put in paper bags that have a high wet strength to resist sample moisture content. The above order of sample collection was found by experience to reduce possible contamination between soil and plant materials.

In the sample preparation laboratory, foliage, bark, humus and B horizon soils were air dried in heated cabinets at 50 degrees centigrade for as long as three days in the case of wet humus. All material was then subsampled as follows: foliage separated into needle and twig organs; bark reduced to small fragments less than 1/4 inch thick; B horizon sieved to -80 mesh for colorimetric analyses; and humus sieved to obtain the -10 to +80 mesh fraction. The subsampled bark, twig, needle and humus samples were then oven dried at 80 degrees centigrade for 10 hours.

A 10-gram oven-dry amount of each sample of plant organ or humus material was dry ashed in a muffle furnace on a time-temperature controlled cycle. The cycle permits the temperature to slowly increase to 435 degrees centigrade until all the organic material is thoroughly charred. The temperature is maintained automatically at 435 degrees centigrade for the remainder of the 10-hour cycle. Each ash sample was completely mixed and stored in sealed plastic vials for subsequent analyses.

# APPENDIX B

## Operational Procedure for Colorimetric Analyses of Soils and Organic Material Ash

These analyses were carried out in the Chemical Laboratory of the Geochemical Section of the Geological Survey of Canada under the direction of J. J. Lynch.

Procedure: (summary only)

(1) One hundred milligrams of minus 80 mesh soil material or organic material ash is placed in a platinum dish and treated with 5 millilitres of concentrated HF, 5 millilitres concentrated $HNO_3$ and 2 millilitres of 70 per cent of $HClO_4$ and allowed to digest overnight.

(2) The mixture is evaporated to fumes of $HClO_4$ and then the sides of the dish washed with metal-free water. Fuming and washing are repeated four more times before evaporating to dryness.

(3) Residue dissolved in 5 millilitres of I N HCl and diluted to 10 millilitres with metal-free water.

(4) Aliquots of this solution are removed as required for zinc, lead, copper, and nickel tests. These elements were determined by methods due to Gilbert (1959) in the case of lead and zinc, Almond (1955) in the case of copper, and Stanton and Coope (1958) in the case of nickel. The method for zinc was slightly modified by the addition of sodium fluoride to the acetate buffer to suppress any interference due to aluminum, Stanton (1962).

(5) The performance of these methods in the normal working range (20-1,000 ppm) is within 25 per cent of the total amount of metal present.

(6) Molybdenum was determined by a method described in North (1956). This method involves a fusion with modified $Na_2CO_3$ flux, leaching with water and a final determination of molybdenum with zinc dithiol rather than dithiol as described by North. The performance of this method is similar to that of the other four.

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## APPENDIX C

### Semiquantitative Scan Spectrographic Method of Analyses

A 10 milligram sample of ash, held in suspension in a 5 per cent sugar solution, was placed on top of a sugar impregnated 1/2-inch graphite platrode. Using heat lamps, the sample was dried to a thin layer, like icing on a graphite cake. The sample sugar solution contains indium as an internal reference standard for control of analytical precision. During analyses, the sample platrode was rotated at 10 rpm, and excited by means of a high voltage a. c. spark source. The spectrogram was recorded on 35 millimetre film during a 20-second exposure in a Jarrell-Ash 1. 5 metre Wadsworth grading spectrograph. By matching the sample film in a densitometer-comparator, a visual estimation was made of the concentration of the elements detected. Results are recorded on special data recording sheets which are forwarded to the computer centre for processing. For each material analyzed concentrations on an oven-dry basis and in ash were provided with certain statistical information computed for each element.

# APPENDIX D

## HAMMER REFRACTION SEISMIC SURVEY TO ASSIST BIOGEOCHEMICAL PROGRAM, HUCKLEBERRY MOUNTAIN, BRITISH COLUMBIA

George D. Hobson

A hammer seismograph survey was conducted along selected lines over the Huckleberry Mountain Property of the Kennco Explorations (Western) Limited in north-central British Columbia. The property is located about 60 miles south of the town of Houston immediately north of the Tahtsa Reach, Figure D-1. The survey was conducted between August 12-31, 1967.

A Huntec model FS-2 portable seismograph was used to record all seismic data. A 16-pound sledge hammer struck against a steel plate on the ground provided the seismic energy. Explosives were not used as an energy source.

Ninety-six reversed refraction seismic profiles were obtained over three lines. The interval between each individual reversed profile was 100 feet.

Topography varies approximately 230 feet over the project area. Station 28 was assigned the arbitrary value of +3600 feet and all other elevations are relative to it. The lowest elevation relative to station 28 is +3369 feet at station 9. The central part of the project area is a mound with the topography dipping away from it in all directions. Elevations were obtained by means of a Wild level. The area had been burned over about 50 years ago; the lines were cut by Kennco through predominantly fir forest.

The mound structure in the centre of the project area is a quartz diorite stock surrounded by Middle Jurassic sediments and volcanics of the Hazelton Group. The sediments include greywacke, tuff, andesite and argillite. The area has been glaciated several times leaving till overlying bedrock at some locations. The entire area is covered with a loose sandy outwash type of material.

A histogram of observed seismic velocity versus frequency of occurrence is depicted in Figure D-2. These velocities are as observed and are uncorrected for dip.

The velocity of seismic waves through bedrock appears to be in excess of 8700 feet per second. Over several portions of the profiles, it is possible by seismic methods to distinguish between the dry surface materials, the underlying outwash material, and the till overlying bedrock. All materials above bedrock are essentially dry except in the low-lying swampy areas at the edge of the central mound.

The thickness of overburden over the project area is shown in Figure D-1. The overburden varies in thickness from about 6 feet beneath station 49 to about 68 feet at station 18. Cross-sections are not presented in this report because the thinness of overburden combined with considerable topographic relief does not permit the construction of publishable sections. All basic and computed seismic data are presented in Table D-1 so that Table D-1 and Figure D-1 should permit any further interpretation to be attempted.

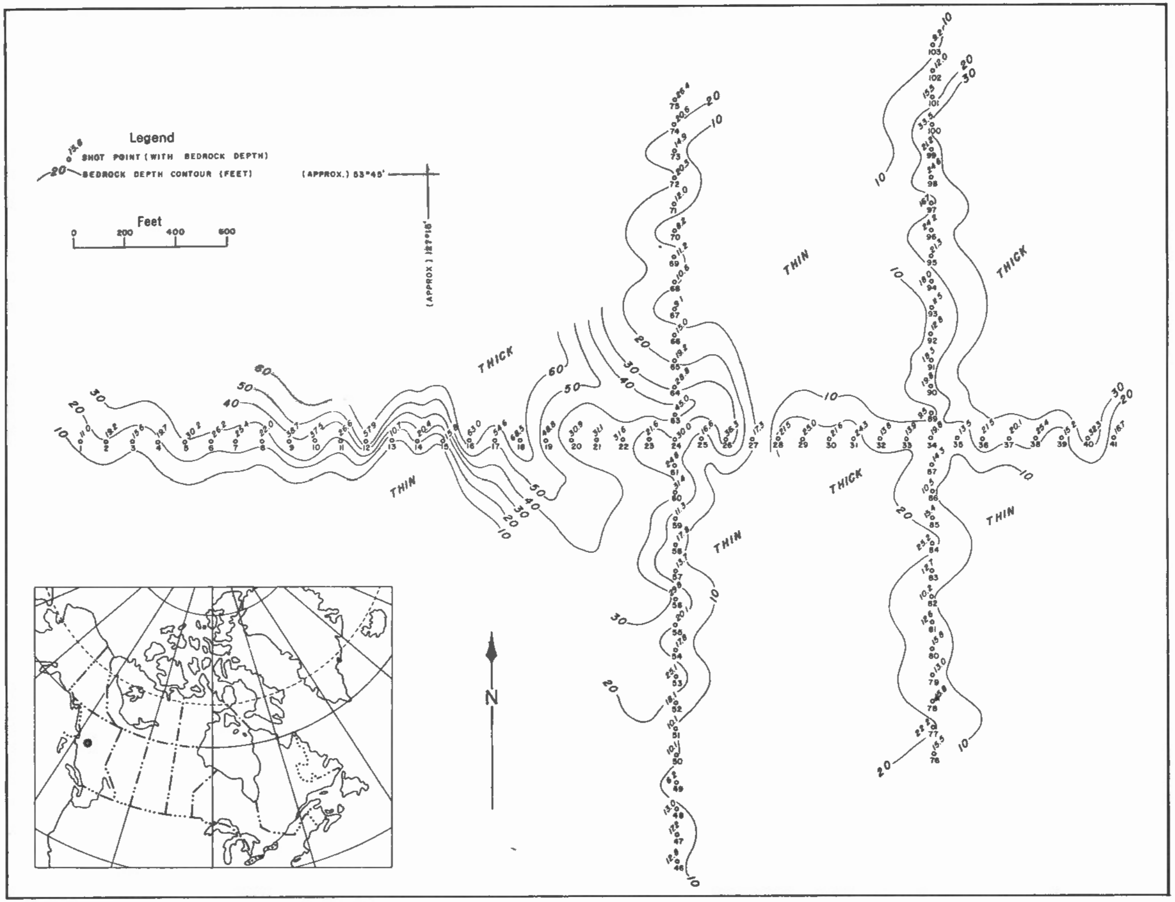

Figure D-1. Seismic locations and thickness of overburden, Huckleberry Mountain, British Columbia.

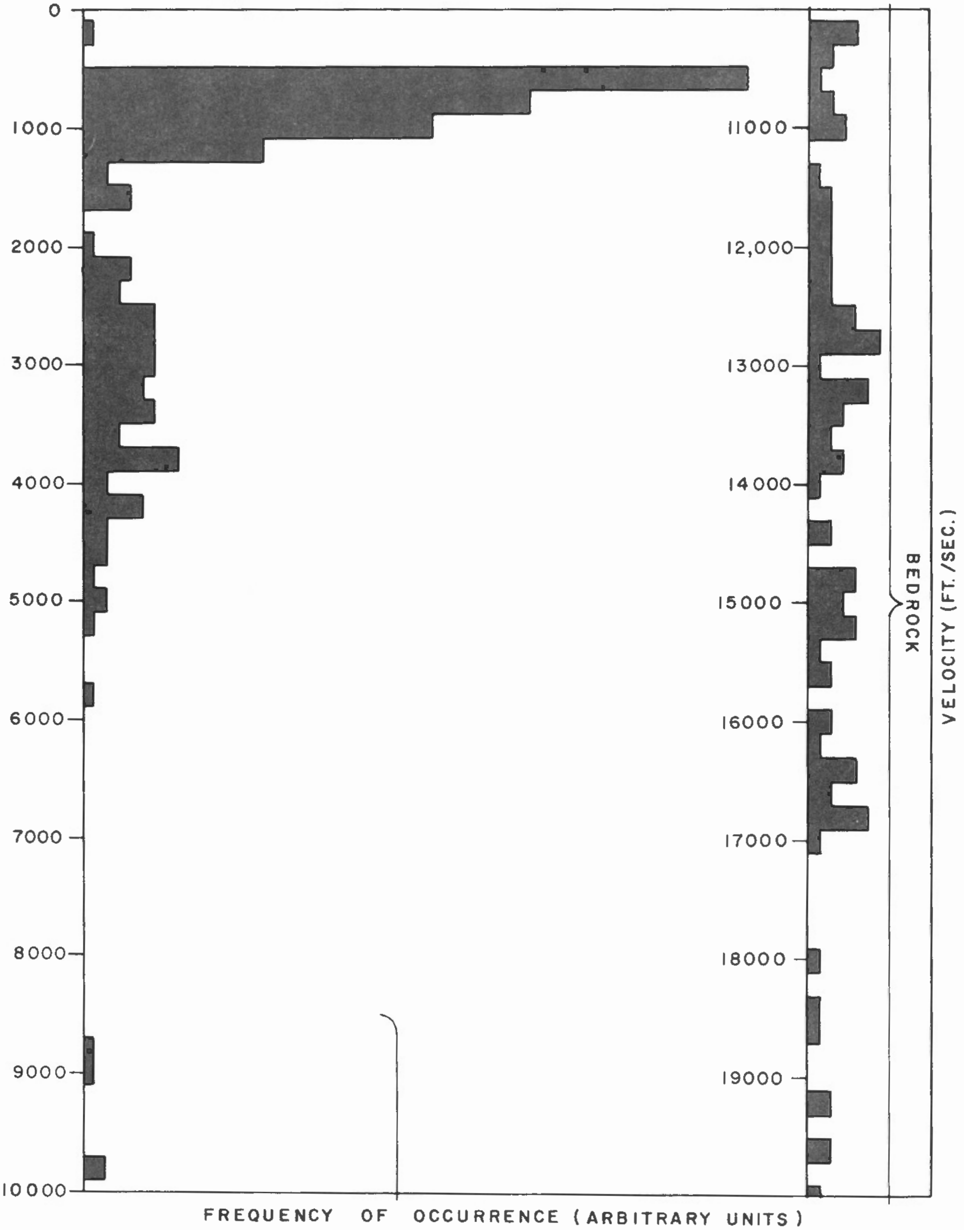

Figure D-2. Histogram of observed velocity versus frequency of occurrence, Huckleberry Mountain, British Columbia.

The bedrock surface is identified by a seismic velocity in excess of 8,700 feet per second. The velocities of seismic energy in the bedrock formations have been plotted on a plan map of the area but it is impossible to contour these velocities to define the contact between the quartz diorite stock and the surrounding Middle Jurassic sediments and volcanics.

Overburden materials can be differentiated on the basis of seismic velocities and there is a good contrast between velocities in the overburden and the bedrock thus permitting reasonable calculations of drift thickness. However, bedrock lithology in this area cannot be defined on the basis of seismic velocity.

## TABLE D-1

| Reversed Pair | $V_0$ | $V_1$ | $V_2$ | $V_3$ | $\phi_1$ | $\phi_2$ | $\phi_3$ | $Z_0$ | $Z_1$ | $Z_2$ | $\sum Z$ | Station Elevation | Bedrock Elevation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1E-2W | 695 | 1,020 | 10,300 | | 1.0° E | 1.6° W | | .6 | 10.4 | | 11.0 | 3454.4 | 3443.4 |
| 2E-3W | 830 | 3,150 | 9,010 | | .8° E | 3.0° W | | 6.2 | 13.0 | | 19.2 | 3444.2 | 3425.0 |
| 3E-4W | 770 | 2,140 | 8,790 | | 3.1° W | 11.7° E | | 3.6 | 12.0 | | 15.6 | 3432.5 | 3416.9 |
| 4E-5W | 760 | 2,800 | 12,570 | | 2.6° W | 5.5° E | | 5.5 | 14.3 | | 19.7 | 3426.5 | 3406.5 |
| 5E-6W | 720 | 5,710 | 19,190 | | .2° W | 3.9° E | | 6.6 | 23.6 | | 30.2 | 3404.0 | 3373.8 |
| 6E-7W | 830 | 3,750 | 15,170 | | .6° E | 7.2° W | | 6.9 | 19.4 | | 26.2 | 3399.6 | 3373.4 |
| 7E-8W | 825 | 3,170 | 10,730 | | .8° W | 4.2° E | | 5.6 | 19.7 | | 25.4 | 3389.6 | 3364.2 |
| 8E-9W | 780 | 2,910 | 10,200 | | 8.2° W | 39.1° E | | 4.2 | 17.8 | | 22.0 | 3373.4 | 3351.4 |
| 9E-11W | 640 | 3,470 | 14,890 | | .6° E | 4.4° W | | 4.2 | 34.5 | | 38.7 | 3368.8 | 3330.1 |
| 10E-12W | 570 | 3,230 | 10,460 | | 1.7° W | 6.3° E | | 3.3 | 34.2 | | 37.5 | 3368.8 | 3331.3 |
| 11E-13W | 785 | 3,560 | 11,480 | | .7° E | 8.9° W | | 5.4 | 21.2 | | 26.6 | 3374.8 | 3348.2 |
| 12E-14W | 550 | 4,300 | 20,530 | | .1° W | 2.3° W | | 6.7 | 51.3 | | 57.9 | 3381.8 | 3323.9 |
| 13E-15W | 770 | 2,200 | 11,560 | | 6.1° E | 16.4° W | | 4.2 | 6.4 | | 10.6 | 3391.8 | 3381.1 |
| 14E-16W | 680 | 1,130 | 2,710 | 14,880 | 0° | 3.4° E | 5.2° W | .9 | 6.2 | 13.2 | 20.4 | 3400.3 | 3379.9 |

| Reversed Pair | $V_0$ | $V_1$ | $V_2$ | $V_3$ | $\phi_1$ | $\phi_2$ | $\phi_3$ | $Z_0$ | $Z_1$ | $Z_2$ | $\sum Z$ | Station Elevation | Bedrock Elevation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15E-17W | 755 | 4,570 | 10,320 |  | 1.1° W | 7.4° E |  | 4.6 | 11.2 |  | 15.8 | 3420.0 | 3404.2 |
| 16E-18W | 785 | 5,230 | 20,320 |  | 1.4° E | 12.3° W |  | 6.1 | 56.9 |  | 63.0 | 3439.6 | 3376.6 |
| 17E-19W | 745 | 2,410 | 4,710 | 10,630 | 2.1° W | 9.2° E | 5.7° W | 3.5 | 8.3 | 42.7 | 54.6 | 3460.8 | 3406.2 |
| 19E-20W | 745 | 3,390 | 16,810 |  | 1.6° E | 7.6° W |  | 3.4 | 45.4 |  | 48.8 | 3494.0 | 3445.2 |
| 20E-21W | 1,020 | 2,990 | 13,730 |  | 4.7° W | 19.6° E |  | 6.7 | 24.2 |  | 30.9 | 3510.9 | 3480.0 |
| 21E-22W | 650 | 1,220 | 4,280 | 14,860 | 1.6° E | .9° E | 17.4° W | 1.7 | 3.0 | 26.4 | 31.1 | 3525.9 | 3494.8 |
| 22E-23W | 575 | 3,940 | 15,210 |  | .7° W | 5.5° E |  | 3.2 | 28.4 |  | 31.6 | 3541.3 | 3509.7 |
| 23E-24W | 715 | 3,400 | 13,190 |  | 1.1° W | 11.5° E |  | 4.0 | 17.6 |  | 21.6 | 3555.9 | 3534.3 |
| 24E-25W | 600 | 5,080 | 19,970 |  | .0° | .9° E |  | 4.7 | 33.1 |  | 37.8 | 3568.2 | 3530.4 |
| 25E-26W | 525 | 2,880 | 15,410 |  | .1° E | 3.2° E |  | 2.5 | 14.2 |  | 16.6 | 3580.1 | 3563.5 |
| 26E-27W | 605 | 5,040 | 11,960 |  | .1° W | 4.8° W |  | 3.0 | 33.3 |  | 36.3 | 3589.0 | 3552.7 |
| 27E-28W | 695 | 2,380 | 13,870 |  | .4° W | 2.2° W |  | 2.7 | 14.6 |  | 17.3 | 3598.0 | 3580.7 |
| 28E-29W | 940 | 4,590 | 9,560 |  | 1.0° W | 7.1° E |  | 1.1 | 20.4 |  | 21.5 | 3600.0 | 3578.6 |
| 29E-30W | 690 | 3,660 | 17,920 |  | 1.8° E | 11.8° W |  | 3.3 | 21.7 |  | 25.0 | 3596.2 | 3571.2 |

| Reversed Pair | $V_0$ | $V_1$ | $V_2$ | $V_3$ | $\phi_1$ | $\phi_2$ | $\phi_3$ | $Z_0$ | $Z_1$ | $Z_2$ | $\sum Z$ | Station Elevation | Bedrock Elevation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30E-31W | 750 | 2,990 | 16,150 | | 2.9° W | 11.9° E | | 4.8 | 16.8 | | 21.6 | 3585.7 | 3564.1 |
| 31E-32W | 630 | 4,310 | 20,200 | | 1.2° E | 7.6° W | | 5.1 | 19.2 | | 24.3 | 3579.5 | 3555.2 |
| 32E-33W | 570 | 1,230 | 3,860 | 11,040 | .7° W | 5.3° E | 14.4° W | 1.4 | 6.2 | 6.1 | 13.8 | 3581.5 | 3567.7 |
| 33E-34W | 670 | 3,480 | 13,920 | | .2° W | .4° W | | 5.5 | 8.4 | | 13.9 | 3569.5 | 3555.6 |
| 34E-35W | 810 | 4,190 | 12,810 | | .6° W | 4.1° E | | 3.9 | 15.8 | | 19.8 | 3556.9 | 3537.1 |
| 35E-36W | 665 | 3,300 | 13,890 | | 1.7° E | 4.5° W | | 5.0 | 8.5 | | 13.5 | 3544.3 | 3530.8 |
| 36E-37W | 775 | 3,770 | 16,850 | | .9° W | 1.0° E | | 5.6 | 15.9 | | 21.5 | 3534.0 | 3512.5 |
| 37E-38W | 680 | 1,620 | 15,010 | | 7.9° W | 16.7° E | | 1.9 | 18.3 | | 20.1 | 3511.9 | 3491.8 |
| 38E-39W | 720 | 3,060 | 12,580 | | 3.1° W | 15.5° E | | 3.7 | 21.7 | | 25.4 | 3489.7 | 3464.3 |
| 39E-40W | 645 | 1,390 | 11,030 | | 1.8° W | 5.1° E | | 1.8 | 13.4 | | 15.2 | 3474.5 | 3459.3 |
| 40E-41W | 715 | 4,290 | 15,930 | | 2.8° W | 20.2° E | | 4.4 | 27.9 | | 32.3 | 3458.7 | 3426.4 |
| 46N-47S | 640 | 1,000 | 12,790 | | 4.1° S | 4.7° N | | 1.0 | 11.8 | | 12.8 | 3379.8 | 3367.0 |
| 47N-48S | 570 | 1,910 | 16,850 | | 1.8° N | 7.7° S | | 1.7 | 15.5 | | 17.2 | 3366.4 | 3349.2 |
| 48N-49S | 660 | 1,400 | 12,710 | | 6.9° S | 14.8° N | | 1.9 | 11.1 | | 13.0 | 3385.2 | 3372.2 |
| 49N-50S | 740 | 13,480 | | | .5° S | | | 6.2 | | | 6.2 | 3405.1 | 3398.9 |

| Reversed Pair | $V_0$ | $V_1$ | $V_2$ | $V_3$ | $\phi_1$ | $\phi_2$ | $\phi_3$ | $Z_0$ | $Z_1$ | $Z_2$ | $\sum Z$ | Station Elevation | Bedrock Elevation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50N-51S | 690 | 1,610 | 16,620 | | 4.9°N | 12.1°S | | 3.9 | 6.2 | | 10.1 | 3431.3 | 3421.2 |
| 51N-52S | 730 | 2,570 | 12,420 | | 4.1°S | 18.6°N | | 3.1 | 7.0 | | 10.1 | 3458.5 | 3448.4 |
| 52N-53S | 750 | 2,820 | 16,450 | | 2.9°S | 12.3°N | | 3.1 | 14.9 | | 18.1 | 3492.9 | 3474.8 |
| 53N-54S | 835 | 3,410 | 19,560 | | 3.0°S | 12.4°N | | 2.4 | 22.7 | | 25.1 | 3527.8 | 3502.7 |
| 54N-55S | 760 | 4,050 | 12,240 | | .3°S | 1.1°N | | 5.4 | 12.4 | | 17.8 | 3539.9 | 3522.1 |
| 55N-56S | 650 | 1,140 | 3,650 | 14,990 | .7°N | 2.1°N | 7.6°S | 1.6 | 3.4 | 15.1 | 20.1 | 3550.3 | 3530.2 |
| 56N-57S | 680 | 1,160 | 4,230 | 21,920 | 4.5°S | 8.6°N | 4.3°S | 1.5 | 7.0 | 21.3 | 29.8 | 3544.1 | 3514.3 |
| 57N-58S | 615 | 4,500 | 13,370 | | 1.0°N | 4.4°S | | 5.1 | 8.5 | | 13.7 | 3544.1 | 3530.4 |
| 58N-59S | 535 | 1,130 | 2,380 | 16,780 | 2.4°S | 8.1°N | 7.2°S | 1.1 | 6.3 | 10.4 | 17.8 | 3546.1 | 3528.3 |
| 59N-60S | 640 | 1,680 | 13,220 | | 5.3°S | 13.4°S | | 4.2 | 7.2 | | 11.3 | 3550.5 | 3539.2 |
| 60N-61S | 690 | 3,900 | 16,560 | | .5°N | 3.3°S | | 5.1 | 26.3 | | 31.4 | 3563.0 | 3531.6 |
| 61N-24S | 715 | 1,070 | 3,760 | 15,280 | .5°S | .1°N | 4.9°N | 1.3 | 4.7 | 18.9 | 24.8 | 3572.8 | 3548.0 |
| 24N-63S | 790 | 3,370 | 16,410 | | .3°N | .8°S | | 5.9 | 24.1 | | 30.0 | 3568.2 | 3538.2 |
| 63N-64S | 900 | 3,730 | 16,770 | | 1.9°S | 8.7°N | | 5.6 | 39.4 | | 45.0 | 3550.1 | 3505.1 |
| 64N-65S | 575 | 1,080 | 3,760 | 15,660 | 1.0°S | 3.0°N | 3.9°S | 1.4 | 8.6 | 18.8 | 28.8 | 3530.7 | 3501.9 |

| Reversed Pair | $V_0$ | $V_1$ | $V_2$ | $V_3$ | $\phi_1$ | $\phi_2$ | $\phi_3$ | $Z_0$ | $Z_1$ | $Z_2$ | $\sum Z$ | Station Elevation | Bedrock Elevation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65N-66S | 670 | 1,090 | 19,640 | | 5.6° N | 9.3° S | | 2.1 | 12.1 | | 14.2 | 3511.8 | 3497.6 |
| 66N-67S | 605 | 1,180 | 12,580 | | .6° N | 2.5° S | | 1.7 | 13.3 | | 15.0 | 3497.0 | 3482.0 |
| 67N-68S | 620 | 1,220 | 12,880 | | 1.4° N | 1.2° S | | 1.8 | 7.3 | | 9.1 | 3487.1 | 3478.0 |
| 68N-69S | 635 | 1,120 | 9,650 | | 5.0° N | 9.3° S | | 2.1 | 8.4 | | 10.6 | 3481.0 | 3470.4 |
| 69N-70S | 545 | 1,100 | 15,640 | | 1.2° N | 2.4° S | | 1.4 | 9.8 | | 11.2 | 3470.1 | 3458.9 |
| 70N-71S | 725 | 14,410 | | | .5° N | | | 8.2 | | | 8.2 | 3462.9 | 3454.7 |
| 71N-72S | 610 | 1,100 | 11,580 | | 2.2° S | 3.2° N | | 1.3 | 10.7 | | 12.0 | 3476.0 | 3464.0 |
| 72N-73S | 760 | 2,230 | 14,420 | | 2.6° S | 11.2° N | | 4.0 | 16.3 | | 20.3 | 3482.6 | 3462.3 |
| 73N-74S | 575 | 2,800 | 12,140 | | | 1.5° N | | 6.3 | 8.6 | | 14.9 | 3525.4 | 3510.5 |
| 74N-75S | 710 | 2,570 | 18,600 | | .5° N | 2.3° S | | 7.2 | 13.4 | | 20.6 | 3542.6 | 3522.0 |
| 76N-77S | 750 | 1,660 | 12,660 | | 7.3° S | 17.2° N | | 2.6 | 13.0 | | 15.5 | 3443.6 | 3428.1 |
| 77N-78S | 740 | 2,560 | 13,180 | | 3.5° S | 8.3° N | | 3.5 | 18.7 | | 22.2 | 3458.1 | 3435.9 |
| 78N-79S | 775 | 2,690 | 14,930 | | 2.4° S | 10.0° N | | 4.4 | 11.5 | | 15.8 | 3455.1 | 3439.3 |
| 79N-80S | 780 | 2,180 | 12,430 | | 2.8° S | 8.9° N | | 4.0 | 9.0 | | 13.0 | 3442.0 | 3429.0 |
| 80N-81S | 590 | 1,270 | 16,470 | | .6° N | 1.6° S | | 2.7 | 13.2 | | 15.8 | 3448.1 | 3432.6 |

| Reversed Pair | $V_0$ | $V_1$ | $V_2$ | $V_3$ | $\phi_1$ | $\phi_2$ | $\phi_3$ | $Z_0$ | $Z_1$ | $Z_2$ | $\sum Z$ | Station Elevation | Bedrock Elevation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 81N-82S | 630 | 970 | 18,410 | | 5.2°N | 8.3°S | | 1.6 | 11.0 | | 12.6 | 3463.7 | 3451.1 |
| 82N-83S | 640 | 1,100 | 11,980 | | 1.7°S | 3.9°N | | 1.2 | 9.1 | | 10.2 | 3484.7 | 3474.5 |
| 83N-84S | 670 | 980 | 13,560 | | 7.4°N | 12.2°S | | 1.8 | 10.9 | | 12.7 | 3500.4 | 3487.7 |
| 84N-85S | 805 | 3,820 | 13,110 | | .6°N | 4.6°S | | 5.5 | 19.7 | | 25.2 | 3515.9 | 3490.7 |
| 85N-86S | 620 | 3,110 | 16,920 | | 5.5°N | 30.7°S | | 5.8 | 9.6 | | 15.4 | 3530.2 | 3514.8 |
| 86N-87S | 560 | 1,020 | 13,270 | | 2.8°S | 3.6°N | | 1.2 | 9.4 | | 10.5 | 3550.0 | 3539.5 |
| 87N-88S | 640 | 2,680 | 13,680 | | .4°N | 2.2°S | | 3.8 | 10.5 | | 14.3 | 3558.8 | 3544.5 |
| 88N-89S | 650 | 3,080 | 12,820 | | 2.0°S | 9.6°N | | 3.2 | 16.6 | | 19.7 | 3556.9 | 3537.2 |
| 89N-90S | 670 | 930 | 16,370 | | 1.9°N | 2.0°S | | 1.2 | 8.3 | | 9.5 | 3558.7 | 3549.2 |
| 90N-91S | 670 | 2,520 | 19,280 | | 1.1°N | 4.0°S | | 5.8 | 14.0 | | 19.8 | 3545.8 | 3526.0 |
| 91N-92S | 615 | 1,050 | 2,850 | 10,600 | 6.5°N | 14.2°S | 7.3°N | 1.9 | 6.6 | 9.8 | 18.3 | 3524.9 | 3505.7 |
| 92N-93S | 660 | 1,300 | 10,190 | | 1.3°S | 2.6°N | | 2.3 | 10.4 | | 12.8 | 3517.8 | 3505.0 |
| 93N-94S | 610 | 1,000 | 13,430 | | 3.6°S | 3.9°N | | .8 | 10.8 | | 11.5 | 3511.5 | 3500.0 |
| 94N-95S | 610 | 1,090 | 15,190 | | 1.6°N | 4.0°S | | 2.2 | 15.8 | | 18.0 | 3501.2 | 3483.2 |
| 95N-96S | 610 | 1,110 | 11,040 | | 1.7°N | 2.2°S | | 1.8 | 19.5 | | 21.3 | 3505.3 | 3484.0 |

| Reversed Pair | $V_0$ | $V_1$ | $V_2$ | $V_3$ | $\phi_1$ | $\phi_2$ | $\phi_3$ | $Z_0$ | $Z_1$ | $Z_2$ | $\sum Z$ | Station Elevation | Bedrock Elevation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 96N-97S | 715 | 1,110 | 14,820 | | .8° S | 1.7° N | | 1.4 | 22.8 | | 24.2 | 3515.0 | 3490.8 |
| 97N-98S | 260 | 960 | 12,810 | | .8° N | 2.8° S | | 2.5 | 14.3 | | 16.7 | 3526.4 | 3509.7 |
| 98N-99S | 690 | 1,120 | 15,910 | | 1.7° N | 4.2° S | | 1.8 | 22.8 | | 24.6 | 3536.6 | 3512.0 |
| 99N-100S | 650 | 1,160 | 11,740 | | 1.3° N | 2.5° S | | 2.0 | 19.2 | | 21.2 | 3546.5 | 3525.3 |
| 100N-101S | 670 | 2,960 | 10,140 | | 1.4° S | 7.1° N | | 4.5 | 29.0 | | 33.5 | 3554.9 | 3521.4 |
| 101N-102S | 655 | 1,020 | 11,850 | | 1.2° S | 2.4° N | | .9 | 14.5 | | 15.5 | 3569.8 | 3554.3 |
| 102N-103S | 815 | 13,080 | | | .5° S | | | 12.0 | | | 12.0 | 3583.7 | 3571.7 |
| 41W-40E | 715 | 4,290 | 15,930 | | 2.8° W | 20.2° E | | 6.0 | 10.7 | | 16.7 | 3449.9 | 3433.2 |
| 75S-74N | 710 | 2,570 | 18,600 | | .5° N | 2.3° S | | 3.1 | 23.2 | | 26.4 | 3582.6 | 3556.2 |
| 103S-102N | 815 | 13,080 | | | .5° S | | | 9.2 | | | 9.2 | 3605.2 | 3596.0 |
| 18W-16E | 785 | 5,230 | 20,320 | | 1.4° E | 12.3° W | | 5.2 | 63.3 | | 68.5 | 3479.9 | 3411.4 |