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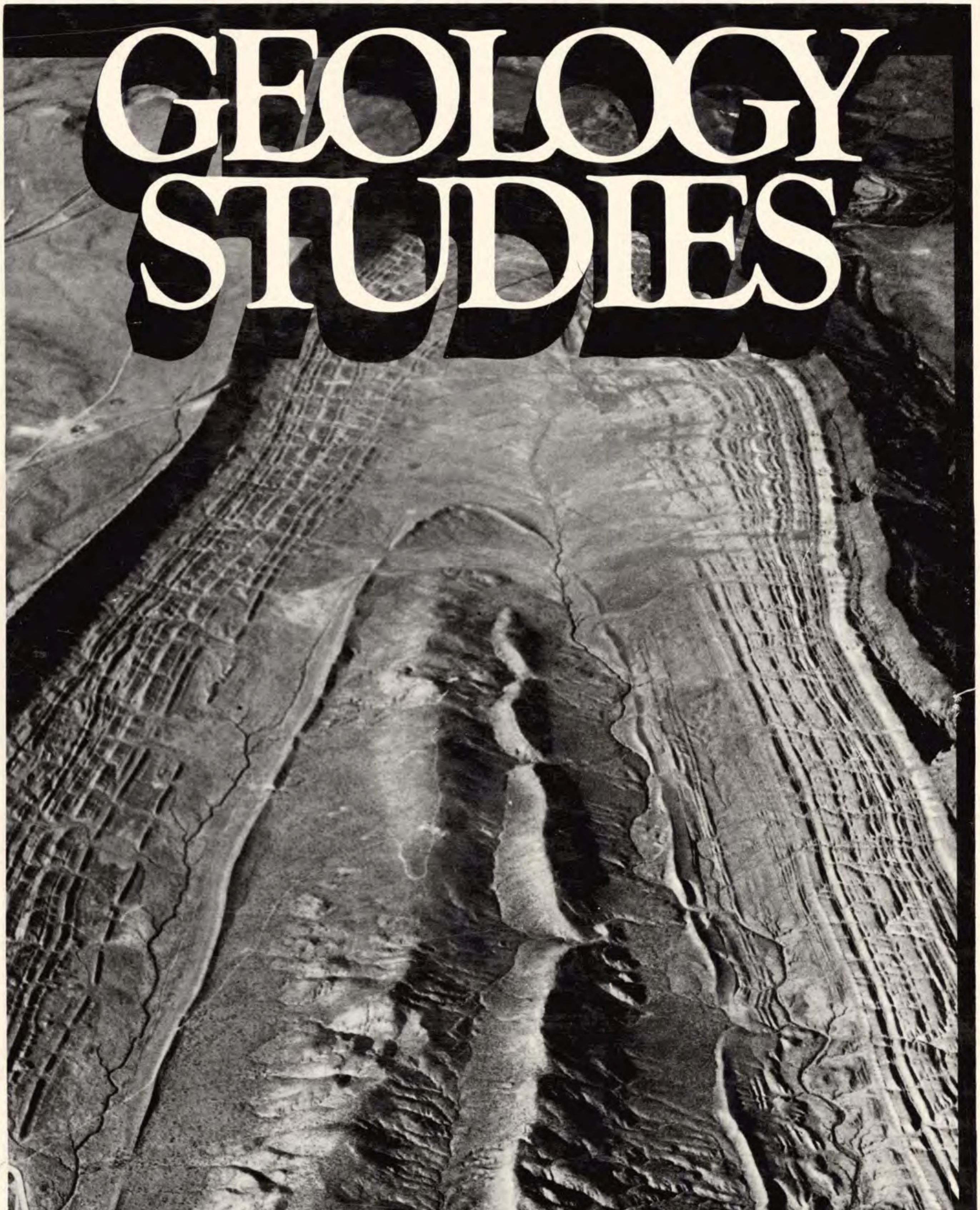

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CONTENTS

THE GLORY OF GOD IS INTELLIGENCE

Cover: *Virgin anticline near St. George, Washington County, Utah.*

Biogeochemical Exploration for Cu, Pb, and Zn Mineral Deposits, Using Juniper and Sagebrush, Dugway Range, Utah*

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ABSTRACT.—Sagebrush leaves and stems and juniper needles carry anomalous concentrations of Cu, Pb, and Zn near shallow mineral deposits of the same elements in the Dugway Range, Utah. Sagebrush stems carry larger concentrations than do sagebrush leaves or juniper needles.

Sampling of sagebrush offers some advantages over sampling of soils because sagebrush roots extend to depths of as much as 60 feet and draw nutrients from a relatively large volume of soil. Moreover, sagebrush and, to some extent, junipers are widely distributed in the arid west.

The technique can be of great value in delineating hidden ore bodies when the alteration halo from the mineralization is within reach of the roots and may be an effective adjunct to other methods of reconnaissance exploration.

INTRODUCTION

Biogeochemical exploration relies on chemical analysis of plants to reveal possible mineralization in the substrate. Previous research provides conclusive evidence that plants can concentrate heavy metals from soil and underlying bedrock (Hawkes 1957; Hemphill 1972). When plant roots reach a mineralizing halo, higher than normal concentrations of the mineralizing elements may be absorbed, and analysis of the plant for those elements may reveal anomalous concentrations in the substrate.

Analysis of plants for metal content offers some possible advantage over analysis of soil or bedrock because plant roots may tap mineralization at depth; for example, juniper roots reach depths of 200 feet, and sagebrush roots reach depths of 60 feet. The roots also penetrate relatively large volumes of substrate, thus providing more representative samples. Another advantage is that sampling of vegetation is effective where soils are thin or absent, as they are in much of the arid west.

Sagebrush and, to some extent, junipers are widely distributed in the arid west, where many mineral deposits occur. The purpose of this investigation is to evaluate, in a preliminary way, the value of these plants as concentrators of copper (Cu), lead (Pb), or zinc (Zn) in the vicinity of known ore deposits and to demonstrate the usefulness of the plants in locating shallow, covered deposits of these minerals.

Scope of Study

The study has three major objectives: (1) to demonstrate the effectiveness of biogeochemical exploration with sagebrush and junipers in western Utah; (2) to conduct an orientation (preliminary) survey to determine the most effective and efficient procedures for sampling in the field and for analysis in the laboratory; (3) to conduct an extended study based on the outcome of the orientation survey.

Geologic Setting

The Dugway Range is a northwest trending mountain range located in western Utah between the Thomas Range and Dugway Proving Grounds (fig. 1). The exposed formations range in age from lower Cambrian (Prospect Mountain Quartzite) to upper Mississippian (Ochre Mountain Limestone).

The Dugway Range was formed by four major geologic events (Staatz and Carr 1964): (1) compressional forces causing thrust faulting during mid-Cretaceous time, (2) early Miocene transverse and strike faults, (3) post-late Miocene basin-and-range faulting which raised the mountains and tilted them to the west, and (4) volcanic eruptions from late Miocene through Pliocene.

Ore Occurrence and Controls

The ore bodies of the Dugway Range may be classified in two main groups: (1) fissure veins in quartzite, and (2) fissure veins and replacement deposits in dolomite.

About one-third of the deposits in the Dugway Range are fissure veins in quartzite, contain mainly lead-silver ore, and range in thickness from a few inches to ten feet. Most of them occur along faults striking north to northeast and dipping steeply to the east (Staatz and Carr 1964).

The deposits in dolomite contain mainly lead, zinc, copper, and silver and range in thickness from a few inches

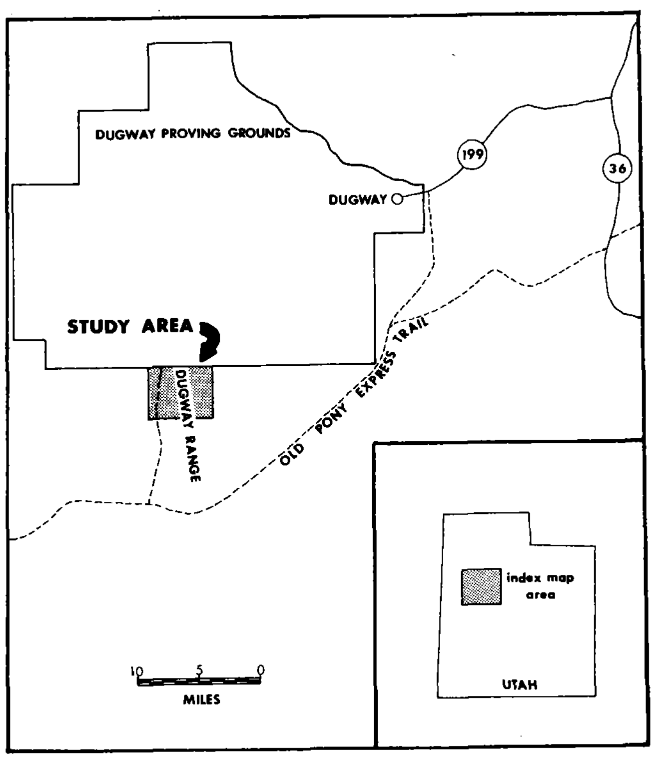

FIGURE 1.—Index map to study area.

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science August 1975: Willis H. Brimhall, thesis chairman.

to over thirty feet. They occur along northwest and northeast trending high-angle faults, some of which are in close proximity to the Buckhorn Thrust fault. Mineralization in limestone is commonly associated with dolomitization, silicification, or bleaching of the dark-colored carbonate rocks. It is believed that this alteration was caused by a preliminary barren surge of hydrothermal fluids (Staatz and Carr 1964).

Vegetation

The vegetation of the Dugway Range is typical of that found in most of western Utah, so information obtained in this study would apply to many other areas. The three species studied under this thesis were (1) juniper tree (*Juniperus osteospermada*), (2) big sagebrush (*Artemisia tridentata*), and (3) black sagebrush (*Artemisia nova*), As will be noted later, big sagebrush and black sagebrush contain the same background trace-element concentrations (no statistical difference was found), so the two species were treated as one.

Other types of vegetation indigenous to the area*, such as shadscale (*Atriplex confertifolia*), Brigham's tea (*Ephedra nevadensis*), rabbit brush (*Chrysothamnus sp.*), horse brush (*Tetradymia glabrata*), and various grasses were not included in this study because of difficulty of identification or because of lack of widely distributed population.

Acknowledgments

Willis H. Brimhall, my thesis chairman, provided direction and assistance throughout the study. His critical analysis and words of encouragement are appreciated. Kenneth C. Bullock had done research on Dugway Range ore deposits, and his suggestion that the area might work well for this thesis project was invaluable. Floyd Cannon, owner of much of the land included in this study, gave his consent to the project. He and his son, Douglas, provided helpful information concerning the mining and exploration history of the district. Their help was appreciated. I am most grateful to my wife, Patricia, for her patience, her encouragement, and the personal sacrifices she willingly made to facilitate the completion of this project.

ORIENTATION SURVEY

Purpose

The orientation survey, or preliminary assessment, consisted of a sampling and analysis program which served to (1) detect and limit the variables which most affect results, (2) determine the most effective sampling methods, (3) provide the necessary background information needed to carry out a substantial biogeochemical exploration project.

Procedure

Prior to sampling, extensive library research helped to define procedures to be used in selecting targets for sampling and analysis. Orientation surveys conducted by workers revealed some important variables which could be used in this research project. Some of the most important were (1) different plant species concentrate varying amounts of trace elements (Awad 1963); (2) differing organs of the same species concentrate varying amounts of trace elements; for general base metal prospecting, leaves and needles are most effective (Botova 1963, Poskotin 1963); (3) any one organ of a single species will carry differing amounts of a given trace element at different seasons of the year (Cannon, Papp, & Anderson 1972); (4) the same organ of a single species may concentrate an element differently at varying heights above the ground (Brooks 1972); (5) Eh, pH, exchange capacity, complexing agents, clay fraction, interelement interactions, age of plant organ, temperature, and precipitation all influence the absorption of trace elements in plants (Horvath 1972, Hawkes 1957); (6) plants are able to restrict uptake of some elements (Malyuga 1964); (7) plants attempt to maintain constant concentrations of essential elements such as Cu, Zn, and Mo. Pb, a typical nonessential element, is not so controlled (Timperley, Brooks, & Peterson 1970); and (8) some elements, such as Fe:Mn, Zn:Cu, and P:Zn and Cu, are competitive. An increase of one element in a plant results in a decrease of its competitor element (Hemphill 1972, Timperley, Brooks, & Peterson 1970).

After the above variables were considered, known shallow ore bodies of the Dugway Range were examined for suitability as targets for study. Among the factors considered in selecting the targets were (1) contamination (roadways, dumps, or other mining activities which disrupt the surface and may influence trace-element content of plants); (2) rock type (it was necessary to determine whether this type of exploration would be effective over both quartzite and carbonate terrain); and (3) special controls such as faulting, alteration, etc.

The Four Metals, Lauris, and Bertha deposits were chosen for preliminary sampling and analysis because they represented three different environments of mineral deposition and because sagebrush and juniper were distributed on and around these deposits in a manner typical of the region. The Four Metals is situated in dolomitized, bleached, and silicified limestone. The Bertha is in sugary-textured, dolomitized rocks. The Lauris is within the generally homogeneous Prospect Mountain quartzite (fig. 2).

Short traverses were made over these ore bodies so they would cross the mineralized zones but remain a safe distance from obvious contaminating influences such as dumps, haulage paths, adits, and shafts.

In all three areas, juniper needles, sagebrush leaves and stems, and soil were collected from each sample site and analyzed by atomic absorption spectrophotometry for Cu, Pb, and Zn. Care was taken to sample the plants and soil in the same manner at each site to avoid unnecessary variations in the results. The preliminary sampling established basic data on (1) trends of elemental background concentrations, (2) which sample type (leaves, needles, stems, or soil) and elements best reflect the ore body, and (3) the most simple, effective method of sample collection and preparation.

Vegetation Sampling.—Juniper needles were collected 4 feet above the ground from the entire circumference of the tree. The needles (about 100 gms) were placed in a paper bag and labeled.

Sagebrush samples were collected by clipping small branches, including the leaves, from one or more bushes

*Personal communication, Stanley Welsh, BYU Botany Department.

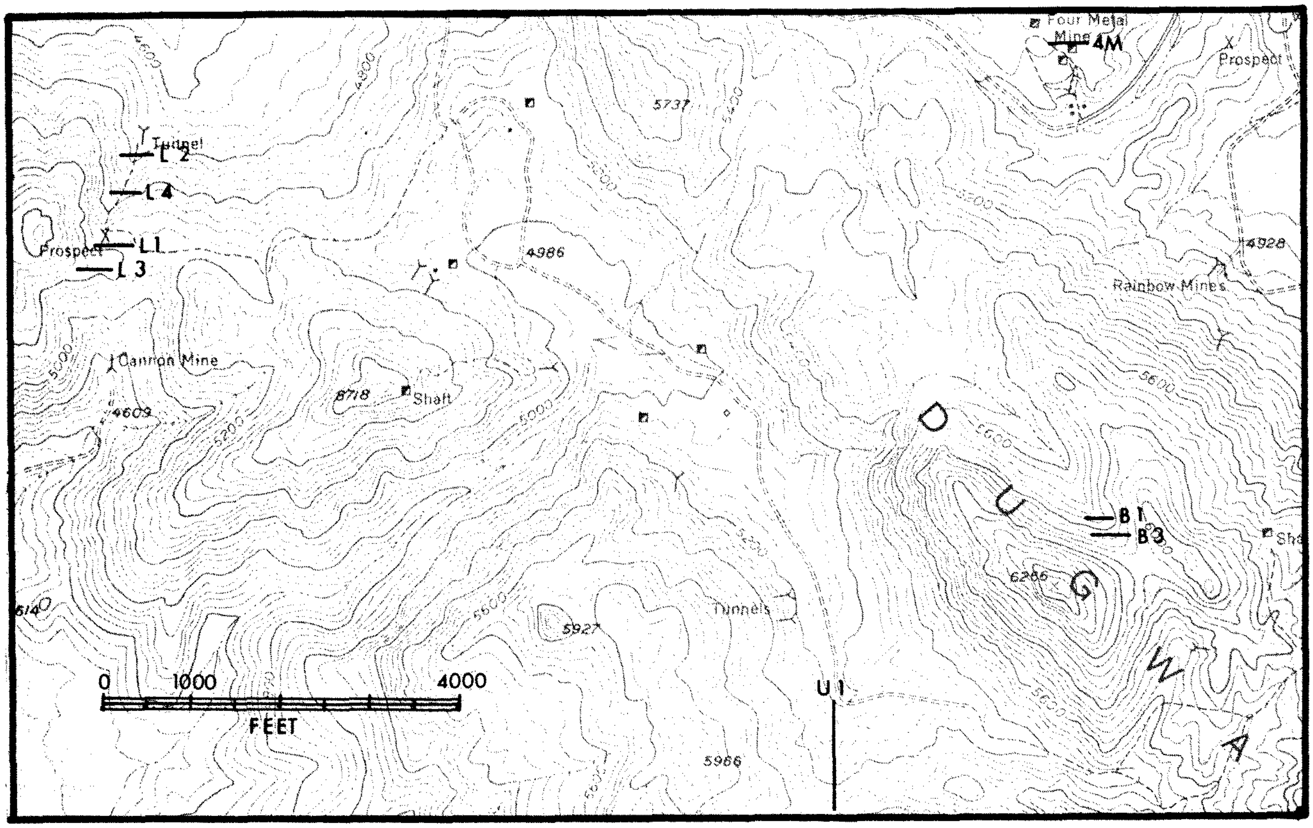

FIGURE 2.—Traverse index map.

at each sample site. A piece of labeled flagging tape was tied to a bush at the sample site to identify the exact location from which the specimen was taken.

Soil Sampling.—The soil on the Dugway Range is classified as juvenile mountain soil (Andrews-Jones 1968). The brown zone of accumulation (illuviation) was, in all areas, within 1 or 2 inches of the surface, with little or no organic debris covering it.

Soil samples were collected from points surrounding the sampled bush. In most cases, three holes were dug about 5 feet apart, with the sample bush located in the center of the triangle. The holes were made 2 to 6 inches deep, and about 500 grams of the soil were collected.

Sample Preparation

Vegetation.—Dried vegetation was placed in heavy aluminum foil and heated over a propane burner until it ignited and burned. The ash was then placed in porcelain dishes and left in a 750° C muffle furnace until no embers remained. After it was cooled to room temperature, 0.250 mg of white ash was weighted into a 100-ml beaker and digested with 10 ml concentrated HNO_3. The resulting solution was transferred to a 50-ml volumetric flask and diluted to volume with distilled water. The solution was filtered through rapid, high wet strength, lintless filter paper to remove traces of insoluble matter.

The solution was then ready for analysis by atomic absorption spectrophotometry.

Soil.—Soil samples were prepared and analyzed so the results could be compared with those of the vegetation. Five grams of soil which could pass through an 80-mesh screen were placed in a 250-ml beaker.

Then 25 ml aqua regia (3 HCl: 1 HNO_3) was added, and the solution was heated until almost dry. The sample was then placed in a 250-ml volumetric flask and brought to volume with 2M HCl. The solution was filtered and placed in a properly marked bottle. The residue was discarded.

Precision.—The precision of the laboratory procedure was determined by preparing six replicate samples of each of the sample groups (sagebrush, juniper, and soil) and by calculating the standard deviation of Cu, Pb, and Zn concentrations in each group. The samples were prepared by first forming a composite pile for each sample group, then by separating each pile into six replicate samples; the sampled were then analyzed in the usual manner.

The replicate sample standard deviations of concentrations in sagebrush, juniper and soil, respectively, were (1) Cu: 1.12, .85, and .85 ppm; (2) Pb: 5.75, 6.81, and 7.84 ppm; (3) Zn: .45, .60, and .95 ppm. In general, even in nonmineralized areas, the standard deviations in field samples were at least ten times as high as those associated with laboratory procedures.

Since the standard deviations of elemental concentrations in replicate samples are so much smaller than those of field samples, it is concluded that the variations determined from the field analyses are real.

Results of Orientation Survey

Timperley, Brooks, and Peterson (1970) reported Zn and Cu to be essential to the nutrition of many plants. Because they are essential, plants attempt to maintain a constant concentration of these elements even though soil concentrations vary. When plotted on a graph as plant ppm/soil ppm on the vertical axis, and soil ppm on the horizontal axis, a rectangular hyperbola is produced (fig. 3). Timperley, Brooks, and Peterson (1970) suggested that biogeochemical exploration for Zn and Cu would be ineffective unless the soil concentration *exceeded* the point at which the graph referred to above begins to show a linear trend parallel to the X axis.

The above information led this author to believe Zn and Cu would not be useful in this study, but that vegetation would concentrate anomalous amounts of Pb over the ore bodies. However, results in this study indicate otherwise.

Whereas Zn and Cu consistently produced highly anomalous concentrations in vegetation over the ore bodies, Pb concentrations were sometimes no higher over an ore body than over barren ground. The anomalous concentrations of Zn and Cu must have been obtained because the soil concentrations of these elements were to the right of the curved portion of the essential element diagram used by Timperley, Brooks, and Peterson (1970).

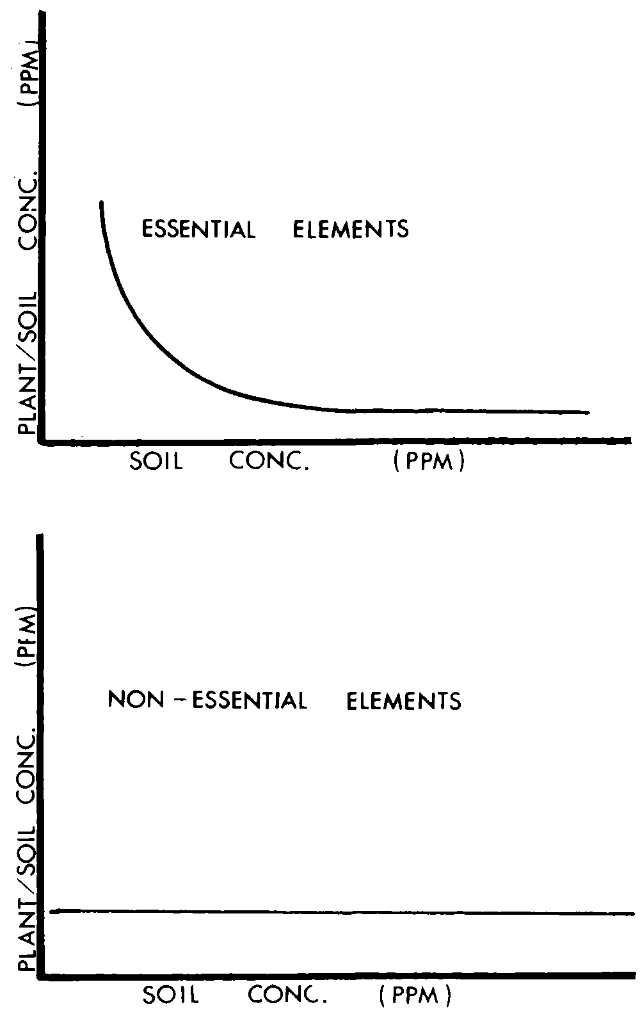

FIGURE 3.—Essential element diagram which shows how plants respond to essential and nonessential elements in the soil (Timperley et al. 1970).

Additional library research indicated that Pb is concentrated erratically in leaves and needles of some plants because the young growing organs draw essential elements from the stems and branches, leaving nonessential elements behind. The stems in those same plants revealed anomalous high concentrations of Pb over mineralized substrate (Brooks 1972, Cannon 1972). Though sagebrush was not mentioned as having this characteristic, the present writer decided that this hypothesis should be tested on the materials at hand.

After processing sagebrush leaves, the writer collected stems from plants at previous sample locations. After the stems were processed, it was found that they also concentrated anomalous amounts of Pb over mineralized substrate and, in some cases, contained more accentuated anomalous cone of Pb than did leaves (figs. 5 and 6). Though Cu and Zn were also highly concentrated in the stems over ore bodies, the anomalous concentrations of these two elements were more accentuated in the leaves.

All the analyses were carried out on the atomic absorption spectrophotometer. The elemental content of the ash is expressed in parts per million (ppm). Results are depicted graphically in figures 4-9.

A discussion of each of the three areas sampled will help the reader more fully understand the biogeochemical results.

Lauris Vein.—1. The Lauris vein, located on the Louis, Brian, and Harding claims, was picked as a target of study because (1) it is located entirely in Prospect Mountain quartzite, a rock body nearly homogeneous in texture and composition; (2) it is covered by about 20 feet of sediment over the upper adit (sampling vegetation and soil over this ore body would help determine how effectively sagebrush concentrates trace elements over mineralized rock at these depths); and (3) no contamination from dumps was apparent.

This fissure-fill vein is located on the northwest side of the Dugway Range along a high-angle normal fault. Erosion has proceeded more rapidly along the vein, and the resulting gully makes it easy to follow the fault trace.

The Lauris vein produced mainly fluorite and some Pb-Ag ore. Malachite and azurite can also be seen in many fractures in the quartzite. Two adits are located along the northern half of the vein. Since the upper adit produced the most ore and was above any other contaminating sources, the first traverse was sampled over the vein 150 feet south of the adit entrance. It is labeled L-1 in figures 2 and 10.

No junipers occur in the vicinity of the Lauris vein, so sagebrush and soil were sampled. Anomalous concentrations occurred in both soil and sagebrush at the second and third sample sites (fig. 5).

The Lauris vein is covered with a 20-foot layer of well-sorted colluvial gravels which settled in the wash.

Because of the masking effect of the overburden, concentrations of Cu and Zn in the soil were low. Cu concentrations were very low (less than 20 ppm), and Zn content was only 105 ppm, just 35 ppm over the threshold value* needed to indicate an anomaly. However, Pb concentrations in the soil were as high as 345 ppm, a surprising 265 ppm over the 80 ppm needed to indicate an anomaly.

Sagebrush, on the other hand, contained highly anomalous concentrations of Cu, Pb, and Zn over the vein (fig. 4). For example, mean Zn background was 287 ppm with a standard deviation of 57.3 ppm, and the peak Zn content was 545 ppm near the ore body; the high Cu concentration was 155 ppm, compared to a mean of 109 ppm and a standard deviation of 6 ppm.

The anomalous concentrations in the vegetation over the covered ore body are attributed to the fact that sagebrush roots reach depths of 60 feet (Brooks 1972), more than enough for the roots to penetrate the ore body below.

Four Metals Mine.—2. The Four Metals Mine is located in the north central portion of the Dugway Range about

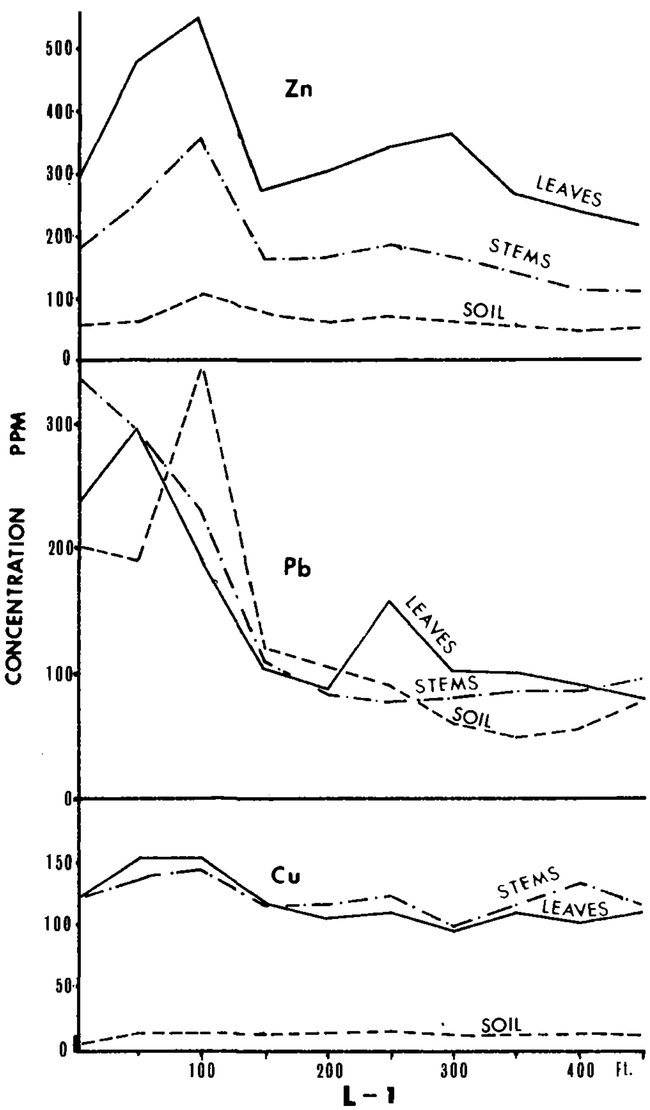

FIGURE 4.—Scan sheet of L-1 traverse.

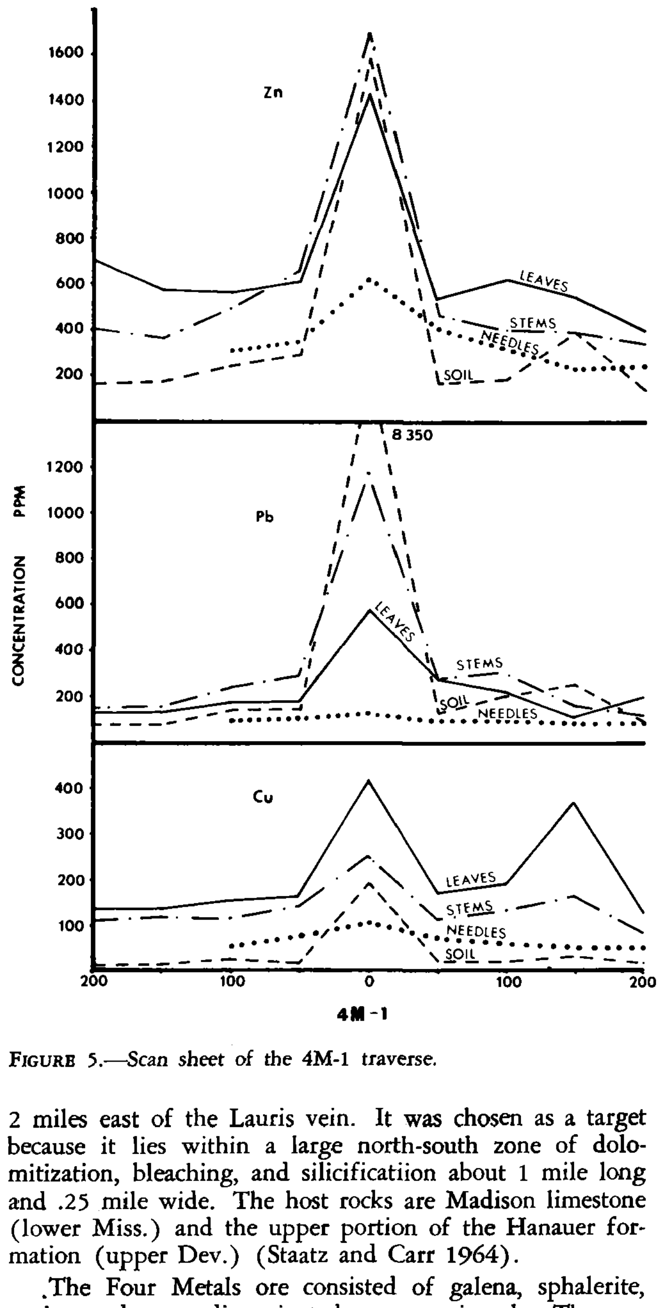

FIGURE 5.—Scan sheet of the 4M-1 traverse.

2 miles east of the Lauris vein. It was chosen as a target because it lies within a large north-south zone of dolomitization, bleaching, and silicificatiion about 1 mile long and .25 mile wide. The host rocks are Madison limestone (lower Miss.) and the upper portion of the Hanauer formation (upper Dev.) (Staatz and Carr 1964).

The Four Metals ore consisted of galena, sphalerite, pyrite, and some disseminated copper minerals. The ore, having a ratio of 2 Zn: 1 Pb, occurred as replacement and fissure fill trending N 9′ W.

A traverse (fig. 11) was plotted in an east-west direction beginning at a shaft at the north end of the workings because open trenches and dumps have contaminated areas to the south. At each sample site (50-foot intervals) sagebrush leaves, sagebrush stems, juniper needles, and soil were collected. Soil and vegetation contained anomalous concentrations of Zn, Pb, and Cu over the vein (fig. 5), but the anomalous concentrations could also be explained by possible surface contamination by mining activity.

*Threshold value is a number which, if exceeded, indicates the presence of abnormally high concentrations of the element being sought. The author calculated this value by adding one standard deviation (of a given sample type and traverse) to the mean concentration of the element under consideration.

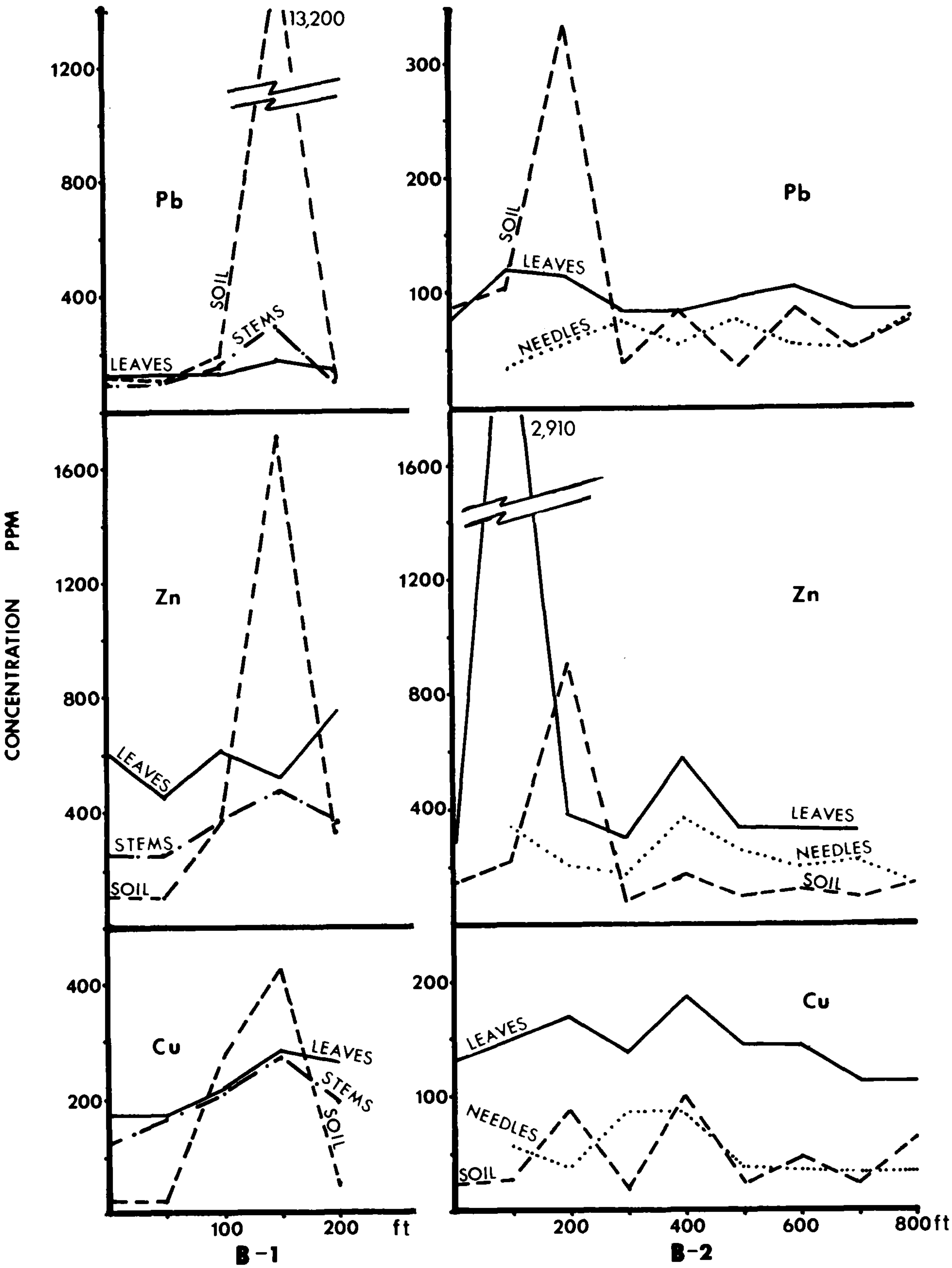

FIGURE 6.—Scan sheet of the B-1 and B-2 traverses.

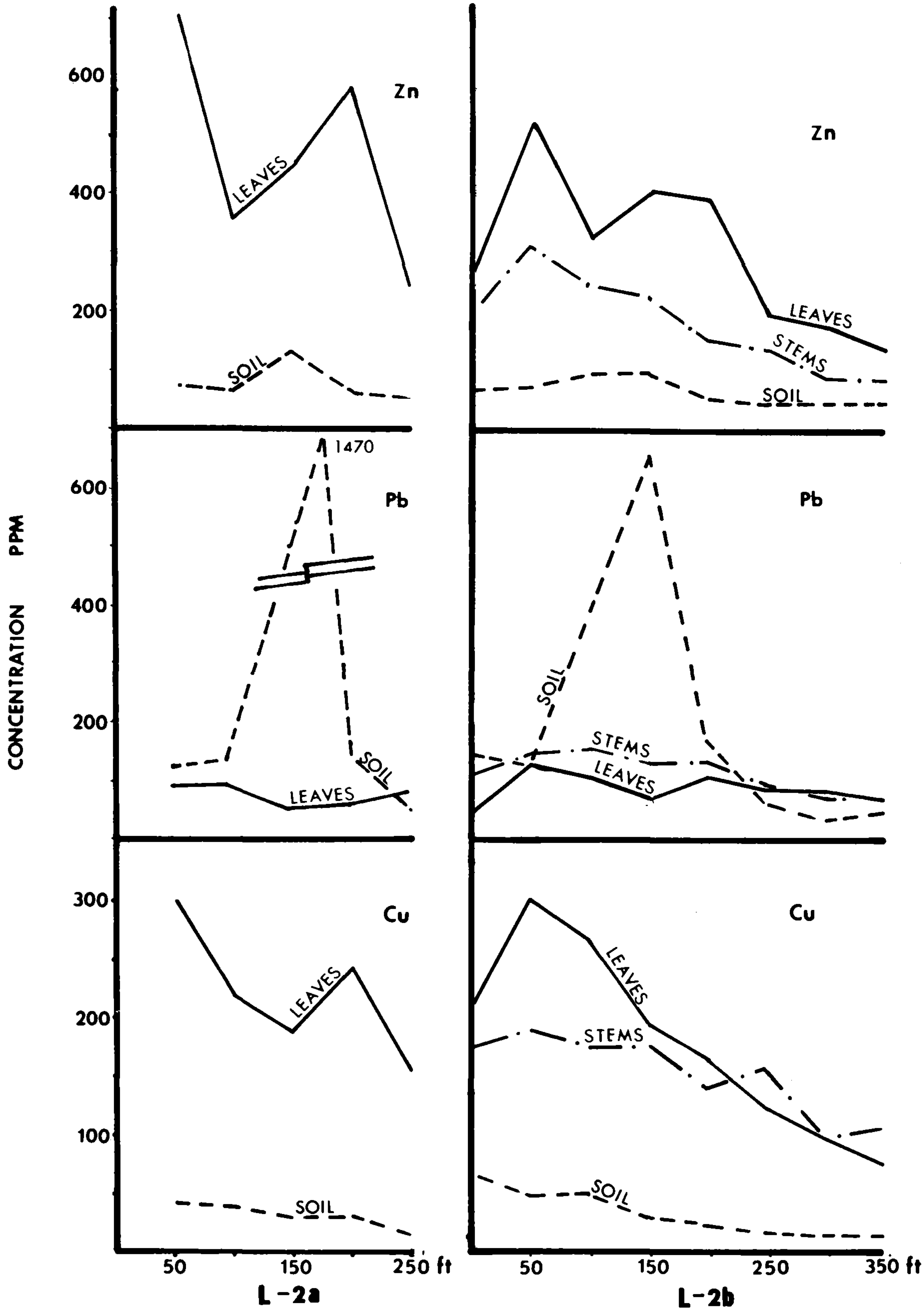

FIGURE 7.—Scan sheet of the L-2a and L-2b traverses.

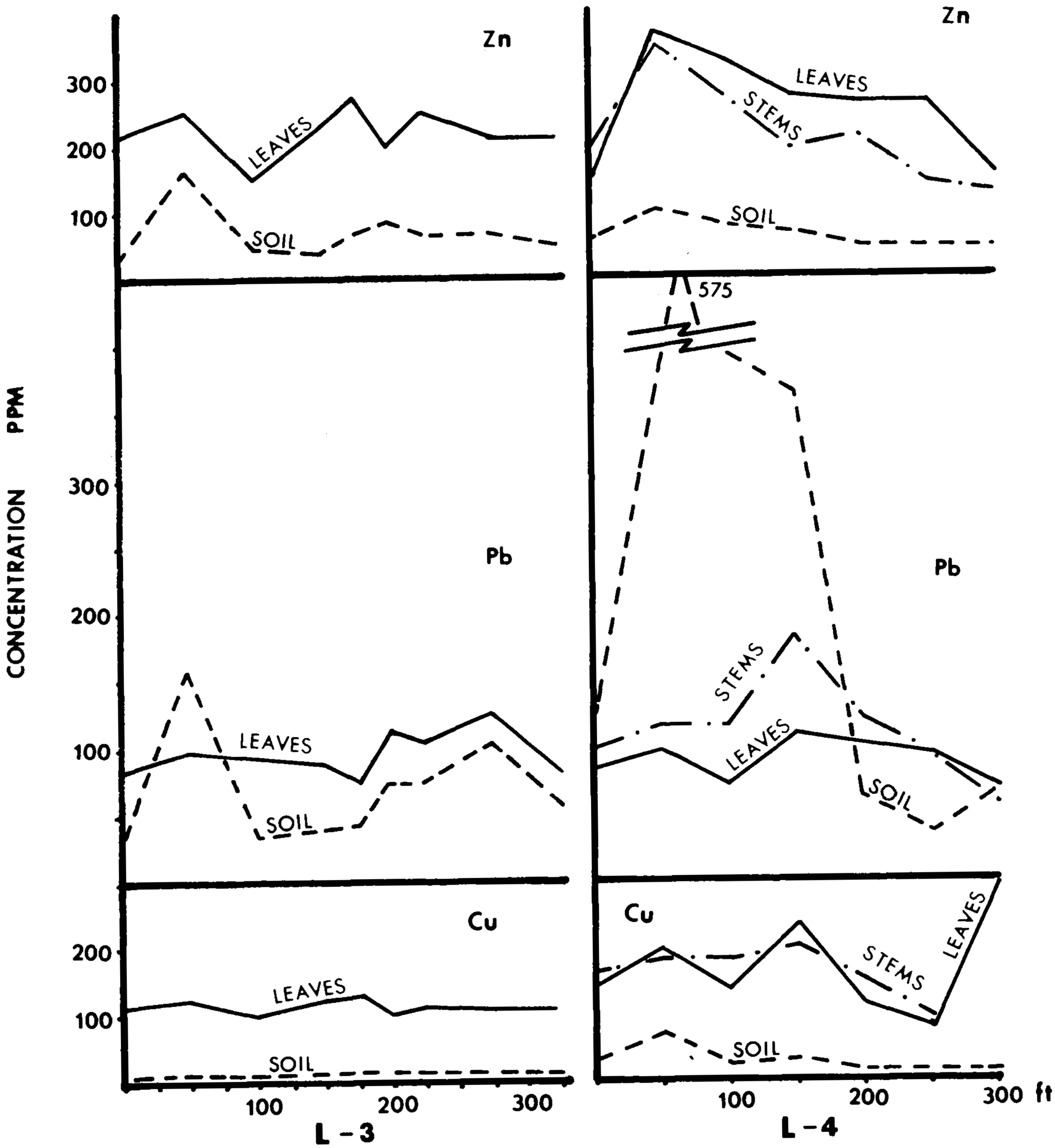

FIGURE 8.—Scan sheet of the L-3 and L-4 traverses.

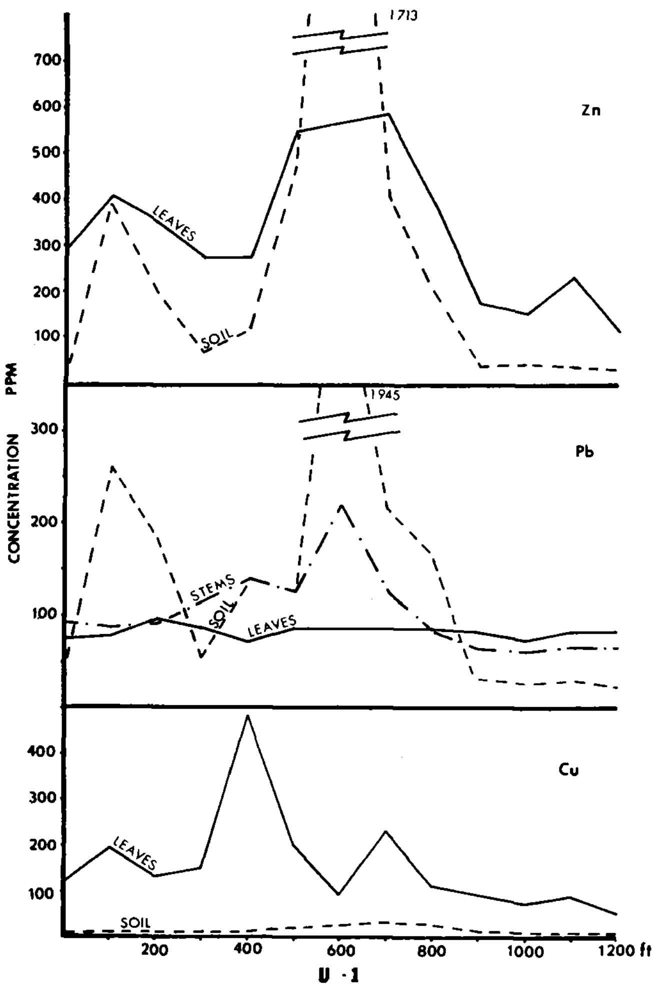

FIGURE 9.—Scan sheet of the U-1 traverse.

Bertha Mine.—3. The Bertha Mine was selected as another target in carbonate rocks because the alteration was much more subtle (dolomitization only) than that of the Four Metals Mine. Less chance of contamination is present in this locality than in the previous one.

The Bertha Mine is located 1 mile south of the Four Metals Mine in the southern end of the Bertha graben (fig. 2). The host rock is a dolomite of unknown age, bounded on the east and west by upfaulted Prospect Mountain Quartzite. The dolomitized rock is one of the formations between the Ochre Mountain Limestone (Miss.) and the poor exposures. Normal contacts between this dolomite and the two formations just mentioned cannot be seen within this graben (Staatz and Carr 1964).

Pyritic copper ore with minor Pb and Zn occurs as replacement along fractures in the dolomite. The ore trend is approximately parallel to the normal faults on the east and west which form the graben. The graben pinches out about 800 feet south of the Bertha shaft.

The first traverse over the Bertha vein was plotted in an east-west direction, coming no closer than 30 feet south of the shaft to avoid contamination from the shaft and an adit dump north of the shaft (there was visible contamination 5 feet south of the shaft). This traverse is labeled

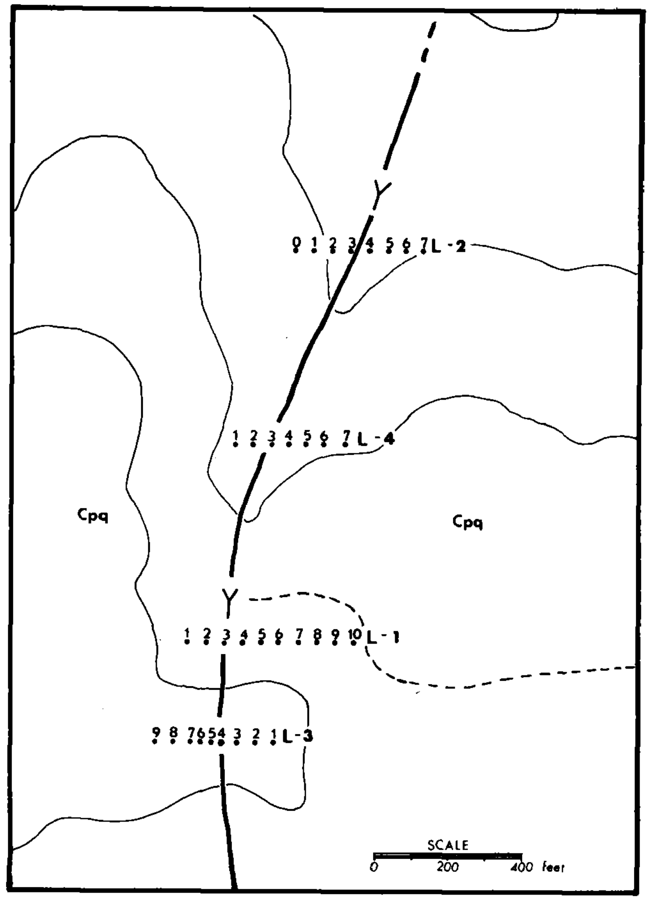

FIGURE 10.—Sampling index map of traverses over the Lauris vein.

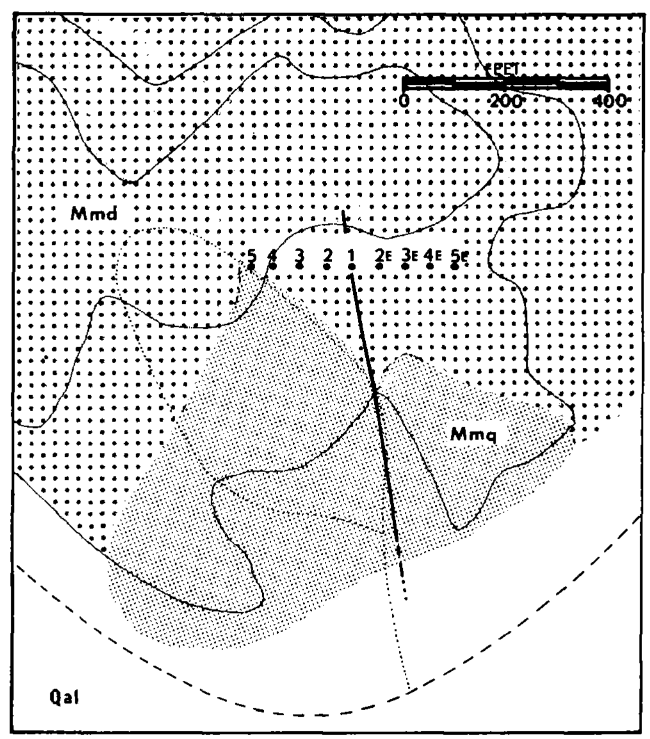

FIGURE 11.—Sampling index map of 4M-1 traverse.

B-1 in figures 2, 6, and 12. Though no evidence of the vein could be seen south of the shaft, it was projected to intercept the traverse near sample number 4.

Both juniper and sagebrush were fairly abundant in the Bertha Mine vicinity; so both were sampled, and the results were plotted on the scan sheet.

All results showed positive anomalies over the vein, except for Zn, which decreased in leaves and needles. It is not known why this drop occurred, but the mineralization below was still evidenced by anomalous concentrations of the two major ore elements Cu and Pb. Sagebrush stems contained anomalous concentrations of all three elements over the ore bodies.

The exceptionally high soil trace-element concentrations indicate the probability that mineralization is near the surface here even though it cannot be seen. For example, in soil sampled along the B-1 traverse, Pb content was 92.3 ppm, and the standard deviation was 27.8 ppm; therefore, values over 120.2 ppm could be considered anomalous. Soil sample 4 contained 13,200 ppm Pb (fig. 6).

Statistical Analysis

Mean concentrations, standard deviations, and Student's t tests* were all used to give additional insight to the information obtained. Table 1 lists all traverses and their associated means and standard deviations for each element and sample type. Some standard deviations and means have already been mentioned under the orientation survey areas.

Mean concentrations were computed to show the average background trace-element concentrations for each traverse. These background counts were computed separately for each element, sample type, and traverse (i.e., mean concentration of Pb in sagebrush leaves along traverse X). Samples collected within 50 feet of known or implied mineralization were not used in computing mean background concentrations. However, since the traverses were plotted to cover mineralized areas, the recorded mean concentrations are probably higher than the mean concentrations would be over totally nonmineralized areas.

Standard deviation measures the dispersion of values about the mean of a population. For this study, addition of the standard deviation to the mean concentration provides a threshold value beyond which the existence of an anomaly is inferred.

The Student's t test was used to answer the following two questions: (1) Do big sagebrush and black sagebrush contain significantly different background concentrations of trace elements being analyzed? (2) Do significant differences exist between elemental background concentrations in quartzite and those in dolomite?

These two problems will be discussed briefly.

Black Sagebrush vs. Big Sagebrush.—Even though anomalous concentrations were easily detectable over some traverses which contained both species of sagebrush (figs. 6 and 9), the question remained as to whether or not these anomalous concentrations were real. The Student's t test was conducted to check for significant differences in background concentrations for the two species.

After samples were taken from four traverses over the quartzite in the vicinity of the Lauris vein, L-4 (totally big sagebrush) and L-3 (totally black sagebrush) were compared using the steps and equations in table 3. The two species of sagebrush were found to have no significant difference in elemental background concentrations at the 95 percent confidence level (table 2). In fact, sagebrush values were in closer agreement than those of soil, as indicated by the Student's t values of 1.30 for soil and –.65 for sagebrush (a closer agreement between populations is inferred as the Student's t values approach 0).

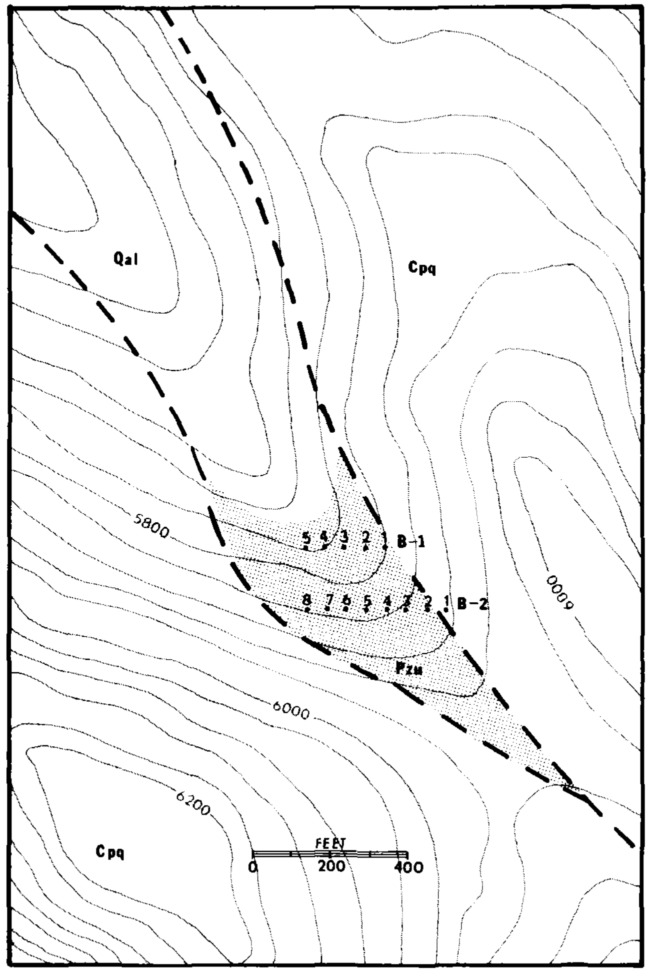

FIGURE 12.—Sampling index map of the B-1 and B-2 traverses.

Dolomite vs. Quartzite.—One might anticipate that soil samples taken from two different lithologies would yield different concentrations of Pb, Zn, and Cu. In an effort to verify this difference, the Student's t test was used for traverse L-3 over quartzite and traverse B-1 over dolomite.

Soil samples taken from the two lithologies contained a significant difference (at the 95 percent confidence level) in elemental background trends; and the difference was even more obvious in sagebrush samples (table 2). The soil values produced Student's t values of 8.1 and 13.5.

These results indicate that quartzite and dolomite do contain significant differences in background elemental concentrations reflected by overlying vegetation and soil.

*The Student's t test is used to compare two statistical populations to determine whether a significant difference exists.

TABLE 1
TRAVERSES WITH ASSOCIATED MEANS AND STANDARD DEVIATIONS FOR EACH ELEMENT AND SAMPLE TYPE*

Sample	Mean	Std. Dev.
L-1 Pb leaves	99.74	25.42
L-1 Zn leaves	287.29	57.25
L-1 Cu leaves	108.93	6.27
L-1 Pb soil	63.27	16.09
L-1 Zn soil	60.87	8.86
L-1 Cu soil	14.00	2.22
L-1 Pb stems	84.17	5.78
L-2 Pb leaves	75.60	14.86
L-2 Zn leaves	221.10	78.63
L-2 Cu leaves	143.58	52.10
L-2 Pb soil	100.97	56.91
L-2 Zn soil	54.72	13.30
L-2 Cu soil	28.78	19.77
L-2 Pb stems	91.50	19.77
L-3 Pb leaves	88.70	8.98
L-3 Zn leaves	203.50	26.77
L-3 Cu leaves	110.14	8.39
L-3 Pb soil	51.84	18.65
L-3 Zn soil	59.40	16.04
L-3 Cu soil	16.41	2.03
L-4 Pb leaves	84.56	11.70
L-4 Zn leaves	193.75	27.34
L-4 Cu leaves	119.15	27.63
L-4 Pb soil	71.50	32.34
L-4 Zn soil	52.90	14.89
L-4 Cu soil	23.42	9.00
B-1 Pb leaves	126.00	0.00
B-1 Zn leaves	543.67	51.40
B-1 Cu leaves	192.00	23.38
B-1 Pb needles	71.20	5.54
B-1 Zn needles	226.40	11.43
B-1 Cu needles	46.03	28.52
B-1 Pb soil	92.27	27.78
B-1 Zn soil	165.00	111.75
B-1 Cu soil	34.60	17.75
B-1 Pb stems	97.33	2.89
B-3 Pb leaves	86.64	3.77
B-3 Zn leaves	310.40	33.78
B-3 Cu leaves	128.96	16.69
B-3 Pb needles	55.65	13.78
B-3 Zn needles	193.90	30.75
B-3 Cu needles	37.66	1.04
B-3 Pb soil	61.02	20.13
B-3 Zn soil	102.88	34.38
B-3 Cu soil	33.22	17.46
B-3 Pb stems	91.40	7.30
U-1 Pb leaves	79.00	4.19
U-1 Zn leaves	250.09	89.74
U-1 Cu leaves	114.15	39.44
U-1 Pb soil	93.13	74.97
U-1 Zn soil	83.29	71.38
U-1 Cu soil	14.03	4.08
U-1 Pb stems	81.88	7.74
Std Pb leaves	82.77	6.00
Std Zn leaves	272.00	0.00
Std Cu leaves	137.00	.87
Std Pb needles	70.50	4.83
Std Zn needles	252.00	0.00
Std Cu needles	28.15	1.34
Std Pb soil	133.40	1.91
Std Zn soil	132.00	0.00
Std Cu soil	29.87	.81

*All numbers are expressed in ppm.

TABLE 2.—STUDENT'S *t* TEST

	Sample Type	Traverse	#	Mean (ppm)	Std.Dev. (ppm)	S_p	t	Conclusions*
Quartzite/Dolomite	Pb-leaves	L-3	7	88.70	8.98	7.33	8.119	Different
		B-1	4	126.0	0.0			
	Pb-soil	L-3	7	51.84	18.65	21.30	-2.748	Different
		B-1	3	92.23	27.78			
	Zn-leaves	L-3	6	203.50	26.77	35.59	-13.517	Different
		B-1	3	543.67	51.40			
	Zn-soil	L-3	8	59.40	16.04	54.55	-2.86	Different
		B-1	3	165.00	111.75			
Big/Black Sagebrush	Pb-leaves	L-4	5	84.56	11.70	10.16	-.650	Same
		L-3	7	88.70	8.98			
	Pb-soil	L-4	4	71.50	32.34	24.09	1.30	Same
		L-3	7	51.84	18.65			
	Zn-leaves	L-4	4	193.75	27.34	26.98	.56	Same
		L-3	6	203.50	26.77			
	Zn-soil	L-4	5	52.90	14.89	15.63	-.730	Same
		L-3	8	59.40	16.04			

*Using 95% confidence level.

Conclusions

Biogeochemical analysis of sagebrush and junipers in the Dugway Range effectively reveals areas of mineralization. The technique can be of great value in delineating hidden ore bodies when the alteration halo from the mineralization is within reach of the roots and may be an effective adjunct to other methods of reconnaissance exploration.

Results indicate that sagebrush stems contain more accentuated concentrations of Pb over hidden ore bodies than do sagebrush leaves.

Sagebrush more effectively reveals mineralization than do soils when searching over hidden ore bodies covered by nonmineralized overburden, as indicated by the L-1 traverse (fig. 4). However, both methods are equally good over very shallow or surfacing ore bodies like the Four Metals and Bertha mines.

TABLE 3.—CALCULATION OF STUDENT'S t

Calculate means ($\overline{X}_1$ & $\overline{X}_2$)

$$\overline{X} = (\Sigma\ x)/n$$

Calculate Standard Deviation (S_1 & S_2)

$$S = \left(\frac{\Sigma(\overline{X} - X)^2}{n-1}\right)^{\frac{1}{2}}$$

Pool standard deviations

$$S_p = \left(\frac{(n_1-1)\ S_1^2 + (n_2-1)\ S_2^2}{n_1 + n_2 - 2}\right)^{\frac{1}{2}}$$

Calculate Student's t value

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S_p\ (1/n_1 + 1/n_2)^{\frac{1}{2}}}$$

Compare resulting t value with those from a table of t distribution, using ($n_1 + n_2$-2) as the *degrees of freedom* (*df*) value.

In the Dugway Mining District, elemental concentrations higher than the sum of the mean concentration plus one standard deviation indicates the presence of mineralized substrate.

Big sagebrush and black sagebrush do not contain significantly different background trace element concentrations. Therefore, for the purpose of biogeochemical exploration, these two species may be sampled as though they were one species.

Prospect Mountain quartzite, in the vicinity of the Lauris vein, contains a significantly different concentration of Cu, Pb, and Zn than does the dolomite in the vicinity of the Bertha vein. This difference is found not only in the bedrock and associated soils, but also in the vegetation growing over the two lithologies.

EXTENDED RESEARCH

After developing effective sampling techniques and analytical procedures, additional samples were collected from the vicinity of the Lauris and Bertha mines, and an exploratory traverse was conducted over a region mapped as mostly barren (Staatz and Carr 1964). This additional research was done to provide more information on the areas studied in the orientation survey and to further demonstrate the effectiveness of biogeochemical exploration over undeveloped areas in the Dugway Range.

Each area sampled will be discussed separately.

Lauris Vein

Because vegetation contained anomalous amounts of Cu, Pb, and Zn over the upper adit of the Lauris vein, three other traverses were set up along the same fault line: (1) L-2 over the lower adit, (2) L-3 along the crest of the divide south of the upper adit, and (3) L-4 halfway between the two adits. These traverses were plotted on figures 2, 7, and 8.

L-2.—The L-2 traverse (fig. 7) was sampled in an east-west direction 200 feet up the wash south of the adit to see if the anomaly showed up below the Lake Bonneville terrace, since the Lake Bonneville episode may have left an additional layer of barren gravels which would have more effectively masked mineralization below.

Figure 7 reveals some anomalous concentrations over the known vein and a reasonable possibility of another vein 150 feet west of the main vein. The main vein was projected to intercept the traverse between samples 3 and 4.

Because of the low Pb content in sagebrush leaves over the known vein and the high trace-element concentrations 150 feet west of the vein, the traverse was resampled and lengthened.

The second sampling of sagebrush leaves along traverse L-2 produced results similar to the first, showing anomalous concentrations of Cu and Zn over a possible vein 100 to 150 feet west of the main vein (L-2b, fig. 7). Pb concentrations in sagebrush leaves were slightly higher on the second series of samples, but the anomaly was still very weak, so sagebrush stems were analyzed. The stems contained much higher concentrations of Pb and indicated Cu and Zn anomalies in much the same fashion as did the leaves.

It was observed that in resampling the L-2 traverse, trace-element content in the soil varied considerably from that of the first series, even though the samples were dug within 3 feet of the original holes. The Pb anomaly was in the same place both times, but higher the second time (140 ppm to 650 ppm). The Zn and Cu were only slightly different.

As can be seen on the scan sheet (fig. 7), Pb and Zn are anomalous over the known vein which the adit underlies. All the data on sagebrush leaves and stems for all three elements indicate the possibility that the roots are penetrating a second vein about 150 feet west of the main vein. This seems to be a logical assumption because the sample was taken near some small ledges which were the source of the surficial material. Trace-element concentrations in the soil were understandably low because the barren surficial material was derived from the small ledges and masked the mineralized vein below; on the other hand, sagebrush trace-element concentrations were high because the sagebrush roots penetrated the mineralized substrate. If this anomaly was apparent only because the dispersion halo of the main vein was not covered by such a deep veneer of gravels, the anomaly would have been picked up by the soil sample as well.

This hypothesis could be further tested by more detailed biogeochemical exploration or by drilling.

L-3.—The L-3 traverse was sampled to determine whether the results would indicate a continuation of the vein south of the reaches of the upper adit. Most results were negative. Weak anomalous concentrations of Zn and Pb were extracted from soil sample 2, but nothing worthy of more detailed sampling (fig. 8).

L-4.—The L-4 traverse was studied to determine whether the vein extended between the two adits. Close study of figure 8 indicated the possibility of two veins, one under sample 2, and the other at sample 4. Sagebrush leaves, sagebrush stems, and soil all contained highly anomalous concentrations of Zn at the sample 2 site.

Soil contained 575 ppm of Pb at sample 2, but sagebrush samples contained peak values of Pb at sample 4. Sagebrush samples contained anomalous amounts of Cu at sample numbers 2, 4, and 7. Sample 7 was taken next to a small fault, but since only Cu values were high, one might conclude that mineralization would be negligible.

Bertha Mine

No surficial evidence of mineralization was seen south of B-1, but the interesting presence of merging faults and dolomitized rocks prompted the author to form another east-west traverse about 400 feet south of the B-1 traverse.

Even a brief glance at the scan sheet for this traverse (fig. 6) indicates the strong possibility of mineralization at sample 2. Tests for Zn from sagebrush and juniper were high, and tests from soil samples peaked out at the next sample point downhill. This might be expected; if an ore body is under sample 2, the mineralized surficial float should be found somewhere downhill from this point, causing the soil values to reach a peak downslope.

Sagebrush and soil samples produced peak Pb values in the same way as the zinc results just mentioned, but Pb in juniper needles decreased over the mineralized area.

The highest Cu concentration was over a smaller anomaly at sample 5 (fig. 6).

It is probable that the mineralization at the Bertha Mine, and perhaps the area of B-2-2, was localized along smaller secondary faults or fractures associated with the major normal fault which borders the east side of the graben. Staatz and Carr (1964) mapped the Bertha shaft as being directly over the major normal fault on the east side of the graben, but dolomite bedrock can be seen on either side of the shaft, and there is no visible quartzite in the dumps.

The exact location of the major normal fault near the B-2 traverse is not known because it is not visible. The B-2-2 sample was taken next to a dolomite outcrop, but the B-2-1 sample was collected in float which appeared to be entirely quartzite.

More detailed geochemical or biogeochemical exploration could be conducted over this anomaly to delineate the zone of mineralization.

Exploratory Traverse (U-1)

After completing the research on the mines, the writer decided to conduct an exploratory traverse over an area which had a possibility of containing mineralization because it (a) was in dolomitized rock, (b) was in close proximity to highly faulted Prospect Mountain quartzite, (c) contained only two prospects, and (d) was close to a small road which could be used for mining purposes. This area is located in the south end of Kelley's Hole.

The traverse was plotted in a north-south direction beginning near a sharp bend in the road, and going south 1,200 feet to the ridge crest. The first five samples were taken in Prospect Mountain quartzite, and the rest were taken in dolomitized Ordovician Garden City formation (figs. 2 and 13).

A small prospect was at the sample 7 site, so the sample was collected 30 feet to the west to avoid possible contamination. As may be noted from figure 9, this sample and the samples on either side contained extremely high concentrations of the elements analyzed for in both sagebrush and soil.

After the high Pb and Zn readings in soil and sagebrush were noted, a 4-foot channel sample was collected from a vein exposed at the small prospect. The results were Pb–43,600 ppm (4.36%), Zn–882 ppm, Cu–66 ppm, and Ag–8 oz/ton.

A large gossan trending in a westerly direction begins at the surface about 200 feet west of sample 8. It almost reaches the top of the ridge west of sample 8. Some malachite and azurite were seen in the float, so a graben sample from a sagebrush near the center of the gossan was collected and analyzed. The results were Pb–180 ppm (97 ppm over the threshold value), Cu–270 ppm (120 ppm over the threshold value), and Zn–776 ppm 436 ppm over the threshold value).

This vein looks promising and should be studied more in detail for three reasons: 1) the ore appears to be of good quality even at the surface; the silver alone makes it attractive; 2) the large gossan west of sample 8 may indicate the general size of the mineralized zone; (3) the ore is close to a road.

CONCLUSIONS

Biogeochemical exploration utilizing sagebrush is an effective method of exploration in the Dugway Range and can be used for extensive exploration in western Utah even by those with a limited background in botany. Analysis of sagebrush proved to be more effective than soil geochemistry over hidden ore bodies covered by barren overburden (i.e., the Lauris L-1 traverse over vein covered by 20 feet of recent sediment [fig. 4]).

For fairly shallow mineralization, such as that of the

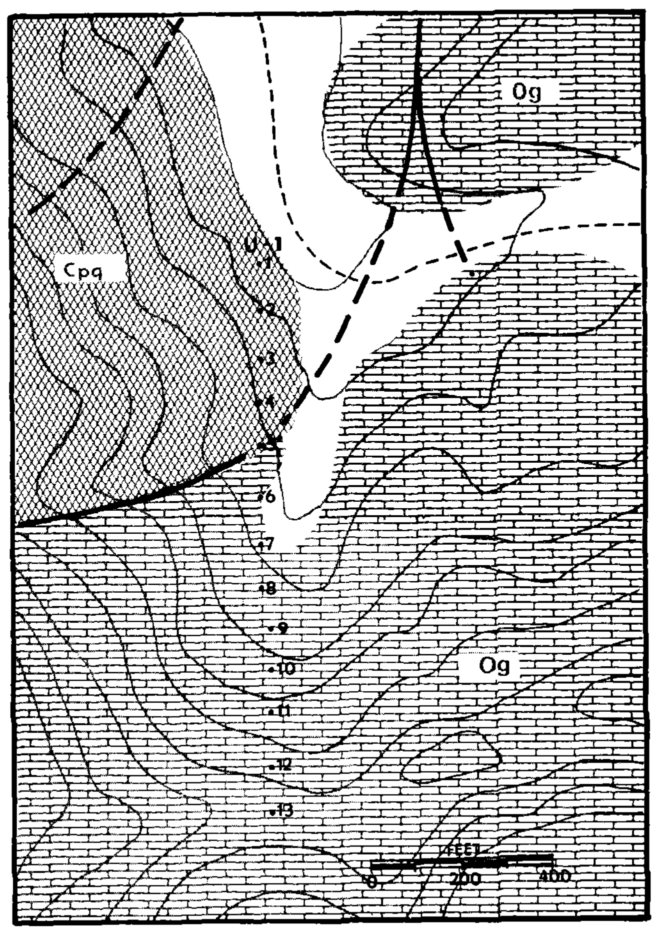

FIGURE 13.—Sampling index map of the U-1 traverse.

Dugway Range, sagebrush more effectively reveals mineralization than do juniper trees. However, if one were looking for deep ore where the alteration is buried also, juniper trees would probably be more effective than sagebrush because their roots reach depths of 200 feet compared to only 60 feet for sagebrush.

Big sagebrush and black sagebrush contain no significant differences in background counts of Pb, Zn, or Cu. Therefore, these two species of sagebrush may be treated as one for the purposes of biogeochemical exploration.

Soil geochemical exploration is an effective method of exploration in the Dugway Range if the mineralization reaches to, or very near, the surface. However, buried ore bodies, like the L-1 traverse, may be difficult to detect using soil geochemistry.

Positive anomalies discovered while sampling for this thesis indicate the possibility of two undeveloped areas of mineralization. Further exploration could be conducted over these two areas to determine their economic potential.

APPENDIX

EXPLORATION GUIDES

Analysis carried out during the course of this study revealed some undeveloped areas which contained anomalous amounts of Pb, Zn, or Cu; these areas should be more extensively researched.

The B-2-2 sample was several hundred feet from the Bertha Mine; yet it contained highly anomalous concentrations of Pb and Zn. This anomaly may extend from B-1-4 to B-2-2, and on south to the Francis claim.

The U-1-7 sample was taken above an old prospect south of Kelley's Hole. The soil sample contained high Zn and Pb, and a channel sample of the vein material contained 4.36 percent Pb and 8 oz/ton Ag. This sample may also represent a large deposit because a large gossan extends several hundred feet west of here.

There are many intriguing areas in the north end of the Dugway Range which were not sampled for this thesis:

1. The Bertha graben is highly faulted and appears, in part, altered. Some gossans here have been trenched by bulldozers, but a soil geochemical study of the area would be more meaningful (vegetation is sparse).
2. The Four Metals Mine is located in, and parallel to, a large area of dolomitization, bleaching, and silicification. An organized biogeochemical or geochemical sampling program plotted normal to the strike of the alteration would best delineate any shallow mineralization.
3. Many mines and prospects were located along the west side of the Buckhorn Thrust fault. This general area would make a good target for exploration, especially where mapped as altered Fandangle limestone.

General Guidelines

Faults are an important guide to ore deposits of the Dugway Range because all known ore bodies in the range are either fissure fill or fissure fill with some replacement. In quartzite, many fault scarps can be seen, as well as major trends of gullies controlled by faulting. Faults in dolomite are often found by identifying trends of other faults and washes. The three major basins in the north end of the Dugway Range contain mineralization: Kelley's Hole, Bertha Graben, and Bullion Canyon.

Many areas of the Dugway Range show obvious alteration. A quick check of the map by Staatz and Carr (1964) shows the large majority of the claims to be either in quartzite or in altered carbonate rocks. The mapped alteration can be used as a guide to areas more likely to be mineralized.

A quick field check was made to see if there was a zonation of alteration over areas studied, but no megascopic evidence could be seen. Even areas displaying several types of alteration failed to show zonation. For example, the Four Metals Mine showed no zonation of the bleaching, dolomitization, or silicification. In fact, silicification covered a fairly large area which crossed the south end of the Four Metals vein. The map (fig. 11) shows this relationship.

Most prospects in the district were found near the turn of the century. It is highly improbable that all of them were completely mined out; in fact, most were mined only near the surface. Today's base metal prices and greatly improved techniques may change what was once only a protore into a profitable venture.

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