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BIOGEOCHEMICAL PROSPECTING FOR MOLYBDENUM IN WEST-CENTRAL BRITISH COLUMBIA

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(with a contribution by G.D. Hobson)

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ABSTRACT

A biogeochemical prospecting program was conducted during the summer of 1967 at a molybdenum deposit to determine the distribution of 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 trailer laboratories (separately developed during earlier work) were simultaneously used under field operating conditions. A sample grid of 144 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, at 60 stations. Shallow seismic determinations of the depth and nature of surficial material were carried out simultaneously with the 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.

An examination of the results of the plant prospecting program show that plant analysis provides a substantially increased magnitude of anomalous to background molybdenum concentrations, an increased ground surface areal extent of the molybdenum anomaly, and a more definite demarcation of its boundaries as compared to soil analysis.

BIOGEOCHEMICAL PROSPECTING FOR MOLYBDENUM IN WEST-CENTRAL BRITISH COLUMBIA

INTRODUCTION

A biogeochemical investigation involving collection, preparation, and analysis of plant and soil material was carried out in west-central British Columbia, during the summer of 1967 at the Lucky Ship molybdenum deposit of Amax Exploration, Inc. The investigation was conducted to determine the distribution of molybdenum and associated elements in plant organs and soils to evaluate the effectiveness of plant prospecting techniques for detecting this and similar deposits.

The property is southeast of Morice Lake which is about 55 air miles south of the town of Smithers, British Columbia (see Fig. 1) and is on the east flank of the Morice-Nanika ridge at lat. 54°01'N. and long. 127°30'W. Access to the property is provided by a 6-mile company road which joins the Morice-Nanika section of the Morice Lake Forestry Development road at Mile 49 from Houston, British Columbia.

The landscape containing this deposit was chosen for biogeochemical investigation primarily because the nature of the mineralization and bedrock geology caused an anomalous molybdenum concentration to develop in the soil in a concentric fashion about a granite plug. A preliminary examination of the landscape in 1966 showed that the soils and vegetation were suitable for a biogeochemical investigation (Fortescue and Hornbrook, 1968, Section E). The circular pattern was first established by over 300 molybdenum results from a soil survey conducted by Amax in 1964. The B horizon soils were collected by Amax along several traverse lines in a sample grid where most of the stations were at 100-foot intervals. Since 1964 Amax has carried out extensive geochemical and geophysical exploration of the deposit. Diamond drilling showed that mineralization occurs in several forms but is generally confined to a circular zone about the granite plug. Some experimental work in biogeochemistry carried out in 1964 by company staff in conjunction with the Department of Geology, University of British Columbia indicated that lodgepole pine and alpine fir contained sufficient molybdenum for detection in a plant prospecting program. In 1967 the writer's party established a sampling grid over the deposit in such a way as to cover the ore zone using stations that were previously used by Amax for their soil survey. Soil and vegetation samples were collected from 144 stations in the sample grid. Samples were prepared and analyzed spectrographically in two mobile trailer laboratories that were stationed at Smithers, British Columbia, for the summer operation. Colorimetric analyses were completed in the Geological Survey of Canada, at Ottawa.

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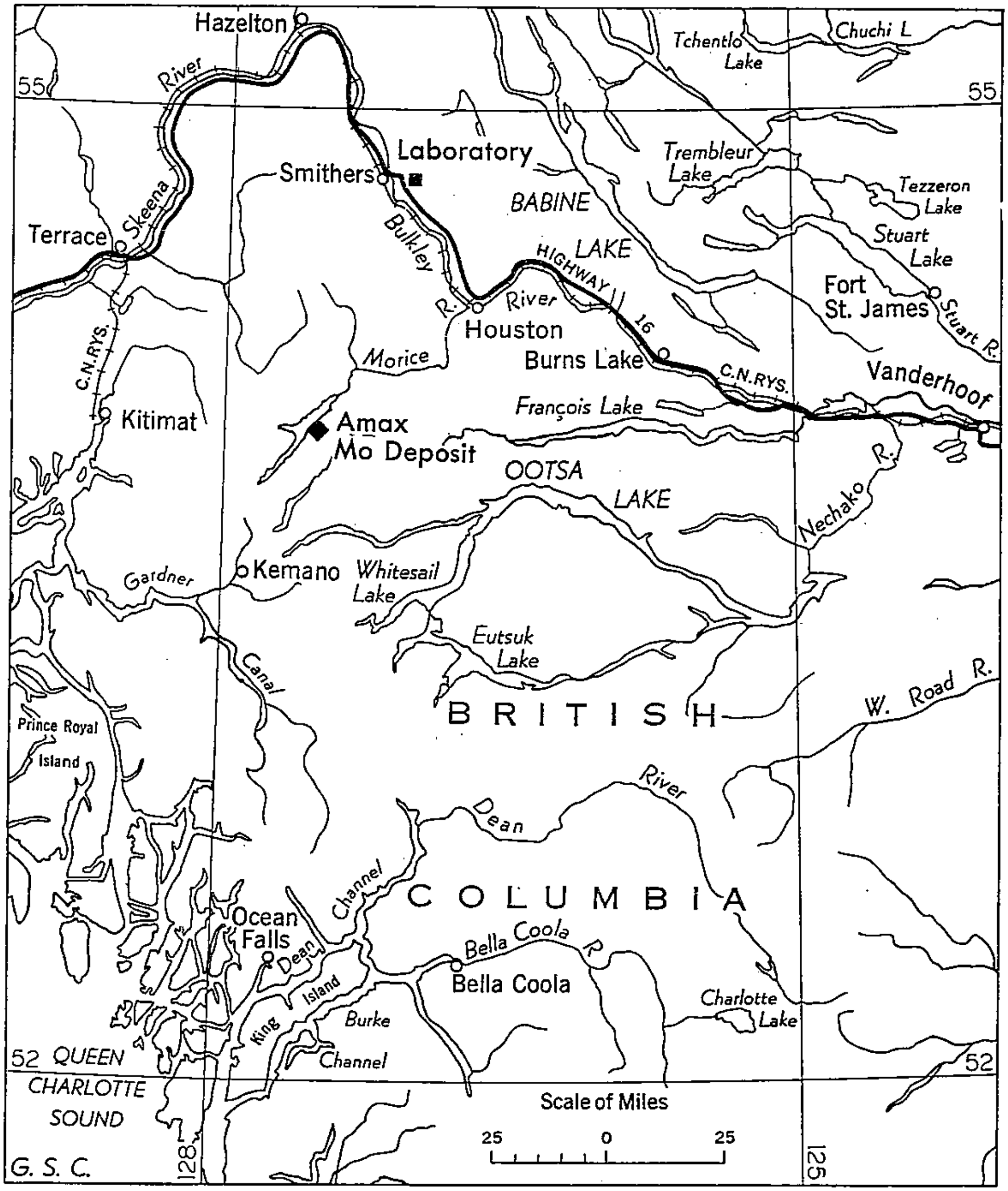

Figure 1. Index map of west-central British Columbia showing the Amax molybdenum deposit and the Trailer Laboratory site near Smithers.

Shallow seismic determinations of the depth and nature of the surficial material were carried by a two-man crew under the direction of G. D. Hobson of the Geological Survey of Canada. A report describing the results of their work 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 officials of Amax Exploration, Inc. who gave permission to carry out biogeochemical investigations at their Lucky Ship molybdenum deposit. Information concerning this property in the report has been reviewed by staff of the company. Thanks are also due to J.J. Lynch under whose direction colorimetric analyses were done in Ottawa.

General Description of the Landscape

Geology of the region has been described by Armstrong (1944) and Duffell (1959) and a generalized geological map of west-central British Columbia is shown in Figure 2. The property is situated in a transitional zone between the Coast Mountains and the Interior Nechako Plateau. In this zone the rocks are mainly volcanic and sedimentary and are cut by local plugs of granitoid rocks. The ridge containing the deposit is formed mainly of volcanic and sedimentary rocks of the Hazelton Group comprising interbedded breccia, tuff, dacite, rhyolite, basalt, argillite, greywacke, chert, conglomerate and minor limestone which are intruded in places by stocks of granitoid rocks. These rocks are part of the main belt of Hazelton rocks which trend northwest along the eastern contact of the main body of the Coast Range Intrusions. Local geology around the property is shown in Figure 3. The largest geological feature is an elongate quartz feldspar porphyry pluton plunging almost vertically in the Hazelton Group host rocks. At the southeast contact of the pluton is a 400-foot by 600-foot granite plug surrounded by a 20-foot to 100-foot wide zone of highly silicified rock. The silicification grades outward into massive quartz feldspar porphyry of the main pluton on the southwest, west, north and east and into the host volcanic and sedimentary rocks on the south and southeast. The molybdenite occurs spatially around the periphery of the granite plug. The molybdenum mineralization varies considerably in nature and amount and generally occurs as follows: molybdenite in complex quartz veins in stockworks; wide-banded quartz-molybdenite vein systems and as thin coatings of molybdenite on dry fractures.

Alpine glaciation is still active in the higher mountains of the region and features such as drumlins and crag-and-tail effect on ridges due to glaciation are widespread. The surficial material overlying the ridges is glacial till but in valley bottoms thick fluvioglacial deposits occur.

Podzolic soils overlying the deposit 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 parent sand and gravel, low lime till under an alpine fir and lodgepole pine type of vegetation. A typical soil profile is shown in Figure 4. The horizon shows much variation in colour and thickness. The usual colour was yellow-orange over a darker brown which was occasionally reddish; rarely was a greyish colour observed. In the B horizon, thicknesses less than 12 inches or more than 20 inches were not common.

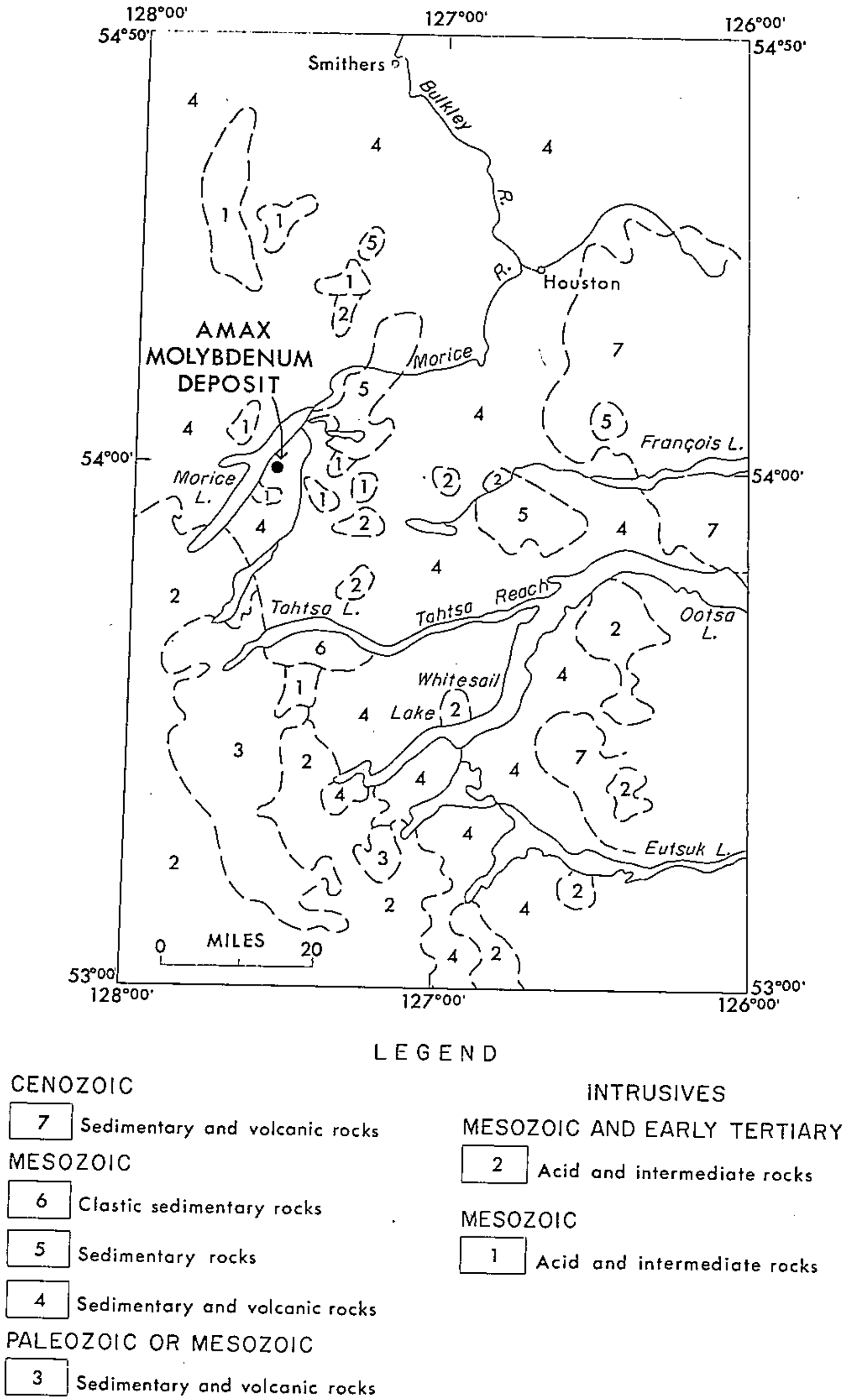

Figure 2. General geology of the transitional zone between the Coast Mountains and the Interior Nechako Plateau.

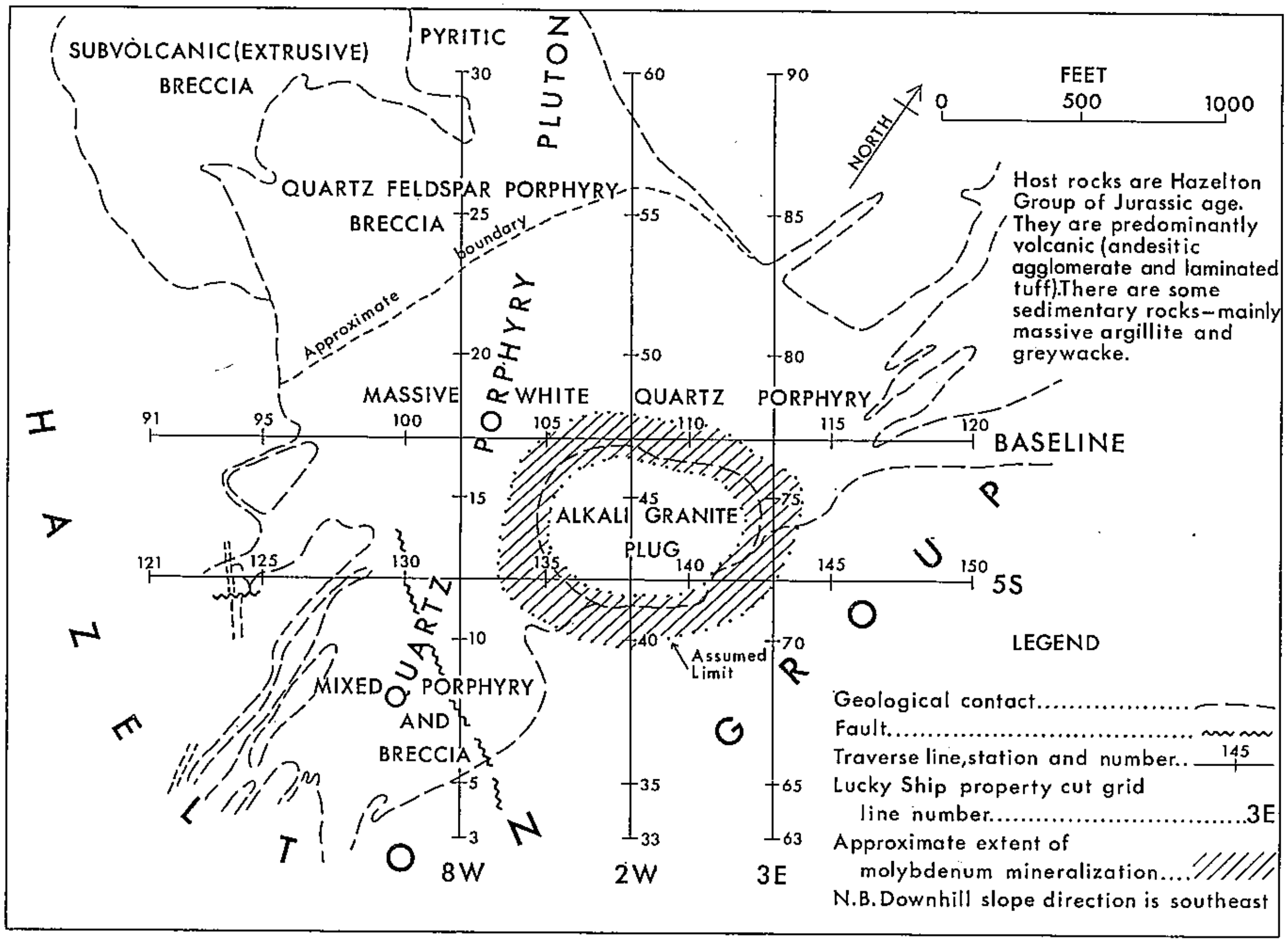

Figure 3. Geological map of the Lucky Ship property showing geology, sample grid and sample stations and the approximate extent of molybdenum mineralization.

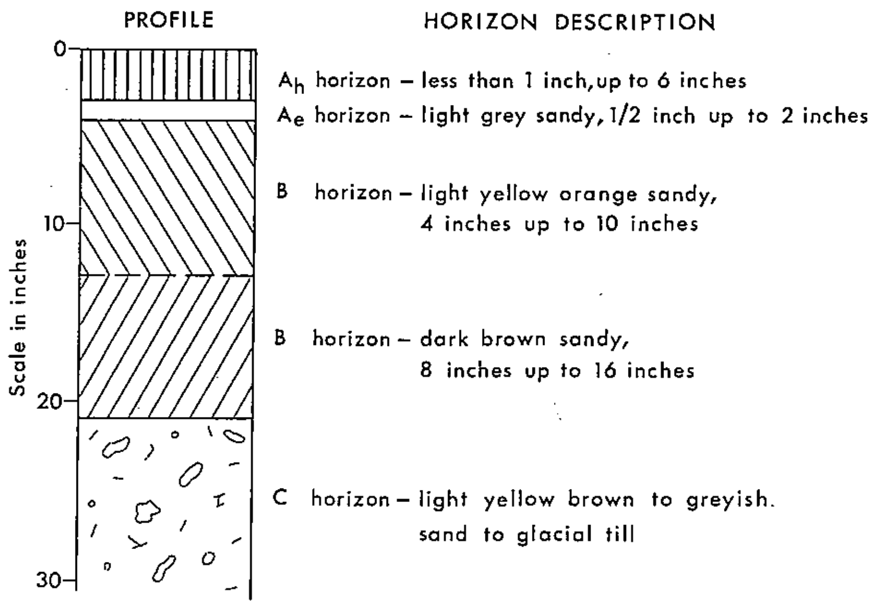

Figure 4. Sketch representing a typical podzol soil profile occurring near the Lucky Ship molybdenum deposit, British Columbia.

Rowe (1959) has described the forest as 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 (Pseudo tsuga 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. commutatata) 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 formally 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 uplant at about 2,500-foot altitude, and only a few hills and low mountains exceed 5,000 feet. The underlying bedrock is of rather flat-lying Paleozoic 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 and lodgepole pine are the dominant species present and the latter becomes more common only in the open slide areas. Other species present are characteristic of the region. An occasional white-bark pine Pinus albicaulis engelm was observed in exposed areas at the top of the ridge. Slide alder Alnus sinuata commonly occurs as thickets growing in peaty soil in local catch basins along drainage courses on ridge flanks but may also randomly occur as a single shrub.

The relief is not as rugged as in the Coast Range but is more rugged than in the plateau. The main mountain ranges in the zone such as the Tahtsa, Kasalka and Sibola trend northeasterly transverse to the general trend of the Coast Mountains and they are characterized by peaks up to 7,000 feet high at their western extremities. On the east, plateau-like areas, common at about 4,500 feet elevation, eventually merge with the main Nechako Plateau. Drainage is into the long narrow lakes separating the transitional zone ranges. These lakes occupy valleys that are erosional rather than orogenic in origin according to Duffell (1959). Data on the climate is not available for the property but monthly, seasonal and annual temperatures recorded at Telkwa, 55 miles north, are shown in Table 1. Rainfall in the area varies considerably and the precipitation for the area including the property is much like that of similar areas throughout rest of the central interior of British Columbia.

Table 1

Monthly, Seasonal, and Annual Temperatures in Degrees F, at Telkwa, British Columbia, 55 Miles North of the Lucky Ship Molybdenum Deposit

MONTH	TEMPERATURE	MONTH	TEMPERATURE
December	18	June	53
January	16	July	56
February	21	August	56
Winter	18	Summer	55
March	30	September	49
April	38	October	39
May	47	November	28
Spring	38	Fall	39
Annual Temperature 38°			

Local contamination on the steep hillside was a factor that could have had an adverse effect on the results if the sample stations had been chosen indiscriminately. The major uphill source of contamination was groundwater run-off carrying dissolved metals from open trenches and drill-holes. Sample stations were located to avoid any possibility of contamination from these sources.

DISCUSSION OF METHODS

Methods of Establishing the Sample Grid over the Mineral Deposit

In previous plant prospecting programs (see Fortescue and Hornbrook, in press, Section G) only one traverse line was established across the strike of an elongated mineral deposit. Information obtained from such a program concerning the lateral distribution of elements in the vicinity of the deposit was restricted to a profile presentation of elements along the traverse line. The characteristics of the mineralization at the Lucky Ship property provided an opportunity for a more sophisticated application of plant prospecting techniques than was previously possible. Because the anomalous metal distribution in the landscape has such a marked geometric configuration, the program provided an excellent test of the effectiveness of plant prospecting techniques. The degree to which the circular pattern is reproduced by the plant results could be readily determined because of the geometric nature of the pattern and a measure of the effectiveness of the plant prospecting techniques was thus determined. To obtain meaningful results, a grid pattern was used for sampling otherwise the circular characteristics of the anomalous molybdenum distribution would not become apparent in a plan anomaly map. Sample stations were established on previously cut traverse lines and these lines were selected so that they intersected enough of the doughnut-shaped zone of mineralization to provide effective coverage of the anomalous areas as well as background remote from the deposit (see Figs. 3, 5, 6 and 7). A total of 144 stations were established at 100-foot intervals and where possible a sample tree and soil pit location was selected at each station.

Methods of Collection and Preparation of Material

Alpine fir occurred in sufficient abundance and uniform density throughout the area so that it could be sampled routinely on a grid pattern. Lodgepole pine was sampled only on the baseline and line 5S because it did not grow in sufficient density to be sampled on lines 8W, 2W and 3E (see Fig. 3). One tree each of slide alder and whitebark pine were sampled at station III in the strongly anomalous zone defined in Figure 7.

The following materials were collected where possible at each station: B horizon, A horizon (humus), bark (collected at breast height, 4 feet 6 inches from the ground), second year twig and needle. Previous experience has shown that it was only necessary to collect these organs to sample representatively the metal distribution in the trees (see Fortescue and Hornbrook, in press, Section G). At only one station, No. 10, was it

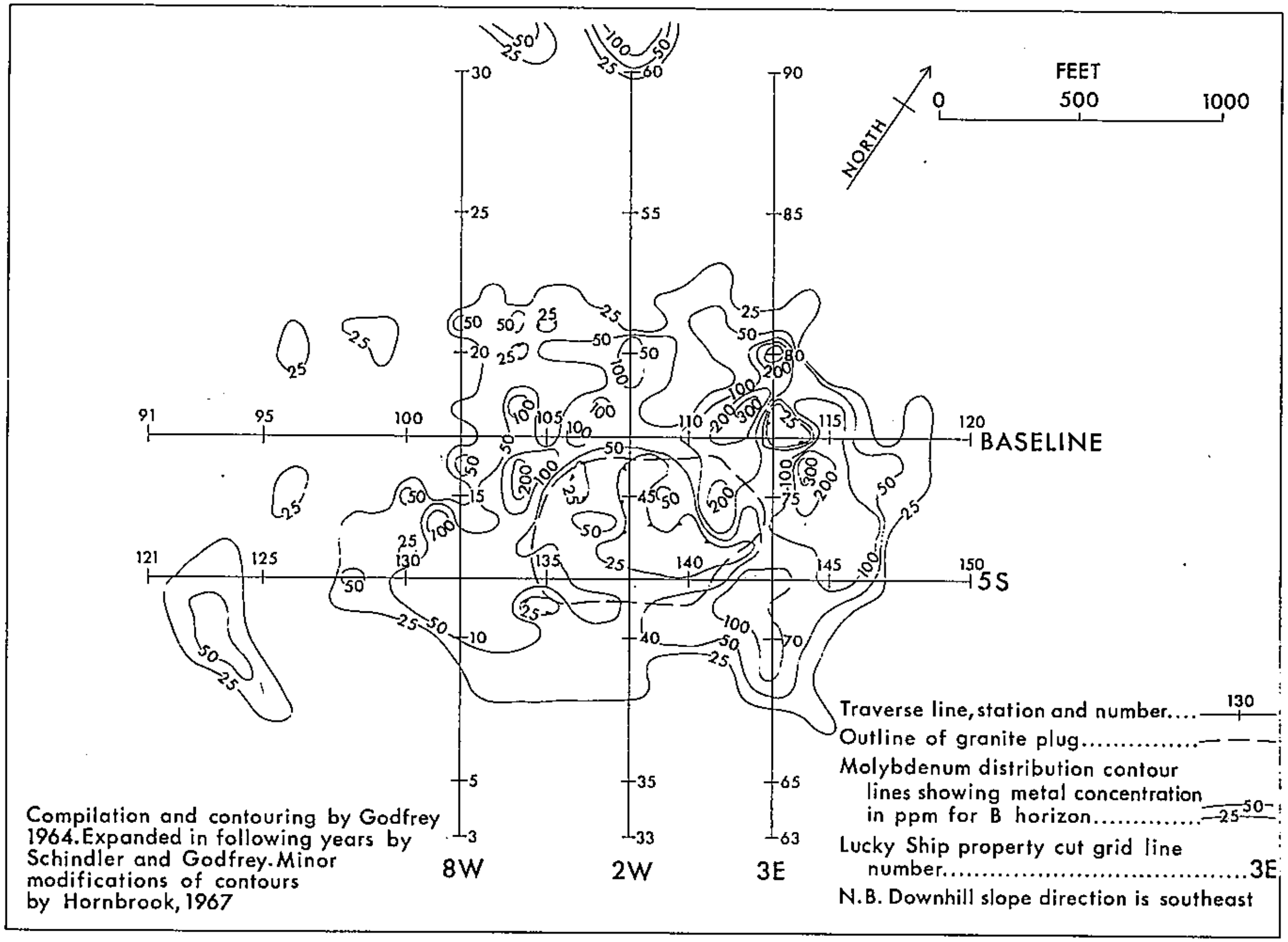

Figure 5. Geochemical anomaly map showing distribution of molybdenum in B horizon over the molybdenum deposit, modified after Godfrey 1964.

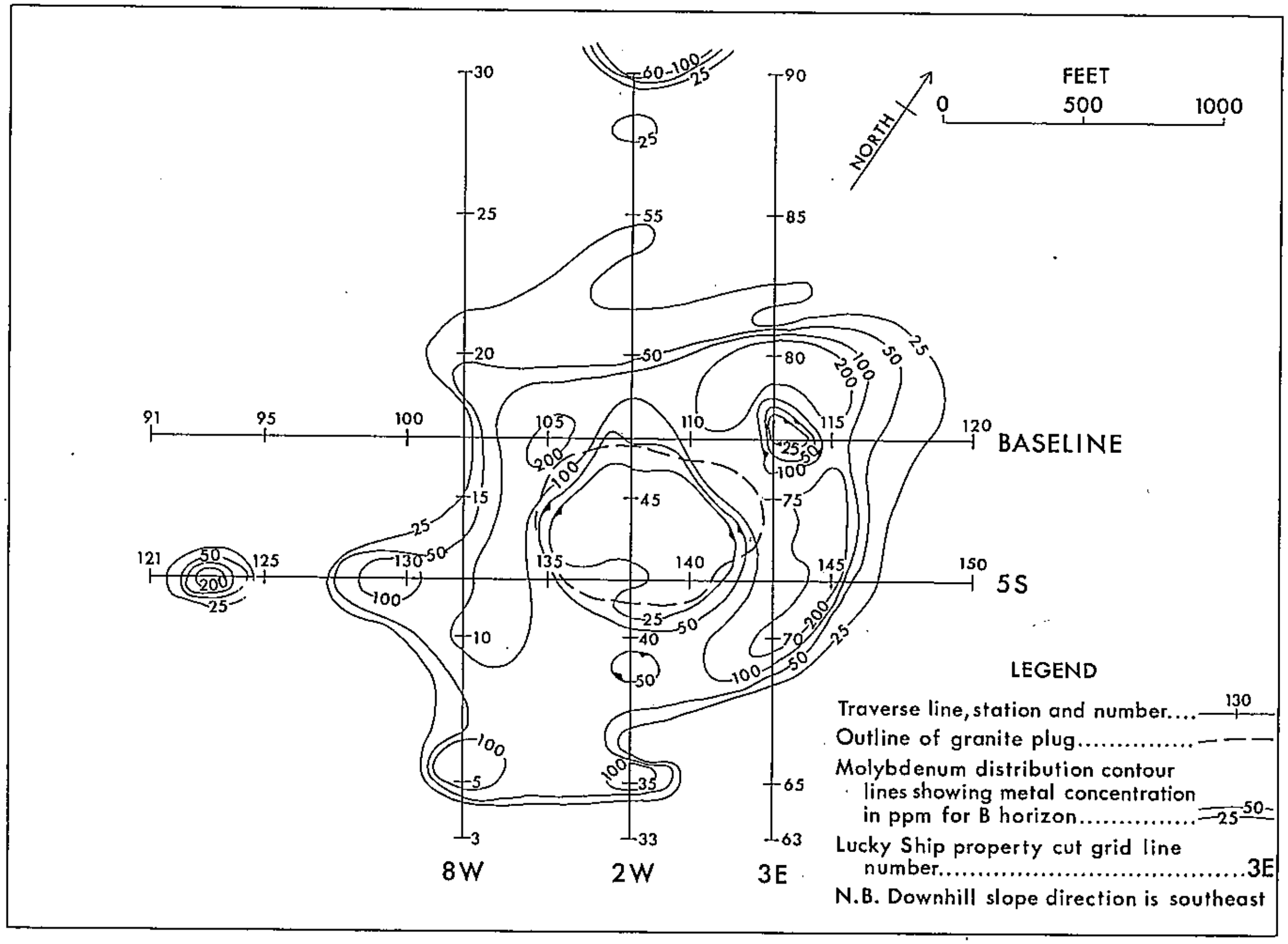

Figure 6. Geochemical anomaly map showing distribution of molybdenum in B horizon over the molybdenum deposit.

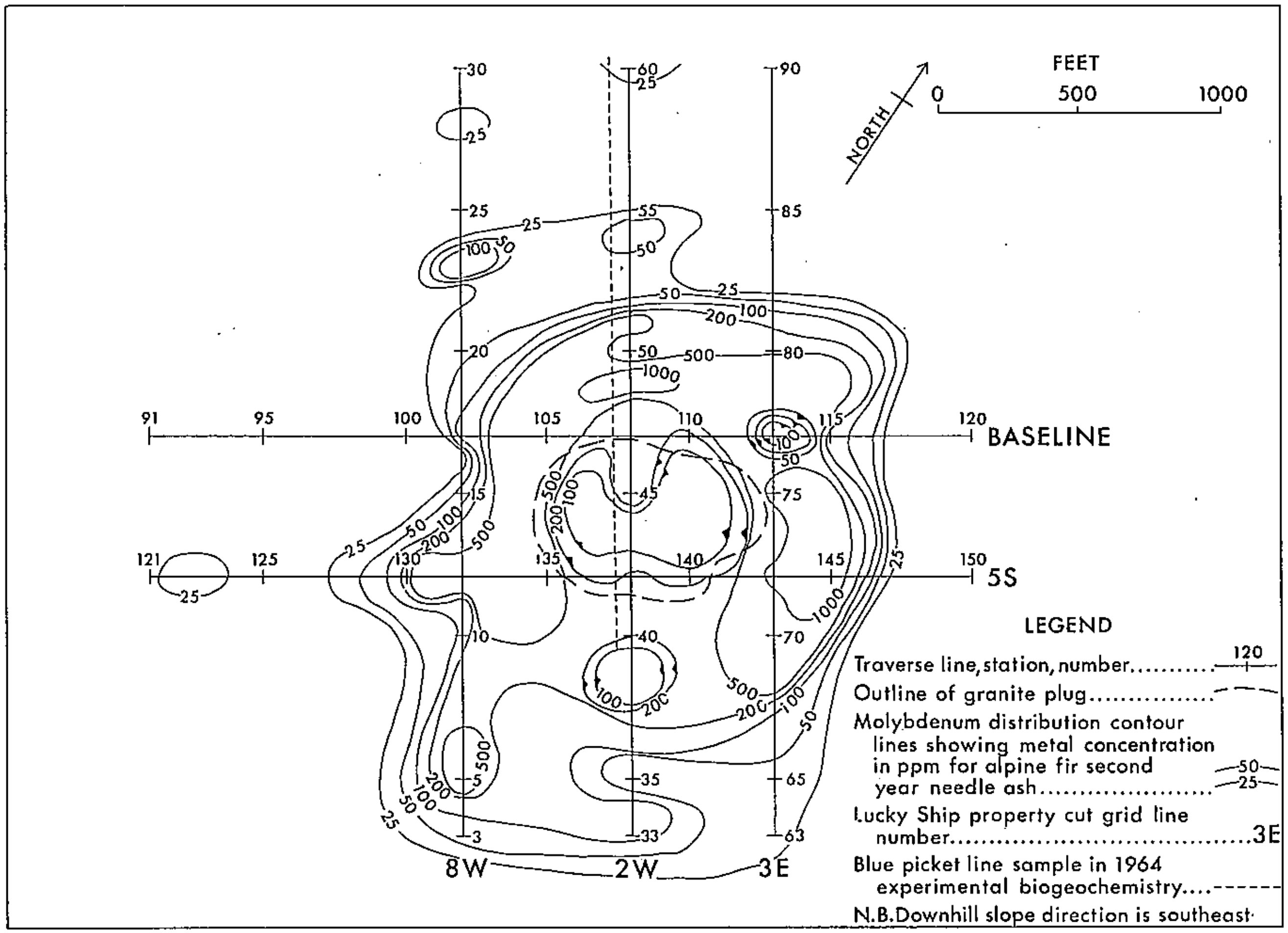

Figure 7. Biogeochemical anomaly map showing distribution of molybdenum in alpine fir second year needle ash over molybdenum deposit.

impossible to sample an alpine fir tree. After collection, all samples were taken to Smithers, British Columbia for preparation in the trailer laboratories. Collection and preparation techniques have been described in detail by Fortescue and Hornbrook (1967) and are briefly reviewed in Appendix A.

During a 4-week period 288 samples of soil and 620 samples of vegetation were collected and prepared for analysis.

Details of height, age and breast height diameter were recorded for each sample tree at all stations. Alpine fir and lodgepole pine sample trees were commonly 50 feet high, 9 inches thick at breast height, and about 100 years old.

Colorimetric Method of Analyses

Plant ash, humus ash and mineral soil were analyzed colorimetrically at the Geological Survey of Canada, Ottawa, for molybdenum, copper, zinc, nickel and lead after decomposition with HF, HNO_3 and $HClO_4$. 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 was used to provide semiquantitative results for the determination of barium, strontium, manganese, titanium, chromium, cobalt and silver in plant and humus material ash. These results, which are not necessarily absolute, were examined mainly to determine if there was a significant activity or anomalous distribution that could be related to the economic metal distribution in the vicinity of the molybdenum deposit.

Although the method was not relatively accurate it was relatively precise as compared to the colorimetric method described above. Previous work by Hornbrook (Fortescue and Hornbrook, in press, Section G) has shown that the method produces satisfactory results for biogeochemical investigations of this type. The method is described in detail in Fortescue and Hornbrook (1967) and a brief review is given in Appendix C. The results in Table 2 for the coefficient of variation of indium, which was added to every sample, show that the required precision was maintained for the analyses of bark, needle, twig and humus ash batches of sample material. For each sample material in Table 2, the coefficient of variation is shown for a batch of samples which were collected from the group of sample-stations indicated. Each batch contains up to a maximum of 15 samples depending on the number of adjacent stations available for sampling in each group.

PRESENTATION OF RESULTS

The metal content is recorded as ppm in ash for all organic materials unless described otherwise. All results for metals in bark, twig, needle and humus ash and mineral soil were compiled as tables which are on file at the Geological Survey. Results required to illustrate certain interpretations developed in this paper, have been extracted from the tables and are usually plotted in the form of a distribution profile.

Table 2

Coefficient of Variation for the Internal Reference Standard Indium in each of the 52 Batches of Like Samples of Humus and Plant Ash Analyzed Spectrographically

GROUPS OF SAMPLE STATIONS	SAMPLE MATERIALS				SPECIES
	HUMUS	BARK	TWIG	NEEDLES	
3-17	16	23	26	11	Sample Tree alpine fir
18-30	28	15	19	17	
33-47	25	8	26	30	
48-60	33	36	27	31	
63-77	21	25	25	23	
78-90	0	25	0	34	
91-105	15	9	26	27	
106-120	29	14	31	28	
121-135	15	16	30	31	
136-150	27	15	26	26	
91-105		8	23	13	Sample tree lodgepole pine
106-120		13	27	11	
121-135		13	12	14	
136-150		13	25	25	

$$\text{Percentage coefficient of variation} = 100 \times \frac{\text{Standard deviation}}{\text{mean}}$$

$$\text{where standard deviation} = \sum_{i=1}^{n} \frac{(xi - \overline{x})^2}{N-1}$$

Description of the Anomaly Maps

Amax data obtained from the analyses of B horizon samples collected in 1964 were used by Godfrey (1964) to construct the anomaly map shown in Figure 5 which has been slightly modified by the author to incorporate additional data from further sampling carried out in 1965 and 1966. Over 300 molybdenum determinations in B horizon soil were used to construct this map.

An additional soil anomaly map (see Fig. 6) was constructed using 144 molybdenum determinations in B horizon soil obtained during the 1967 program. A third anomaly map (see Fig. 7) was constructed using 143 molybdenum determinations in second year alpine fir needles. Needles were used because they have the highest concentration of molybdenum of any alpine fir organ sampled.

The three anomaly maps were constructed on the same scale and with the same molybdenum concentration level isograds and to simplify the comparison of molybdenum among them they have as common points of reference, the sampling grid and the outline of the granite plug.

DISCUSSION OF RESULTS

Regional Background, Local Threshold and Anomalous Concentration of Molybdenum

On the Amax anomaly map for molybdenum distribution in mineral soil (see Fig. 5) background concentrations are much less than 25 ppm and the local threshold level about the deposit is approximately 25 ppm. Low, moderate, and strongly anomalous concentration levels over the deposit are plus 50 ppm, plus 100 ppm, and plus 200 ppm. A frequency distribution plot of the 1967 results for molybdenum in mineral soil and second year alpine fir needles was constructed to compare the distribution of molybdenum in these materials (see Fig. 8). The regional background concentration in needles and soil is 1.0 ppm and 2.5 ppm respectively and the threshold concentration of the same materials near the deposit is 25 ppm and 17.5 ppm respectively. The background and threshold concentration levels show an excellent agreement with each other and with the Amax data. The low, moderate and high anomalous values of 50 ppm, 100 ppm and 250 ppm in mineral soil compare well with the Amax data but the anomalous molybdenum concentrations in the needle ash is considerably different. The low, moderate and high anomalous values of molybdenum in needles are 175 ppm, 500 ppm and plus 750 ppm. However in all three sets of data for molybdenum distribution in this landscape three distinct concentration levels can be defined: (1) anomalous concentrations; (2) local threshold level and (3) regional background level. The local threshold level (see Figs. 5, 6, 7) defines the boundaries of the pluton excluding the quartz-feldspar porphyry breccia section in the northwest part of the pluton (see Fig. 3) and the low and moderate anomalous levels define the approximate extent of significant peripheral molybdenum mineralization about the granite plug. High anomalous concentration levels are probably due to a local higher grade molybdenum section within the mineralized zone

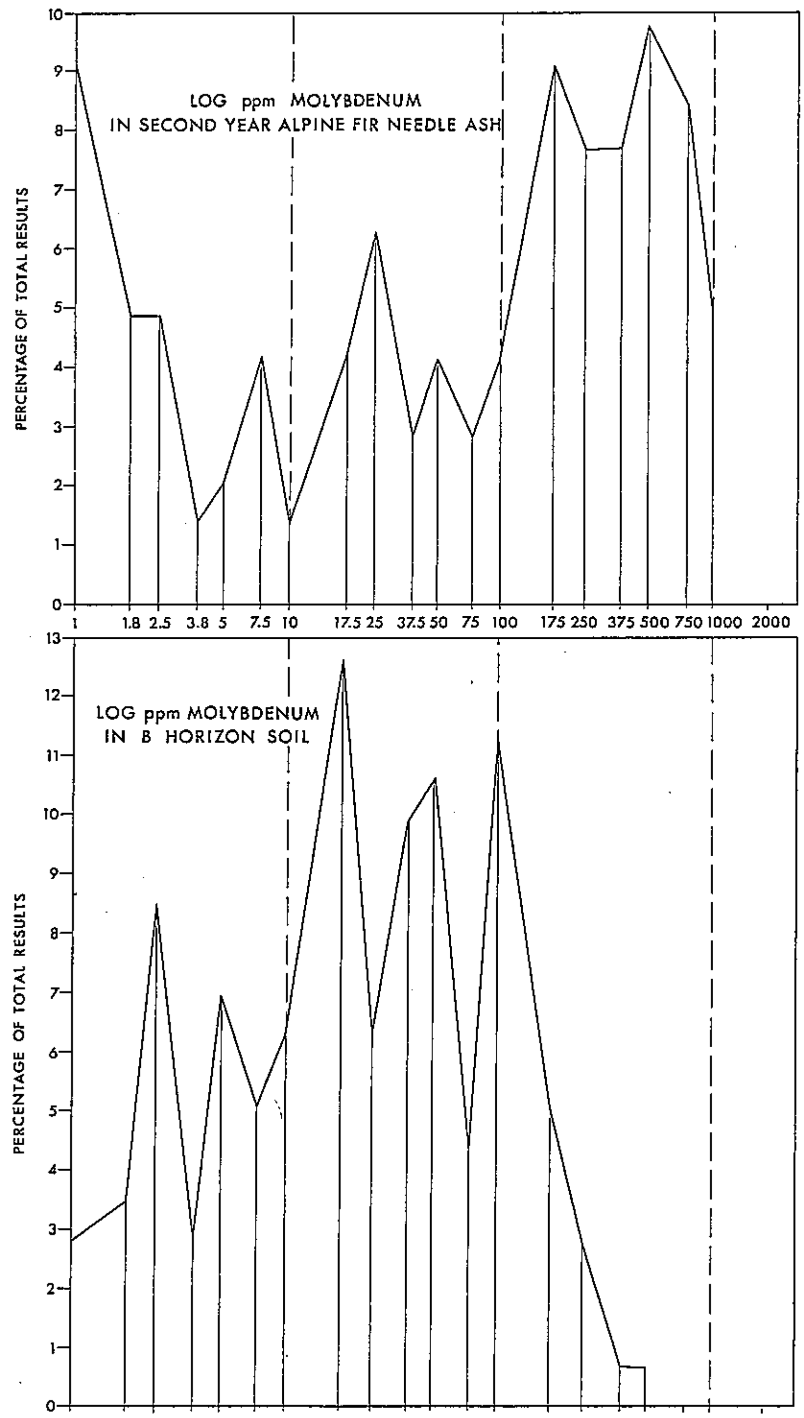

Figure 8. Frequency distribution of molybdenum in second year alpine fir needle ash and B horizon soil calculated from the results of colorimetric analyses of 143 samples of each material.

possibly modified by some contamination. The anomaly maps and defined concentration levels show an excellent correlation to the mineralization and geological features of the landscape.

Comparison of Amax Geochemical Soil Results and Soil and Plant Ash Results of Present Study

A comparison of the distribution of molybdenum in the landscape based on the results of B horizon analyses completed during the biogeochemical program (see Fig. 6) is essentially the same as previously determined in 1964 by Amax whose geochemical soil survey program was much greater in scope and sampling density (see Fig. 5). The major features of molybdenum distribution that are similar in both sets of soil results (see Figs. 5, 6) are: (1) the moderately anomalous concentric zone peripheral to the granite plug; (2) the strongly anomalous horseshoe-shaped zone that is around the granite plug and open to the south; (3) background and local threshold levels of molybdenum concentrations that were obtained over the core of the granite plug. The location and size of the highly anomalous areas within the horseshoe-shaped zone are not exactly coincident for these two surveys. Minor features, including anomalous concentrations of molybdenum in zones adjacent to stations 60 and 123 and background concentrations in the vicinity of stations 77 and 114, are common to both anomaly maps. Therefore the anomaly map (Fig. 6) based on the soil results obtained during the biogeochemical program, provides a satisfactory representation of the molybdenum distribution in the landscape in the vicinity of the mineral deposit.

Distribution of molybdenum in alpine fir needle ash (see Fig. 7) is remarkably similar to its distribution in soils (see Figs. 5 and 6). All major and minor features of the mineral soil results described above in Figures 5 and 6 are also present in Figure 7. Therefore needle ash results not only provide information on the distribution of molybdenum in the landscape equal to that obtained from mineral soils but have several features that are advantageous in prospecting.

Comparison between the Results of Soil and Plant Prospecting Techniques

Features that illustrate the advantages of plant prospecting techniques relative to soil prospecting techniques became apparent during a comparison of the results in Figures 5, 6, 7 and 8. Background concentrations for this comparison were considered to be the threshold concentrations of 17.5 ppm and 25 ppm for soils and needle ash respectively in the vicinity of the mineral deposit.

The magnitude of the difference between anomalous and background molybdenum concentrations is substantially increased in alpine fir needle ash as compared to B horizon soils (see Fig. 8). This increase is commonly by a factor of two to four times. Concentrations of 500 ppm and 750 ppm molybdenum are common and frequently 1,000 ppm concentrations are obtained in needle ash whereas in B horizon results concentrations of 250 ppm or more are rare.

Plant prospecting has an increased sensitivity compared to soil prospecting because the ashed needles of an alpine fir tree usually contain more molybdenum than the soil on which the tree was growing, particularly in the moderately anomalous zone (see Figs. 6, 7). The higher content of molybdenum in ash is of course primarily due to the concentrating function of the ashing in the sample preparation procedures. This relationship was also observed in other biogeochemical studies by Warren (1965). The effect of the relationship is most apparent at the south end of the sampling grid where concentrations up to 175 ppm molybdenum in needle ash are found compared to threshold concentrations of 17.5 ppm or less in B horizon soil. Thus plant prospecting techniques have increased the areal extent of anomalous molybdenum conditions in this landscape.

The improved discrimination between anomalous, local threshold and regional background molybdenum concentration in needle ash results relative to B horizon soil results is most evident in Figure 8. The effect of the improved discrimination is shown by the sharpness of the contrast between anomalous and background molybdenum concentrations particularly on the east side of the sampling grid where it is more abrupt for needle ash results (see Fig. 7) than it is for soil results (see Figs. 5, 6). Therefore in this case needle ash results provide a more definite demarcation of the boundary between anomalous and background concentrations than can be obtained from the soil results.

Comparison of Alpine Fir and Lodgepole Pine Results

Alpine fir and lodgepole pine trees were sampled on lines 5S and baseline to permit a comparison of their element response in background and anomalous areas. The analytical data for molybdenum in the sample trees on line 5S has been used to construct the horizontal distance against concentration profiles in Figure 9. The molybdenum content in the ash of second year needle organs of both species is similar as shown in Figure 9. However, at every station except two, in the oven-dry results, alpine fir needles contain more molybdenum than lodgepole pine needles. A similar relationship between alpine fir and lodgepole pine was also observed in the molybdenum results in a company report by Schindler (1965). This feature is apparently caused by the ash percentage of lodgepole pine needles being consistently about one half that of alpine fir needles. This results in an apparent doubling of the molybdenum content in lodgepole pine ash relative to alpine fir ash. The molybdenum concentration levels determined in alpine fir and lodgepole pine are comparable to that obtained by Warren and Delevault (1965) and Schindler (1965). Therefore both species are equally useful for plant prospecting when the molybdenum content is determined in only the ash of second year needles. It would be possible in most sampling circumstances to substitute one species for another in the event the first species was not available for collection at all sample stations.

Slide Alder and Whitebark Pine Results

A sample of the bark, twig and needle organs was collected from a whitebark pine and slide alder growing close to station III within the extent of the zone of mineralization about the granite plug (see Fig. 3). Neither species

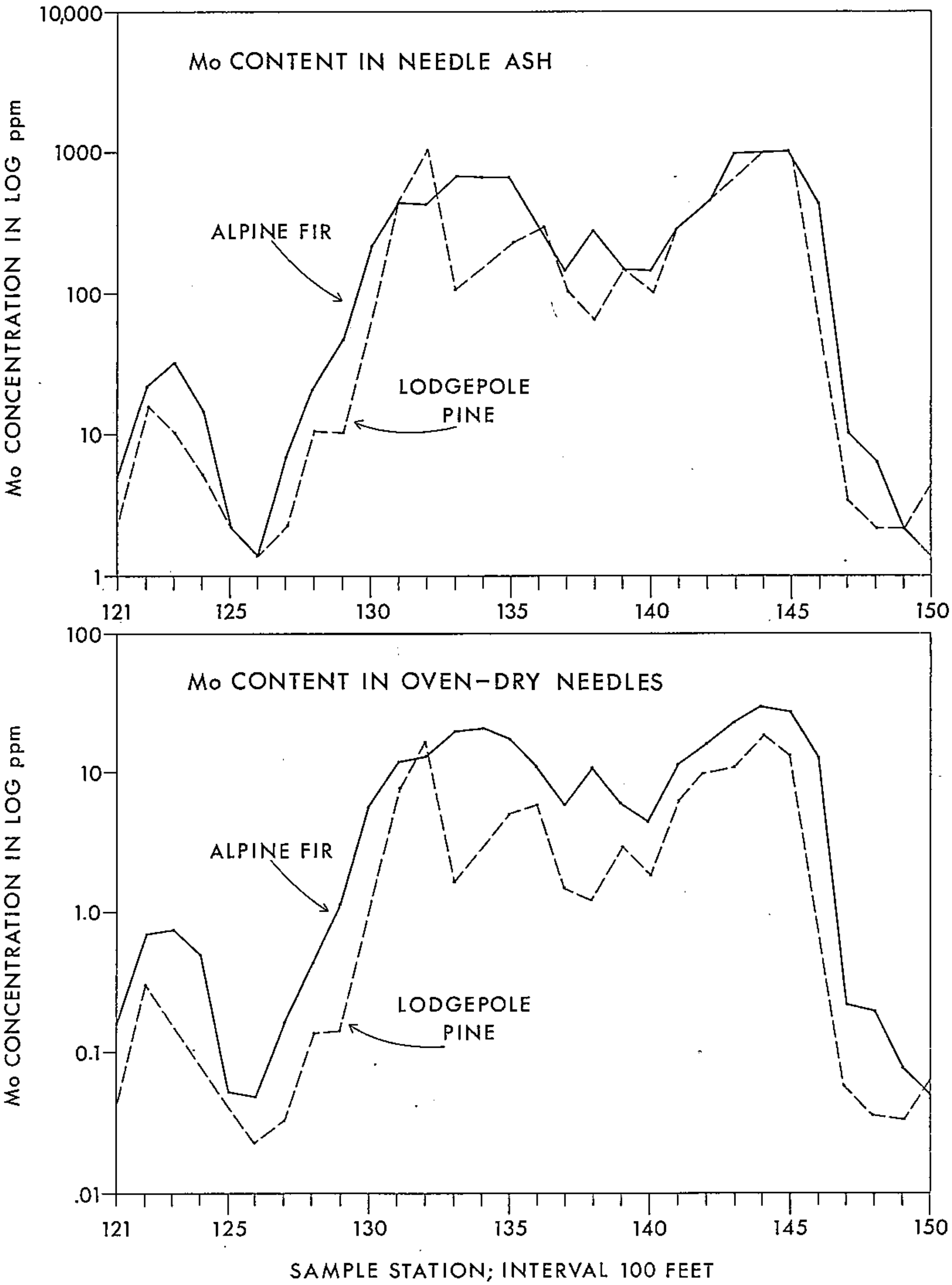

Figure 9. Comparison of molybdenum content in needle ash and oven-dry needles between alpine fir and lodgepole pine.

Table 3

Comparison of Molybdenum Content in Single Samples of Ash and Oven-dry Bark, Twig, and Needle Organs from Whitebark Pine, Slide Alder, Alpine Fir, and Lodgepole Pine Collected at Station III

Tree Species	Whitebark pine		Slide alder		Alpine fir		Lodgepole pine	
Material	ash	oven dry	ash	oven dry	ash	oven dry	ash	oven dry
Bark	100	2	1750	42	75	2	175	4
Twig	500	15	1000	22	500	12	500	11
Needle	250	5	1000	34	750	29	1000	21

grew in sufficient abundance or uniform density to be suitable for sampling on an extensive basis over the mineral deposit. Table 3 shows the molybdenum content in the ash and oven-dry bark, twig and needle organs of the whitebark pine, slide alder, alpine fir, and lodgepole pine trees sampled at station III. High molybdenum concentrations shown are expected because station III is in the zone of anomalous molybdenum values. Although results from only one alder tree were obtained, they show that its organs contain more molybdenum than any of the other species growing at that station. Warren (1962) and Warren and Delevault (1965) also found similar high molybdenum concentrations in slide alder. The concentrating ability of alder suggests its use in regional prospecting for molybdenum and associated elements particularly when it is growing in peaty soil in local alder thickets on wooded ridges, mountain flanks, and in stream beds. Alder predominantly grows in peaty soil in small bogs or swamps that are frequently metal-accumulating. Several metal-accumulating alder swamps occur on the property for example at station 60 (see Figs. 6, 7), where a swamp has produced a high concentration of molybdenum in the soil and second year alpine fir needle samples. Wooded ridges similar to the Morice-Nanika ridge could have their metal potential quickly evaluated by a regional sampling program to determine the metals in alder ash. The results should be representative of most landscapes as alder swamps usually occur at several random locations. The metal content in each of the alder swamps represents the concentrated metal potential of a drainage area much greater than the swamp; hence anomalous metal concentrations, readily detectable in ash of any alder organ are indicative of the presence of metals in extremely large areas. In an exploration program local detailed sampling would follow up anomalies indicated by rapid biogeochemical evaluation of regions.

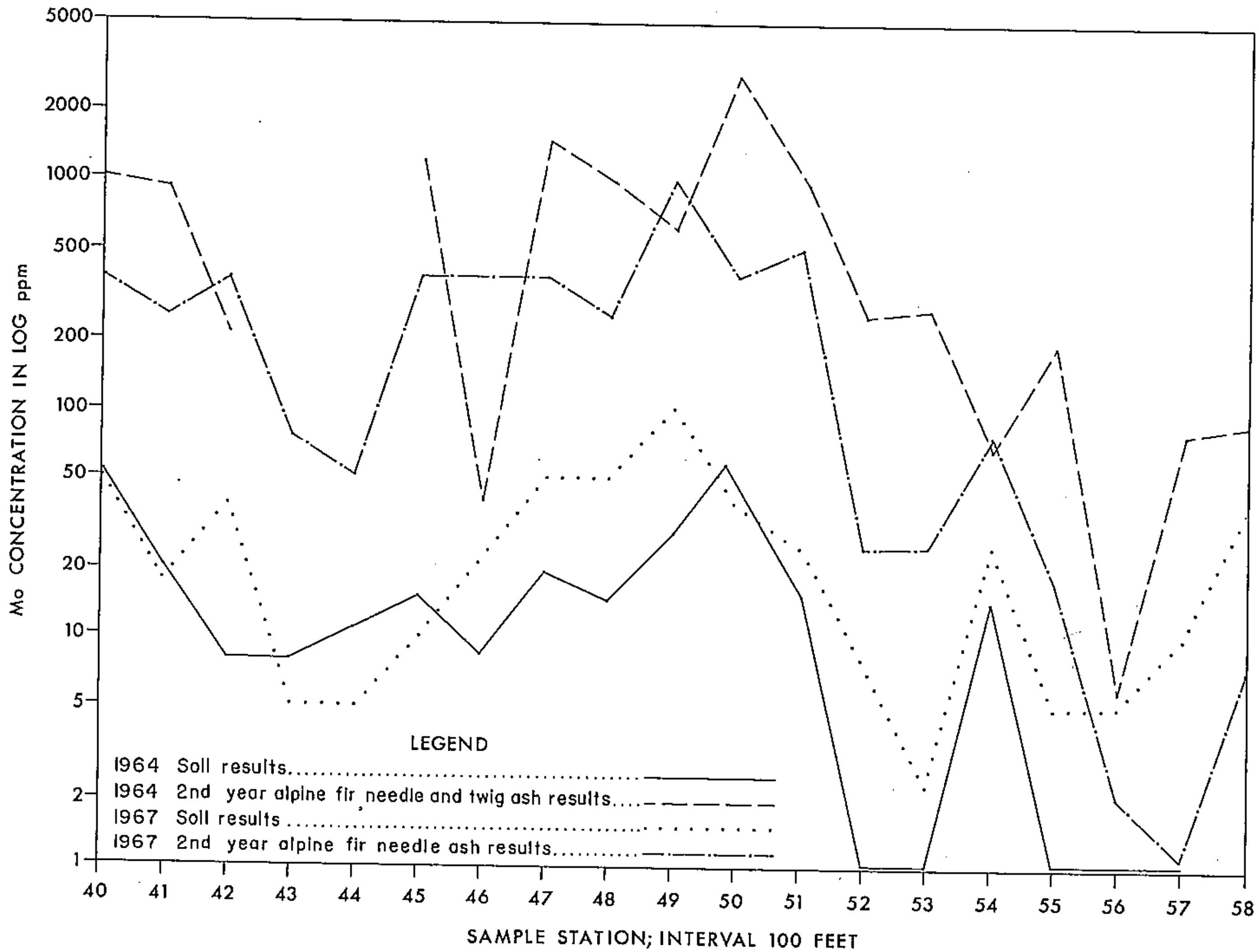

Figure 10. The result of the 1964 and 1967 biogeochemical investigations at the Lucky Ship molybdenum deposit. Data from Schindler and Godfrey, biogeochemical survey, 1964, and Hornbrook, biogeochemical survey, 1967.

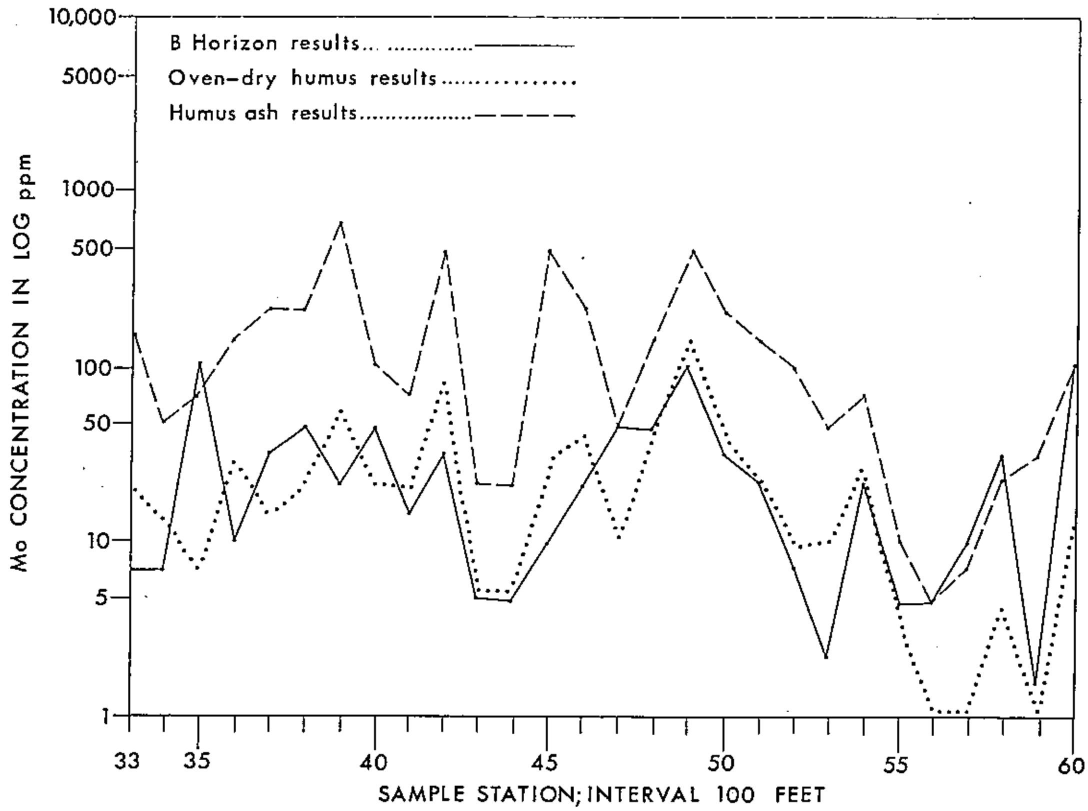

Figure 11. Comparison of molybdenum content among ash and oven-dry humus and B horizon soil collected on line 2W.

Comparison of the 1964 and 1967 Biogeochemical Results

During August 1964 an experimental biogeochemical survey was undertaken by J. N. Schindler (1965), and the results were published by Warren and Delevault (1965). Molybdenum content was determined in ash of combined alpine fir second year twigs and needles and in B horizon samples collected along an 1, 800-foot line (located between lines 2 W and 3 W for most of its length (see Fig. 7)). Molybdenum results for the ash of second year alpine fir needles and B horizon collected along line 2 W in 1967 and the results of the 1964 survey are plotted on Figure 10. It is significant that the results of the earlier survey could be so closely reproduced after a three-year period during which extensive exploration took place including diamond drilling and road building in the vicinity of the traverse line. The excellent agreement suggests that the results of plant prospecting surveys are not as susceptible to contamination and annual climatic conditions as they are often assumed to be.

Comparison of Molybdenum Content Among Ash and Oven-dry Humus and B Horizon Soil

The molybdenum concentration in ash and oven-dry humus and B horizon soil at stations 33 to 60 on line 2 W are plotted in profile in Figure 11. An examination of the molybdenum distribution in the three sample types shows the following relationships: (1) the patterns of ash and oven-dry humus are similar in spite of the large variations in ash percentage of humus; (2) except at 4 stations the humus ash contains more molybdenum that B horizon soil sampled at the same station; (3) approximately half of the oven-dry humus samples contain more molybdenum than the B horizon samples. Therefore humus ash is enriched in molybdenum compared to B horizon and frequently oven-dry humus contains more molybdenum that the B horizon. Similarly the humus ash is found to be enriched in copper, zinc, lead, and nickel. This type of enrichment phenomenon was also observed at Cobalt, Ontario, by Boyle and Dass (1967) for lead, zinc, copper, arsenic, antimony, molybdenum, silver, cobalt, manganese and mercury. The enrichment of lead in humus was also observed by Warren and Delevault (1960). Therefore the humus horizon in many landscapes is suitable and in some cases superior to B horizon soil for determining metal distribution in a landscape as in the case of the Lucky Ship property. However, there are many inherent disadvantages to sampling the A_h horizon including the extreme variation in chemical composition and physical properties.

Results of the Examination of the Burl Growths on Alpine Fir

Throughout the southern part of the sample grid a wart-like growth or burl is common on alpine fir, lodgepole pine and other indigenous species. The burl frequently forms a partial collar as much as 6 inches thick about the main stem of a tree. Proportionately smaller burls are found on branches and shrubs. Samples of bark collected from the burl and from the normal stem of the same tree at a point opposite the location of the burl, were analyzed for their molybdenum content.

Spectrographic analyses showed no obvious difference between the concentration level of molybdenum in the burl bark and stem bark samples and their concentration levels were similar to trees that had no burls. However, burl growths on trees are known from other molybdenum properties in British Columbia (Godfrey, personel communication) and their presence should be investigated further.

General Observations of the Analytical Results

An examination of the molybdenum concentration in alpine fir organs reveals that needles and twigs contain substantially more molybdenum than bark and that needles contain slightly more than twigs. Therefore the molybdenum content in needles was primarily examined to evaluate its application as a plant prospecting technique.

In individual organs of alpine fir and lodgepole pine the following preferential concentrations of nickel and copper occur in second year twigs, the latter also observed by Warren et al. (1966); lead weakly concentrated in twigs because concentrations are at background levels in this landscape, also observed by Warren and Delevault (1960); zinc has a relatively uniform distribution in all organs; barium and strontium in bark (see Fortescue and Hornbrook, in press, Section G); titanium and silver in second year twigs and needles; and manganese is slightly concentrated in needles and twigs.

A detailed study of the results was carried out to determine if there was any significant pattern in the distribution of any element in the landscape. No persistent relationship was observed between the distribution of any element and that of molybdenum. Therefore it would appear that none of the elements has a potential as a pathfinder element in the Lucky Ship property type of landscape. No relationship was revealed between the distribution or absolute concentration of an element and the age, height, or breast-height diameter of the sample trees. There is, of course a pronounced relationship between the concentration of elements and landscape conditions when the sample tree is growing in abnormal conditions such as in a copper-accumulating swamp.

SUMMARY AND CONCLUSIONS

Plant analysis provides a substantially increased magnitude of anomalous to background molybdenum concentrations, an increased ground surface areal extent of the molybdenum anomaly, and a more definite demarcation of its boundaries compared to soil analysis. These findings and evaluations suggest that a plant prospecting program to determine molybdenum in alpine fir needle ash at all of the stations sampled by Amax during the 1964 soil program would have provided more effective and useful knowledge than was obtained from the soil program. Experience gained during the summer program indicated that plant prospecting could be faster, easier and probably less expensive than equivalent programs in which soils are sampled at the same stations. An additional advantage of plant prospecting is that sampling can be carried out during the winter when other geochemical methods are not applicable.

The examination of all analytical results and the comparison of some to relevent geological, geochemical and biogeochemical data reveals the following:

1. The second year needle of alpine fir is the optimum plant organ to sample and analyze to determine effectively molybdenum distribution in landscapes similar to that of the Lucky Ship property.
2. The reproduction of the 1964 biogeochemical results in 1967 shows that results of plant prospecting programs are not as adversely susceptible to contamination from a disturbed landscape or annual climatic changes and conditions as they are commonly assumed to be.
3. At stations where alpine fir is not available for sampling, lodgepole pine may be substituted because it has a similar content of molybdenum in its needle ash.
4. Slide alder, which has a higher content of molybdenum than other species examined, could be successfully used in regional evaluation of landscape metal potential because it preferentially grows on moist peaty soil in metal-accumulating catch basins on wooded ridges and mountain flanks.
5. No element exhibited a variation or distribution in the landscape that was persistently similar to molybdenum that would suggest its use as a pathfinder element.
6. The A_h horizon (humus ash) is enriched in molybdenum, copper, lead, zinc and nickel relative to the B horizon.

7. In alpine fir and lodgepole pine, molybdenum is concentrated in second year needles.
8. Silver, nickel and lead are present mostly at background concentration levels.
9. Erratic high copper concentrations are found due to the presence of metal-accumulating swamps in the vicinity of the sample station.

REFERENCES

Armstrong, J. E.
1944: Preliminary map, Smithers, British Columbia; Geol. Surv. Can., Paper 44-23.

Boyle, R. W., and Dass, A. S.
1967: Geochemical prospecting - use of the A horizon in soil surveys; Econ. Geol., vol. 62, pp. 274-285.

Duffell, S.
1959: Whitesail Lake map-area, British Columbia; Geol. Surv. Can., Mem. 299.

Farstad, L., and Laird, D. G.
1954: Soil survey of the Quesnel, Nechako, Françoise Lake and Bulkley-Terrace areas in the central interior of British Columbia; Brit. Columbia Soil Surv., Rept. No. 4.

Fortescue, J. A. C., and Hornbrook, E. H. W.
1967: Progress report on biogeochemical research at the Geological Survey, 1963-1966; Geol. Surv. Can., Paper 67-23, Part I.

in press: Progress report on biogeochemical research at the Geological Survey, 1963-1966; Geol. Surv. Can., Paper 67-23, Part II.

Godfrey, T. J. R.
1964: Geochemical map, distribution of Mo in Soils; Amax Exploration, Inc., Unpubl. Rept., Vancouver, British Columbia.

Rowe, J. S.
1959: Forest regions of Canada; Canada, Dept. North. Affairs Natl. Resources, Forestry Branch, Bull. 123.

Schindler, J. N.
1965: The biogeochemical survey on the Lucky Ship molybdenum property; Unpubl. Rept., Amax Exploration, Inc., Vancouver, British Columbia.

Warren, H. V.
1962: Background data for biogeochemical prospecting in British Columbia; Trans. Roy. Soc. Can., Ser. 3, vol. 56, sec. 3, p. 28.

Warren, H. V., and Delevault, R. E.
1960: Observations on the biogeochemistry of lead; Trans. Roy. Soc. Can., Ser. 3, vol. 54, sec. 4, pp. 11-20.

1965: Further studies of the biogeochemistry of molybdenum; Western Miner, vol. 38, No. 10, pp. 64-72.

Warren, H. V., Delevault, R. E., and Cross, C. H.
1966: Geochemistry in mineral exploration; Western Miner, vol. 39, No. 2, pp. 22-26.

Warren, H. V., Delevault, R. E., and Routley, D. G.
1953: Preliminary studies of the biogeochemistry of molybdenum; Trans. Roy. Soc. Can., Ser. 3, vol. 47, sec. 4, pp. 71-75.

APPENDIX A

Plant prospecting collection and preparation techniques

At each station the A_h horizon was sampled for a humus sample first to avoid any possible contamination by the mineral soil horizons. Next the sample tree was cut down and the foliage and bark collected. A clean cut wood wheel was obtained from the stem at breast height for growth ring count to determine the age of the tree. The soil pit was dug with a mattock where the humus was sampled as close to the sample tree as possible and a representative sample of the B horizon collected using hand tools. All samples were put in paper bags that have a high wet strength in the event of high sample moisture content.

In the sample preparation laboratory foliage, bark and organic soil were cabinet dried at 50 degrees centigrade (for up to 3 days in the case of organic soil). The material is then subsampled; foliage separated to needles and twigs; bark reduced to small fragments; before it is oven dried overnight at 80 degrees centigrade. Mineral soils were cabinet dried as long as necessary and then sieved to obtain the minus 80 mesh portion for colorimetric analyses. The plus 80 minus 10 sieved portion of the humus sample was retained in sealed plastic vials.

A 10-gram amount of each sample of organic material was dry ashed in a muffle furnace on a time-temperature controlled cycle in which the temperature slowly increases to 435 degrees centigrade and then is maintained at that temperature for the remainder of the 10-hour cycle. The ash was thoroughly mixed and stored in sealed plastic vials.

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 $HClO_4$ 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 (1962) 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.

References

Almond, H.
1955: Rapid field and laboratory method for the determination of copper in soil and rocks; U. S. Geol. Surv., Bull. 1036A, pp. 1-8.

Gilbert, M. A.
1959: Field and laboratory methods used by the Geological Survey of Canada in Geochemical Surveys No. 1 Laboratory methods for determining copper, zinc, and lead; Geol. Surv. Can., Paper 59-3.

North, A. A.
1956: Geochemical field methods for the determination of tungsten and molybdenum in soils; The Analyst, vol. 81, p. 660.

Stanton, R. E.
1962: The field determination of zinc with dithizone in the presence of aluminum; Imperial College of Science and Technology, London; Geochemical Prospecting Research Centre, Technical Communication No. 19.

Stanton, R. E., and Coope, J. A.
1958: Modified field test for determination of small amounts of nickel in soils and rocks; Bull. Inst. Mining Met., London, vol. 623, p. 9.

APPENDIX C

Scan spectrographic method of analyses

A ten milligram portion of ash, held in suspension in a sugar solution, was placed on top of a sugar-impregnated, 1/2-inch graphite platrode. It is then dried to a thin layer-like icing on a graphite cake. The sugar solution contains indium as an internal reference standard for control of the analytical precision. The sample platrode was rotated at ten rpm and excited by means of a high voltage spark source. The spectrogram was recorded on 35 millimetre film during a 20-second exposure in a Jarrell-Ash 1.5 metre Wadsworth grating spectrograph. By matching the sample film with a standard film in a densitometer-comparetor, a visual estimation was made of the concentration of the elements detected. The results are recorded on special data recording sheets which are forwarded to the computer centre for processing. Concentrations on an oven dry basis and in ash with statistical information are printed out on a separate page for each element.

The indium results (see Table 2) show that the required precision was maintained for the analyses of each plant organ and organic soil ash.

APPENDIX D

HAMMER REFRACTION SEISMIC SURVEY TO ASSIST BIOGEOCHEMICAL PROGRAM LUCKY SHIP, BRITISH COLUMBIA

George D. Hobson

A seismic refraction survey, using a portable hammer seismograph was conducted over five cut lines on the Lucky Ship property of Amax Exploration, Inc. in north-central British Columbia to assist the investigations of a Geological Survey of Canada biogeochemical team. The property is near Morice Lake, about 42 miles southwest of the town of Houston (Fig. D-1). The seismic survey was carried out between July 5 and August 9, 1967.

A Huntec model FS-2 portable hammer 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 a source of energy.

Fifty reversed refraction seismic profiles were completed along the five control lines. These reversed profiles were surveyed at intervals of 100 feet along the cut lines except at locations where surface topography or the presence of rock outcrop indicated that the seismic method was not appropriate or not required. A number of short, single-ended profiles, were also completed to provide the biogeochemical team with overburden data at actual sampling sites where reversed profiles were unobtainable.

Surface elevation varies between 3,035 feet at station 33 and 4,065 feet at seismic station 30. Horizontal and vertical survey control were supplied by the biogeochemical team. The control lines had been cut by Amax Exploration, Inc. through predominantly fir and some pine forest. These trees range up to two feet in diameter.

The geology of the project area has been described in detail in the body of this report; a brief geological background to the seismic survey is included in this section. Till covers the lower part of the slopes as a result of glaciation; no till is present at higher elevation. The tops of the hills are generally exposed outcrop with talus down the slope intermingled with or covered by a thin layer of soil. The central part of the project area is occupied by a granite plug in a quartz porphyry pluton which in turn is surrounded by Middle Jurassic sediments and volcanics of the Hazelton Group.

A histogram of observed seismic velocity versus frequency of observation is depicted in Figure D-2. These velocities are as observed and are uncorrected for dip. The velocity of seismic energy through bedrock appears to be in excess of 9,300 feet per second. It is difficult if not impossible to make any correlation between seismic velocities and Pleistocene materials in this area due to a lack of data.

Thickness of overburden varies from nil at several seismic stations to a thickness of about 50 feet beneath station 63. In general, the thickness of overburden is thin, that is less than 15 feet, and consists of a layer of humus overlying a mixture of unconsolidated glacial material and talus. The overburden is dry. Overburden thickness has been contoured in Figure D-3.

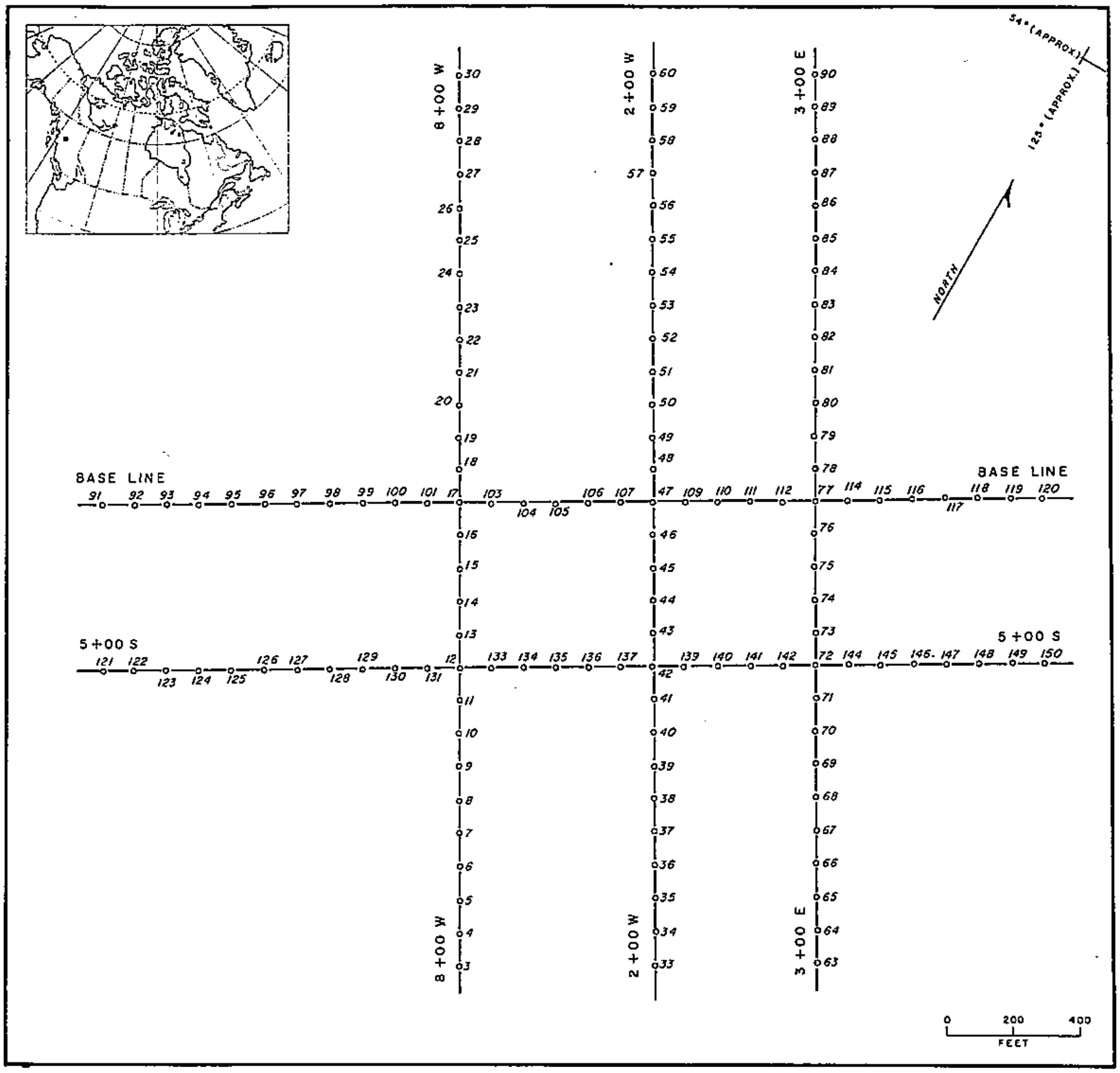

Figure D-1. Seismic locations on cut line grid, Lucky Ship project, British Columbia.

The bedrock surface is identified with a seismic velocity in excess of 9,300 feet per second. The mineralization of this prospect occurs in a zone concentric about a granitic plug. The contact between this plug and the surrounding quartz porphyry is well defined. Bedrock seismic velocities have been plotted at the seismic control points on a plan map of the area resulting in a contour suggesting the contact between the quartz porphyry and the surrounding Middle Jurassic sediments and volcanics. Figure D-3 also shows the areas of rock outcrop in the project area, the granitic plug as indicated on company maps and the contact between the quartz porphyry and the Middle Jurassic sediments and volcanics based upon seismic velocities. Velocities less than 14,500 feet per second have been correlated with the quartz porphyry while velocities greater than that value have been associated with the Middle Jurassic country rock. This contact contour corresponds very favourably with the boundary of the mineralized zone. A few anomalously low velocities within this area are probably due to the fine fracturing in the quartz porphyry into which the mineralization elements have been deposited.

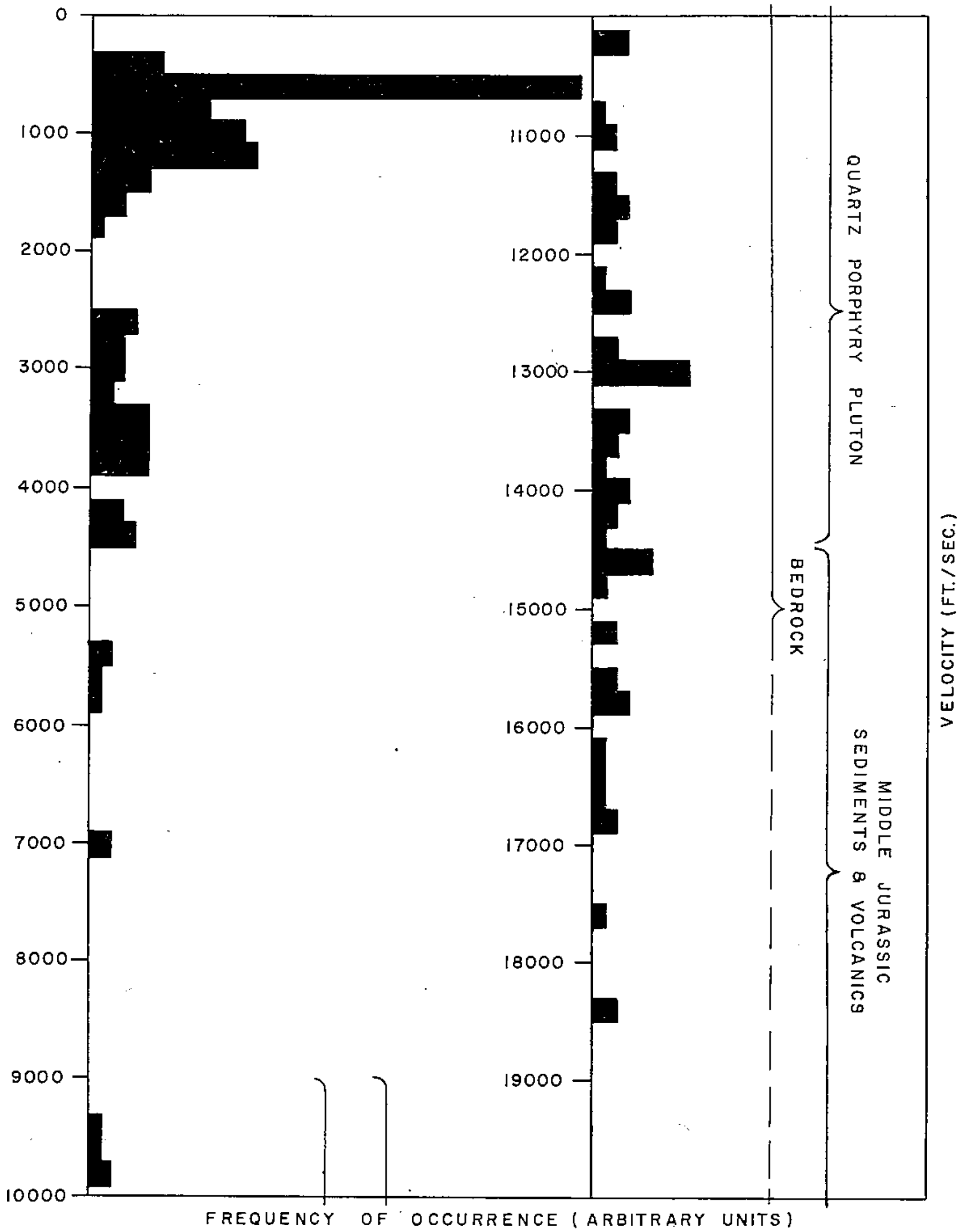

Figure D-2. Histogram of observed velocity plotted against frequency of occurrence, Lucky Ship, British Columbia.

Personal communication with T. Godfrey, Amax geologist, indicates that velocities in excess of 14,000 feet per second were observed for Middle Jurassic sediments and volcanics over a limited survey area about 3 miles from this project site.

VELOCITY (FT./SEC.)

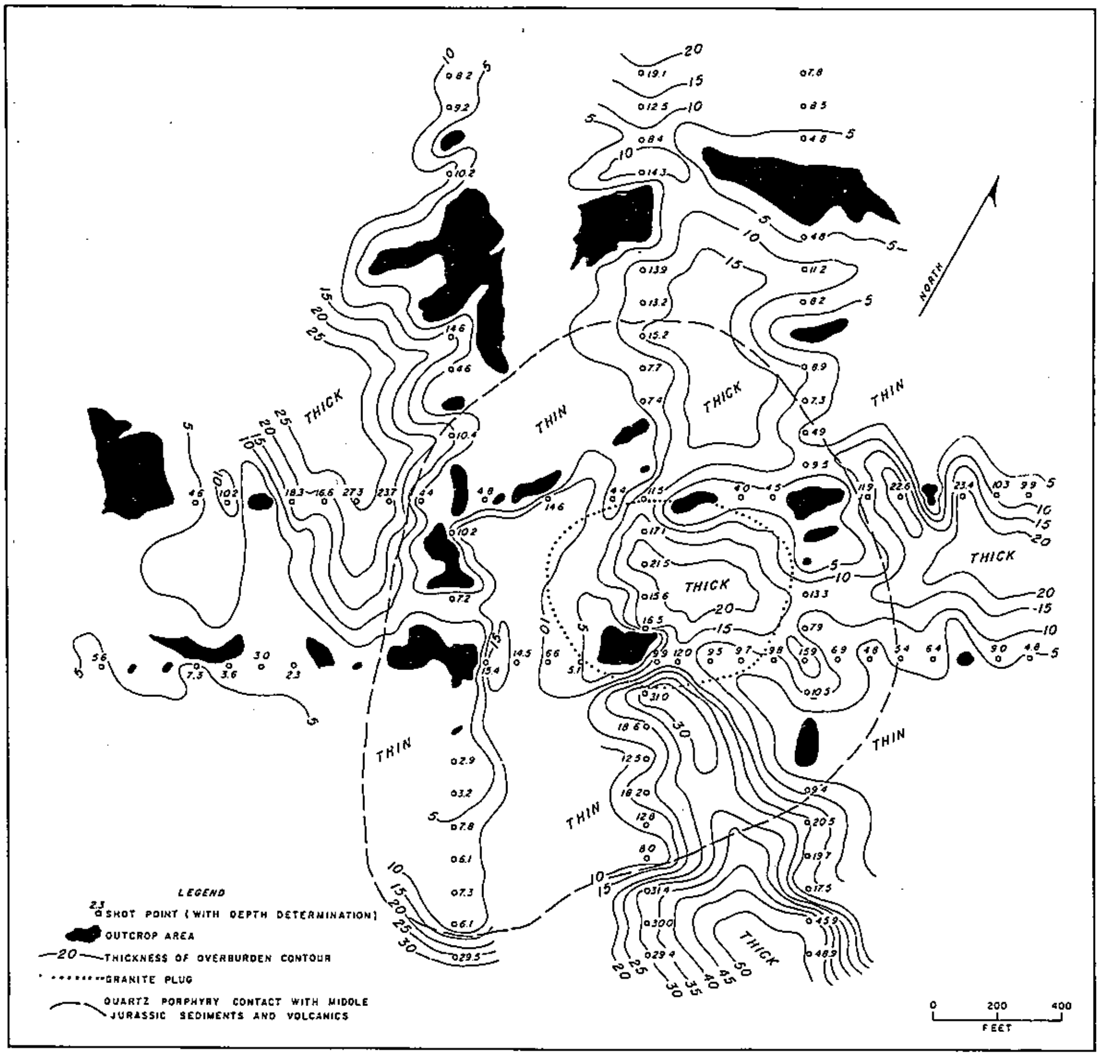

Figure D-3. Thickness of overburden, geological contacts, Lucky Ship, British Columbia.

Cross-sections for the 5 control lines are not included in this report because such presentations were meaningless on a publication scale. The general thinness of overburden and the considerable topographic relief made such a presentation impractical. The basic and computed data are presented in Table D-1; this table and Figure D-3 should be adequate for any further interpretation.

There are no drillhole data available within the project area for correlation between seismic velocities and bedrock or overburden materials.

Extremely good velocity contrasts between overburden and bedrock permit accurate determination of overburden thicknesses. Also the contrast in rate of transmission of seismic energy through the quartz porphyry and the surrounding Middle Jurassic sediments and volcanics permits the contact between these formations to be established fairly accurately.

TABLE D 1

Station	Reversed With	V_o	V_1	V_2	V_3	ϕ_1	ϕ_2	ϕ_3	z_o	z_1	z_2	$\sum z$	Station Elevation	Bedrock Elevation
3S	3S Rev	570	1180	3,840	21,320	.5°S	4.4°N	9.9°S	1.9	4.8	22.9	29.5	3040.0	3010.5
4W	5E	655	9320			.4°W			6.1			6.1	3090.0	3083.9
5N	6S	515	1510	13,450		2.7°S	8.4°N		1.7	5.6		7.3	3140.0	3132.7
6N	7S	550	1130	14,160		1.5°N	3.3°S		1.7	4.4		6.1	3165.0	3158.9
7S	6N	550	1130	14,160		1.5°N	3.3°S		1.6	6.2		7.8	3150.0	3142.2
8	DD	500	18500						3.2			3.2	3180.0	3176.8
9	DD	510	14000						2.9			2.9	3247.0	3244.1
10	O												3300.0	3300.0
11	O												3363.0	3363.0
12	DD	490	1430	15,100					1.8	3.9		5.7	3431.0	3425.3
13	DD	600	2480	14,000					2.8	7.6		10.4	3490.0	3479.6
14	DD	500	1190	14,000					1.5	5.7		7.2	3546.0	3538.8
15N	16S	530	11670			.1°S			4.9			4.9	3584.0	3579.1
16N	16N Rev	585	1520	9.940		1.8°S	1.4°N		2.2	8.0		10.2	3615.0	3604.8
17	DD	490	1200	14,300					1.5	8.0		9.5	3662.0	3652.5
18	DD	430	1130	14,000					1.3	4.7		6.0	3690.0	3684.0
19N	19N Rev	520	1050	14,100		.5°N	1.4°S		1.0	9.3		10.4	3742.0	3713.6
20	O												3749.0	3749.0
21	DD	585	1530	13.900					1.4	3.2		4.6	3796.0	3791.4
22	DD	700	3700	19,600					3.7	10.9		14.6	3840.0	3825.4

Station	Reversed With	V_o	V_1	V_2	V_3	ϕ_1	ϕ_2	ϕ_3	Z_o	Z_1	Z_2	$\sum Z$	Station Elevation	Bedrock Elevation
22	DD	700	3700	19,600					3.7	10.9		14.6	3840.0	3825.4
23	0												3890.0	3890.0
24	0												3940.0	3940.0
25	0												3980.0	3980.0
26	0												4010.0	4010.0
27N	27N Rev	440	1170	13,030		1.3°N	2.5°S		1.8	8.4		10.2	4022.0	4011.8
28	0												4023.0	4023.0
29N	30S	550	1220	10,210		4.2°S	7.7°N		1.2	8.0		9.2	4041.0	4031.8
30S	29N	550	1220	10,210		4.2°S	7.7°N		1.7	6.5		8.2	4065.0	4056.8
33E	33E Rev	575	3270	12,990		.5°E	4.0°W		3.3	26.1		29.4	3035.0	3005.6
34N	35S	945	5420	15,770		1.6°S	11.8°N		6.7	23.3		30.0	3065.0	3035.0
35S	34N	945	5420	15,770		1.6°S	11.8°N		6.9	24.5		31.4	3093.0	3061.6
36N	37S	905	1380	13,100		5.3°S	10.1°N		2.4	6.5		8.9	3146.0	3137.1
37S	36N	905	1380	13,100		5.3°S	10.1°N		3.6	9.2		12.8	3192.0	3179.2
38N	39S	1015	4370	14,010		.5°S	.7°N		2.3	15.8		18.2	3241.0	3222.8
39S	38N	1015	4370	14,010		.5°S	.7°N		5.6	7.0		12.5	3276.0	3263.5
40N	41S	1010	3540	12,990		1.3°N	2.8°S		5.1	13.5		18.6	3340.0	3321.4
41S	40N	1010	3540	12,990		1.3°N	2.8°S		6.4	24.5		31.0	3380.0	3349.0
42N	42N Rev	580	3340	16,700		.1°S	.4°N		2.1	7.8		9.9	3440	3430.1
43N	44S	1190	5750	13,870		.2°S	8.2°N		7.3	9.2		16.5	3495.0	3478.5
44N	45S	1000	3730	13,380		1.7°S	5.6°N		3.4	12.3		15.6	3561.0	3545.4

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Station	Reversed With	V_o	V_1	V_2	V_3	ϕ_1	ϕ_2	ϕ_3	z_o	z_1	z_2	$\sum z$	Station Elevation	Bedrock Elevation
45S	44N	1000	3730	13,380		1.7°S	5.6°N		6.7	14.7		21.5	3614.0	3592.5
46N	46N Rev	710	2850	13,520		2.6°N	14.8°S		2.4	14.8		17.1	3652.0	3634.9
47	DD	500	4220	14,000					3.0	7.7		10.7	3700.0	3689.3
48	0												3723.0	3723.0
49	DD	500	1170	14,000					1.7	6.1		7.8	3744.0	3736.2
50N	51S	1050	9770			.6°N			7.4			7.4	3800.0	3792.6
51S	50N	1050	9770			.6°N			7.7			7.7	3822.0	3814.3
52W	52W Rev	1160	5630	12,780		2.1°W	10.5°E		6.6	8.6		15.2	3850.0	3834.8
53N	54S	795	3690	14,700		1.6°S	8.1°N		3.4	9.8		13.2	3855.0	3841.8
54S	53N	795	3690	14,700		1.6°S	8.1°N		2.9	11.0		13.9	3865.0	3851.1
55	0												3890.0	3890.0
56													3940.0	3940.0
57N	58S	875	4250	9,690		.9°N	6.7°S		3.5	10.9		14.3	3968.0	3953.7
58N	59S	515	1480	14,490		.5°S	1.7°N		2.1	6.3		8.4	3996.0	3987.6
59N	60S	805	3810	12,390		2.8°N	10.3°S		3.5	9.0		12.5	4014.0	4001.5
60S	59N	805	3810	12,390		2.8°N	10.3°S		3.1	16.0		19.1	4005.0	3985.9
63N	64S	640	7040	23,920		.4°S	2.9°N		5.7	43.3		48.9	3045.0	2996.1
64S	63N	640	7040	23,920		.4°S	2.9°N		4.3	45.9		50.2	3075.0	3024.8
65N	66S	585	4190	14,790		.3°N	1.4°S		5.6	11.9		17.5	3103.0	3085.5
66N	67S	510	3410	15,140		0°	1.0°n		4.1	15.6		19.7	3144.0	3124.3

Station	Reversed With	V_o	V_1	V_2	V_3	ϕ_1	ϕ_2	ϕ_3	z_o	z_1	z_2	$\sum z$	Station Elevation	Bedrock Elevation
67S	66N	510	3410	15,140		0°	1.°N		3.9	16.6		20.5	3184.0	3163.5
68N	68N Rev	435	1290	10,840		3.9°N	13.6°S		2.7	6.7		9.4	3230.0	3220.6
69	0												3279.0	3279.0
70	0												3320.0	3320.0
71N	72S	610	2650	11,590		1.5°N	6.0°S		4.9	10.5		15.4	3370.0	3354.6
72S	71N	610	2650	11,590		1.5°N	6.0°S		4.0	11.8		15.9	3419.0	3403.1
73	DD	430	1350	14,000					1.7	6.2		7.9	3462.0	3454.1
74N	74N Rev	710	2970	16,470		.1°S	.5°S		4.6	8.7		13.3	3510.0	3496.7
75	0												3565.0	3565.0
76	DD	745	3340	19,500					3.3	5.6		8.6	3630.0	3621.4
77	0												3690.0	3690.0
78N	79S	575	4370	13,590		.4°S	1.4°N		3.0	6.5		9.5	3717.0	3707.5
79N	80S	640	12480			.1°N			4.9			4.9	3732.0	3727.1
80N	81S	445	1220	16,810		.2°N	.9°S		1.6	5.7		7.3	3755.0	3747.7
81S	80N	445	1220	16,810		.2°N	.9°S		1.6	7.4		8.9	3795.0	3786.1
82	0												3830.0	3830.0
83N	84S	595	1530	12,780		4.6°N	13.2°S		3.4	4.8		8.2	3855.0	3846.8
84N	85S	430	1250	23,630		1.8°S	5.2°N		1.3	9.9		11.2	3871.0	3859.8
85S	84N	430	1250	23,630		1.8°S	5.2°N		2.6	2.2		4.8	3893.0	3888.2
86	DD	570	2760	13,600					1.8	9.0		10.8	3940.0	3929.2

Station	Reversed With	V_o	V_1	V_2	V_3	ϕ_1	ϕ_2	ϕ_3	Z_o	Z_1	Z_2	$\sum Z$	Station Elevation	Bedrock Elevation
87	DD	640	2700	15,400					2.9	8.5		11.4	3990.0	3978.6
88	DD	715	13300						4.8			4.8	3992.0	3987.2
89N	90S	515	1250	13,030		6.1°N	17.6°S		2.2	6.3		8.5	3975.0	3966.5
90S	89N	515	1250	13,030		6.1°N	17.0°S		.9	6.9		7.8	3957.0	3949.2
91	0												3800.0	3800.0
92	0												3805.0	3805.0
93	0												3781.0	3781.0
94	DD	710	14,000						4.6			4.6	3789.0	3784.4
95	ED	590	1410	14,000					2.3	7.0		10.2	3794.0	3783.8
96	0												3760.0	3760.0
97E	98W	550	3510	15,510			1.5°W	10.6°E	5.6	12.7		18.3	3735.0	3716.7
98E	99W	630	1680	15,670			3.7°E	9.1°W	2.2	14.3		16.6	3710.0	3693.4
99E	100W	640	4380	14,680			.9°E	11.6°W	4.2	23.1		27.3	3691.0	3663.7
100E	100E Rev	605	3310	15,870			.8°W	2.8°E	3.7	20.0		23.7	3675.0	3651.3
101	DD	630	14,000						4.4			4.4	3670.0	3645.6
117	0												3662.0	3662.0
103	DD	720	14,000						4.8			4.8	3675.0	3670.2
104	0												3680.0	3680.0
105	106W	855	2840	12,400		5.3°E	15.9°E		4.0	8.6		14.6	3675.0	3660.4
106	105E	855	2840	12,400		5.3°E	15.9°E		3.7	20.5		24.2	3672.0	3647.8

Station	Reversed With	V_o	V_1	V_2	V_3	ϕ_1	ϕ_2	ϕ_3	Z_o	Z_1	Z_2	$\sum Z$	Station Elevation	Bedrock Elevation
106	105E	855	2840	12,400		5.3°E	15.9°E		3.7	20.5		24.2	3672.0	3647.8
107	DD	670	14,000						4.4			4.4	3683.0	3678.6
47	DD	500	4,220	14,000					3.0	7.7	10.7		3700.0	3689.3
109	0												3710.0	3710.0
110	0												3702.0	3702.0
111	DD	500	14,000						4.0			4.0	3685.0	3681.0
112	DD	560	10,200						4.5			4.5	3690.0	3685.5
77	0												3690.0	3690.0
114	0												3680.0	3680.0
115E	116W	610	3,460	18,430			.3°E	1.0°W	3.6	8.3		11.9	3660.0	3648.1
116W	115E	610	3,460	18,430			.3°E	1.0°W	2.4	20.2		22.6	3640.0	1617.4
117	0												3615.0	3615.0
118E	119W	565	3,620	17,670			1.7°E	11.0°W	3.1	20.3		23.4	3600.0	3576.6
119E	120W	500	1,350	14,650			4.0°W	12.2°E	1.5	8.8		10.3	3580.0	3569.7
120W	119E	500	1,350	14,650			4.0°W	12.2°E	2.3	7.8		9.9	3570.0	3560.1
121	DD	500	1,240	20,000					1.6	4.0		5.6	3478.0	3472.4
122	0												3540.0	3540.0
123	0												3595.0	3595.0
124	DD	540	1,100	20,000					1.0	6.3		7.3	3620.0	3612.2
125	DD	630	20,300						3.6			3.6	3610.0	3606.4
126	DD	470	13,700						3.0			3.0	3575.0	3572.0

Station	Reversed With	V_o	V_1	V_2	V_3	ϕ_1	ϕ_2	ϕ_3	Z_o	Z_1	Z_2	$\sum Z$	Station Elevation	Bedrock Elevation
127	DD	555	9,500						2.3			2.3	3535.0	3532.7
128	0												3485.0	3485.0
129	0												3439.0	3439.0
130	0	500	1,320	12,900					1.7	6.4		8.1	3400.0	3391.9
131	0												3415.0	3415.0
12	0	490	1,430	15,100					1.8	3.9		5.7	3430.0	3424.3
133E	134W	555	2,640	11,320		1.7°W	11.3°E		1.5	14.0		15.4	3447.0	3431.6
134W	133E	555	2,640	11,320		1.7°W	11.3°E		3.5	11.0		14.5	3438.0	3423.5
135	DD	670	13,400						6,6			6.6	3420.0	3413.4
136	DD	745	9,750						5.1			5.1	3423.0	3417.9
137	0												3430.0	3430.0
42	139W	620	4,180	10,200		1.1°W	7.5°E		3.0	13.7		16.6	3440.0	3423.4
139E	140W	565	3,250	12,210		1.2°W	9.6°E		2.9	14.1		17.0	3430.0	3413.0
140E	141W	895	2,920	11,720		.9°E	.1°W		3.1	6.4		9.5	3425.0	3415.5
141W	140E	895	2,940	11,720		.9°E	.1°W		4.1	5.6		9.7	3425.0	3415.3
142	DD	545	1,050	15,500					1.0	8.8		9.8	3425.0	3415.2
72S	71N	610	2,650	11,590		1.5°N	6.0°S		4.0	11.8		15.9	3418.0	3403.1
144	DD	730	10,600						6.9			6.9	3413.0	3406.1
145E	146W	520	10,910			.6°W			4.8			4.8	3402.0	3397.2

Station	Reversed With	V_o	V_1	V_2	V_3	ϕ_1	ϕ_2	ϕ_3	Z_o	Z_1	Z_2	$\sum Z$	Station Elevation	Bedrock Elevation
146	145E	520	10,910			.6°W			5.4			5.4	3395.0	3389.6
147	DD	690	10,500						6.4			6.4	3422.0	3415.6
148	0												3425.0	3425.0
149	DD	1460	9,500						9.0			9.0	3423.0	3414.0
150	DD	715	10,300						4.8			4.8	3418.0	3413.2

DD - Single ended profile, less than 50 teet long, not always at station.