1972

Wall rock geochemistry of the Chester Vein, Sunshine Mine, Kellogg, Idaho

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Recommended Citation

Tibbs, Nicholas Howard, "Wall rock geochemistry of the Chester Vein, Sunshine Mine, Kellogg, Idaho" (1972). *Doctoral Dissertations*. 214.
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WALL ROCK GEOCHEMISTRY OF THE CHESTER VEIN, SUNSHINE MINE, KELLOGG, IDAHO

by

Nicholas Howard Tibbs, 1945-

A THESIS

Presented to the Faculty of the Graduate School of the

UNIVERSITY OF MISSOURI - ROLLA

In Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

in

GEOLOGY

1972

Advisor

Paul Dean Proctor

ABSTRACT

The Chester vein has been the major source of ore from the Sunshine mine, largest single producer of silver in the world. 425 samples of quartzite and argillite wall rocks were collected in 13 traverses across this vein on the 4400, 4600, and 4800 mining levels. These samples were analyzed for aluminum, magnesium, calcium, sodium, potassium, manganese, iron, lead, copper, and zinc by atomic absorption spectroscopy, and for silicon and sulfur by x-ray emission spectroscopy. Element distribution plots, linear correlation coefficient matrices, varimax factor analysis, and cluster analysis were employed to determine the geochemical processes that occurred in the wall rock.

Examination of element distributions established that large scale leaching of calcium occurred concurrently with a stage of bleaching in the wall rock. Subsequent to this bleaching process, carbonatization (sideritization) of the wall rock, which occurred during siderite emplacement in the vein, resulted in aureoles of iron, manganese, magnesium, and calcium in the wall rock near the vein. These aureoles were shown to increase the exploration target by a factor of about 10.

An inverse relationship was statistically established between sericite, represented by aluminum and potassium, and siderite, represented by iron and manganese, in the wall rock. The cause of this relationship was not determinable. It is recommended that a mineralogical study supercede this study to resolve this problem.

The technique of cluster analysis was modified in order to permit meaningful geochemical interpretations. The modified technique provided the same results as factor analysis, but offered the advantage of an easily understood graphical representation of results.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the guidance received from his graduate advisor, Dr. Ernst Bolter, in the conductance of this investigation. The author is indebted to the staff of the Sunshine mine for permission to conduct the investigation in that mine. Particular thanks must go to Don Long, Geologist, for his personal attention to this work and contribution to the author's knowledge of the mine geology. Gratitude must be expressed for the assistance in sampling given by Terry Durham, geology student at the University of Missouri-Rolla. The research was funded in part by the V. H. McNutt Memorial Foundation. It must be added that without the generosity of Mrs. V. H. McNutt, materially expressed through various scholarships and grants, the author would not have been able to continue his education to this point.

The author dedicates this work to the memory of the miners who lost their lives in the recent disaster at the Sunshine mine.

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I. INTRODUCTION

A. Purpose and Scope of the Study

The Coeur d'Alene district ranks as one of the great mining districts of the world. Since about 1884 it has produced silver, lead, zinc, and copper with a gross value of over $2,000,000,000.

Previous investigations of the wall rock geochemistry of the types of country rocks present in the Coeur d'Alene district are virtually unknown. These country rocks consist of low grade regionally metamorphosed intercalated quartzose and argillaceous sedimentary rocks. Within the district, the especially predominant wall rock alteration expressed by large scale bleaching has been previously recognized.

A controversy has raged over the identification of the geochemical processes which accompanied bleaching in the Coeur d'Alene district. With the emphasis on solving this controversy, the possible occurrence of other less conspicuous types of wall rock alteration has been largely ignored. Structural and stratigraphic control of ore shoots has been carefully studied, but an insignificant amount of effort has been contributed to identification of the possible geochemical controls of wall rock composition on mineralization.

In an effort to solve these specific problems and to contribute to the general knowledge of wall rock alteration a detailed study was conducted on samples collected from the Sunshine mine, Kellogg, Idaho. Approximately 425 samples were collected from diamond drill cores and crosscuts in 13 traverses across the Chester vein. Sampling of the vein was limited to three levels of the mine representing 400 feet in the vertical dimension and 2000 feet in the horizontal dimension.

The concentrations of aluminum, magnesium, calcium, sodium, potassium, manganese, iron, lead, copper, zinc, silicon, and sulfur in these samples were determined. Direct examination of the data distributions, interpretation of linear correlation coefficient matrices, factor analysis, and cluster analysis were employed to delineate the geochemical features present in the wall rocks. Interpretation of these features was made to gain insight into the geochemical processes which occurred in the wall rock during bleaching and vein formation.

B. Location of the Sunshine Mine

The Sunshine mine is located in the Coeur d'Alene district, Shoshone County, Idaho. The district, as defined by Fryklund (1964, p. 2) occupies an east-west elongate area 25 miles by 10 miles on the eastern edge of the panhandle of northern Idaho (Figure 1). The principal access is via U.S. Highway 10 - Interstate 90 which roughly bisects the area from east to west. Within the district the major towns along this route from east to west are Mullan, Wallace, Osburn, and Kellogg. Drainage of the area is by the South Fork of the Coeur d'Alene River which flows from east to west across the center of the district. These features are outlined in Figure 2. The Sunshine mine plant and shaft are located three miles southeast of the city of Kellogg in the Big Creek valley (Figure 2).

C. History and Production of the Sunshine Mine

The following history of the Sunshine mine is condensed from Schulze (1963).

Attention was first drawn to the mineral wealth of the Coeur d'Alene area by the discovery of gold by Andrew Prichard in 1882 in the

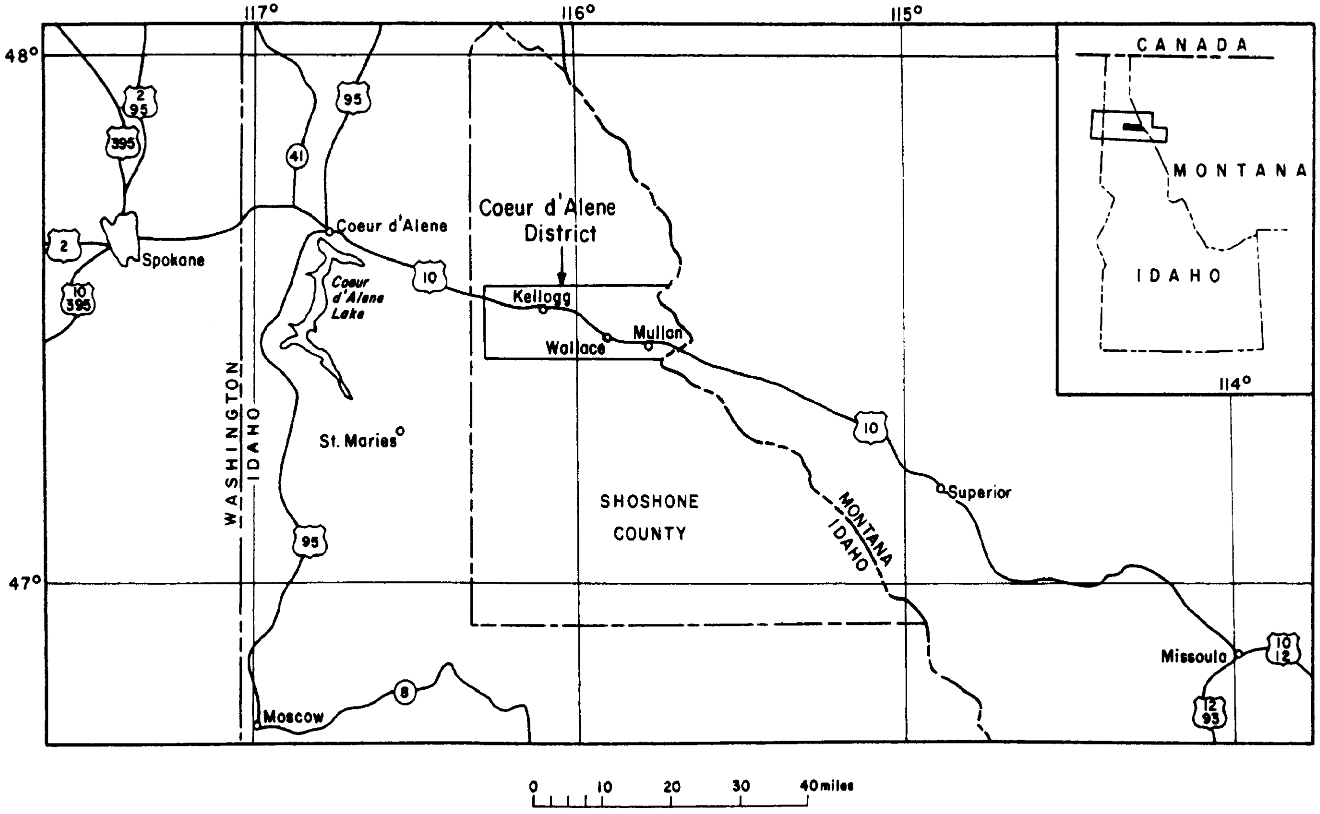

Figure 1. Map of northern Idaho showing location of the Coeur d'Alene district. (After Fryklund, 1964)

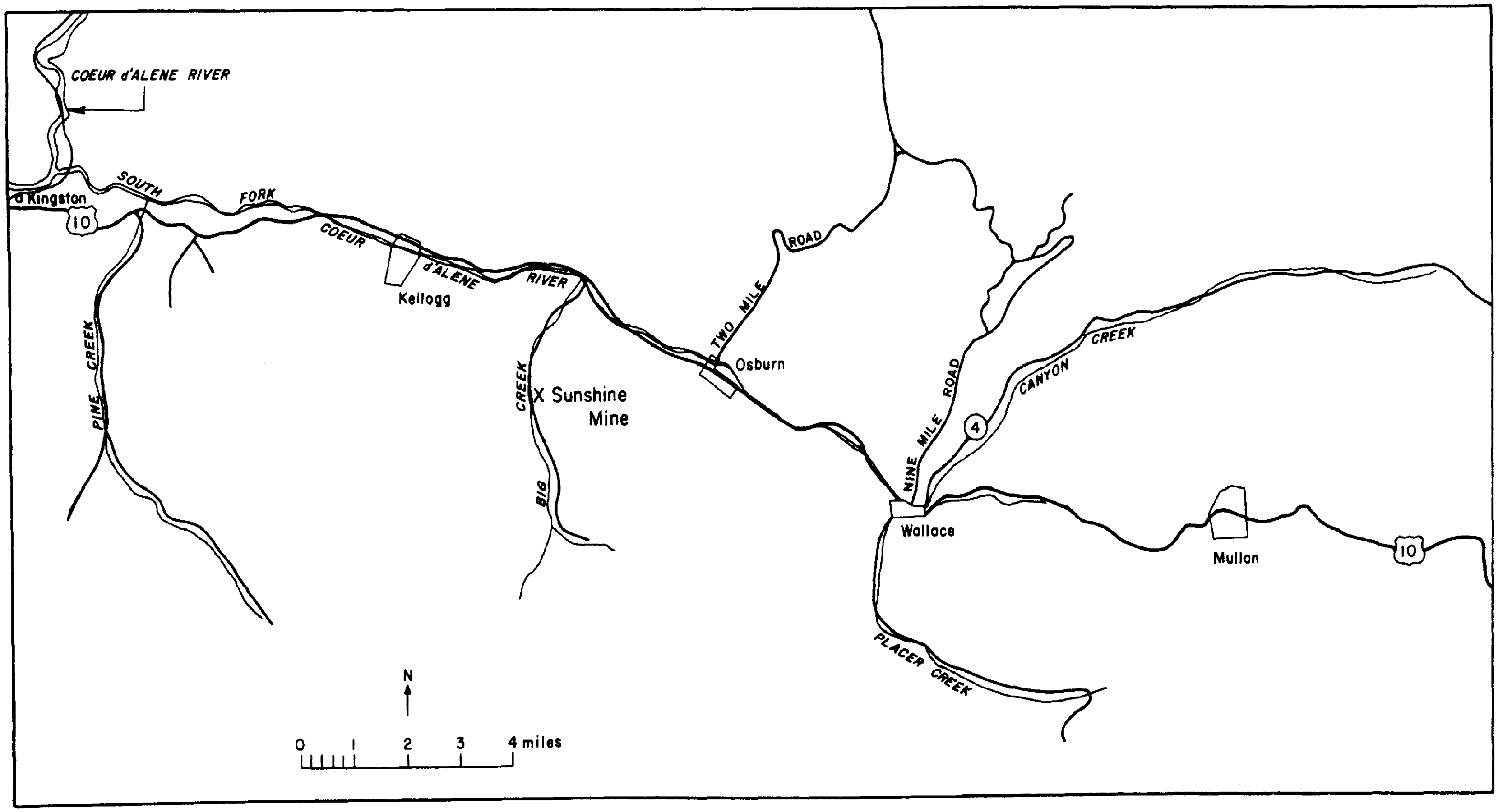

Figure 2. Map showing location of the Sunshine mine in the Coeur d'Alene district. (After Day, 1963)

vicinity of the present towns of Murray and Prichard approximately twelve miles northeast of the city of Kellogg. Prichard had previously discovered a lode in the present Coeur d'Alene district in 1878. During 1884 several of the major outcropping lodes of the district were discovered and claimed. Brothers True and Dennis Blake located the Polaris lode in August of that year and on September 25, 1884 they discovered the Yankee lode which became the nucleus of the present Sunshine Mining Company holdings.

The Sunshine Mining Company was organized in the state of Washington in 1918. It was acquired by parties interested in the Yankee lode claim group about 1920. Through this company, control of this claim group was realized and development of the claim then proceeded in earnest. The company enlarged its holdings farther through the acquisition of the Yankee Girl Mining Group in 1924.

About this time, a mill was constructed with a capacity of 25 tons per day; concentrates averaged 150 ounces of silver per ton. These were obtained from mill heads of about 15 ounces of silver per ton. The vein width being mined at this time consisted of rich stringers which averaged only one half inch in width.

The company's serious financial condition was alleviated in 1927. At this time development on the 500 level struck ore of improved tenor. The resultant profits enabled exploration to greater depths and in 1931 exceedingly rich ore was struck on the 1700 level. At this level the vein was twenty feet wide and solid high grade ore was frequently encountered. During 1931 Sunshine mine became the second largest producer of silver in the United States. In 1937 the production from the Sunshine mine placed it as the largest producer of silver in the world.

The year 1943 marked the discovery of the Chester-Syndicate vein and fault zone. This high grade silver and lead ore shoot topped at about the 2300 level; no significant mineralization was present on this structure at the surface.

In 1949 uraninite veins were first discovered in the Sunshine mine. They have subsequently been identified in several other mines in the district. Although they have not been of economic value, the radiometric dating of these veins has added an important fact for use in recent attempts at unraveling the geologic history of the district.

Present production of the Sunshine mine is principally from the Chester vein and the Syndicate fault structures. Ore is being mined to the 5200 level, and the shaft servicing this section of the mine is being driven to the 7000 level.

Mine production for the period 1904 to 1968 is listed in Table 1. Yearly production for the years 1968 to 1970 is shown in Table 2. For comparison, total district production since discovery exceeds a gross value of $2,000,000,000.

Table 1. Production of the Sunshine mine for the period 1904 to 1968. (After Anderson, 1968)

Tons Produced	7,817,546
Ounces Silver Recovered	242,632,196
Ounces Gold Paid For	2,143
Pounds Lead Recovered	140,023,914
Pounds Copper Recovered	73,174,234
Pounds Antimony Recovered	45,021,989
Smelter Returns	$228,032,681

Table 2. Annual production of the Sunshine mine for the years 1968 to 1970. (After Sunshine Mining Company, 1969 and 1970)

	1968	1969	1970
Ounces Silver Recovered	7,870,837	8,375,775	8,441,961
Pounds Lead Recovered	654,398	873,637	467,220
Pounds Copper Recovered	2,902,669	3,217,530	3,433,905
Pounds Antimony Recovered	2,088,374	1,844,518	1,986,001

D. Previous Related Investigations of Wall Rock Geochemistry

Meyer and Hemley (1967) provide a concise summary of the state of the art of wall rock alteration research. They discuss the specific mineral assemblages of alteration zones, the significance of the geometry of alteration zones, and some of the chemical reactions which occur in wall rock alteration. Of value is their definition of wall rock alteration (p. 166) to include "...those mineralogical and chemical changes brought about by circulating solutions within the host rocks of ore bodies."

There is a paucity of investigations concerning wall rock alteration of mildly metamorphosed quartzose rocks similar to the Beltian rocks of the Coeur d'Alene district. Meyer and Hemley (1967, p. 200) account for this stating, "Detailed studies of alteration zoning next to sulfide veins in metamorphic rocks are scarce mainly because the patterns are usually relatively diffuse and obscure."

Knopf (1929) in a study of the Mother Lode system of California found that gold veins in Carboniferous black phyllites and slates were accompanied by extensive carbonatization of wall rocks, as expressed by ankerite aureoles about the veins.

Barnes (1959) in discussing the effect of metamorphism on zinc distribution near ore bodies, negated the possibility that accumulation of these ores was the result of lateral secretion.

In a subsequent study in the Wisconsin zinc-lead district, Lavery and Barnes (1971) developed a mathematical model for the prediction of ore proximity through the statistical analysis of observed zinc dispersion patterns in the limestone host rocks.

Bailey (1971) derived composite distributions for trace heavy metals and silver in the Weber Quartzite of the Park City district. He concluded that haloes of these metals extended from the vein for 50 feet into the wall rock. Individual traverses did not show a uniform pattern, however. Bailey observed no evidence of mineralogical haloes about the veins in the quartzite; nor, were such haloes evidenced by distributions of the major elements.

Tooker (1963) reported the results of an extensive study of wall rock alteration in the Front Range mineral belt of Colorado. Of special pertinence to the Author's investigation was Tooker's discussion of several methods of presenting distributions of major elements in wall rocks (p. 42). He compared distributions reported both as oxides and ions in terms of both weight and volume percent, and demonstrated that these methods were all similar in the appearance of the final distributions. He assumed that the movement of ions in the wall rock occurred through a network of close-packed oxygen ions. He concluded that the representation of chemical distributions as oxides was unrealistic in the context of wall rock alteration processes, and he presented distributions in terms of volume percent of ions.

Weis (1964) studied the occurrence of bleaching in the Coeur d'Alene district. He attributed this bleaching to color changes caused by the alteration of hematite to goethite, degradation of green chlorite, and the destruction of carbonaceous material. He expressed the opinion that bleaching was accomplished without significant alteration of the composition of the wall rock.

Shaw (1959) recognized a zonal distribution of iron rich carbonate minerals about veins in the Bunker Hill mine of the Coeur d'Alene district. He identified the sequence of siderite - ankerite - calcite with increasing distance from the vein. Calcite was never closer than 200 feet to the vein. Shaw interpreted this as a result of hydrothermal differentiation during mineralization.

Both Mitcham (1952) and Kerr and Robinson (1953) discussed the occurrence of alteration in the Sunshine mine. Their investigations are discussed more fully in Chapter III.

II. GEOLOGY OF THE COEUR D'ALENE DISTRICT

The first published report of the geology of the Coeur d'Alene district was by Clayton (1888), four years after the first major lead-silver discoveries in the district. Clayton outlined a structural evolution for the district essentially the same as that derived through the research of Hobbs, et al. (1965). Of interest is the following statement by Clayton.

> "From a careful study of the facts, the evidences are abundant to show that the vein system and mineralization of this country was produced during the great continental uplift that culminated in forming the Rocky Mountain ranges."

Research on the geology of the Coeur d'Alene district by the United States Geological Survey has been essentially continuous from the original cursory investigation of Lindgren (1904) to the present time. This work has culminated in reports by Ransome and Calkins (1908), Umpleby and Jones (1923), Fryklund (1964), and Hobbs, et al. (1965). These reports contain a comprehensive bibliography of papers dealing with both district-wide geology and specific research within the district. A concise summary of the more recent research has been presented by Hobbs and Fryklund (1968). The following discussion of the general geology of the district is drawn principally from these reports.

A. Physiography

The Coeur d'Alene district is located in the Bitterroot Range of the northern Rocky Mountains. The area is eroded to the stage of full maturity. Drainage is by the South Fork of the Coeur d'Alene River which bisects the district from east to west. Valleys are narrow and steep walled with local relief of 3000 to 4000 feet. The highest elevations of the area are about 7000 feet.

B. Rock Types

The principal country rocks of the Coeur d'Alene district are mildly metamorphosed sedimentary rocks of the Precambrian Belt Series (Table 3). They have a minimum thickness of 21,000 feet (Hobbs and Fryklund, 1968, p. 1422). Gradations from pure quartzite through argillite comprise the different lithologies with the exception of the Wallace Formation which contains appreciable quantities of dolomite rocks. The formations are distinquished according to their relative proportions of quartzite to argillite and contacts are gradational over a broad zone.

The Gem stocks of Cretaceous age (Larsen and Schmidt, 1958, p. 54) are the principal intrusives in the district. They occur in two clusters north of the town of Wallace (Figure 4). The bulk of these stocks is of monzonite to quartz monzonite composition; the remaining rock types range in composition from diorite to syenite. Anderson (1949) concluded from textural studies that the stocks were originally of dioritic composition and had been converted to monzonite and syenite through endomorphic alteration by potassium rich solutions, that is, soon after crystallization the stocks were permeated by potassium bearing fluids which were derived from a differentiating parent magma at depth.

Other intrusive rocks in the district consist of diabase and lamprophyre dikes of probable Tertiary age.

Table 3. Stratigraphy of the Coeur d'Alene district. (After Hobbs and Fryklund, 1968)

	Formation	Lithology	Thickness (feet)
	Striped Peak Formation	Interbedded quartzite and argillite with some sandy dolomitic beds. Purplish gray and pink to greenish gray. Ripple marks, mud cracks common. Top eroded.	1,500+
Wallace Formation	Upper part	Mostly medium- to greenish-gray finely laminated argillite. Some arenaceous dolomite and impure quartzite, and minor gray dolomite and limestone in the middle part.	4,500-6,500
	Lower part	Light-gray more or less dolomitic quartzite interbedded with greenish-gray argillite. Ripple marks, mud cracks abundant.	
St. Regis Formation	Upper part	Light greenish-yellow to light green-gray argillite; thinly laminated. Some carbonate-bearing beds.	1,400 2,000
	Lower part	Gradational from thick-bedded pure quartzite at base to interbedded argillite and impure quartzite at top. Red-purple color characteristic; some green-gray argillite. Some carbonate-bearing beds. Ripple marks, mud cracks, and mud-chip breccia common.	
	Revett Formation	Thick-bedded vitreous light yellowish-gray to nearly white pure quartzite. Grades into nearly pure and impure quartzite at bottom and top. Cross-stratification common.	1,200-3,400
	Burke Formation	Light greenish-gray impure quartzite. Some pale red and light yellowish-gray pure to nearly pure quartzite. Ripple marks, swash marks, and pseudo-conglomerate.	2,200-3,000
Prichard Formation	Upper part	Interbedded medium-gray argillite and quartzose argillite and light-gray impure to pure quartzite. Some mud cracks and ripple marks	12,000+
	Lower part	Thin- to thick-bedded, medium gray argillite and quartzose argillite; laminated in part. Pyrite abundant. Some discontinuous quartzite zones. Base buried.	

C. Structure

The Coeur d'Alene district is located at the intersection of a northerly trending broad anticlinal arch and the Lewis and Clark lineament (Billingsley and Locke, 1941). This lineament consists of a series of shear fractures which extend from Coeur d'Alene, Idaho southeastward to beyond Phillipsburg, Montana. The part of the line from Coeur d'Alene to Superior, Montana is known as the Great Coeur d'Alene Mineral Belt and is outlined by veins bearing massive siderite and ankerite followed by specular hematite (Fryklund, 1964, p. 50).

A simplified view of Hobbs, et al. (1965) concept of the structural evolution of the district is presented in Figure 3. The Trout Creek, Burke, and Big Creek anticlines of Figure 3(c) were originally one continuous structure and would be the structure representative of the northerly trending regional anticline. The Osburn fault (Figure 3(c)) is the main structural feature representative of the Lewis and Clark Lineament. Right lateral displacement along this fault is 16 miles. In the western part of the district up to four miles of this displacement in the northern block has been absorbed by low angle normal displacement along the Dobson Pass fault. Additional shearing has taken place on other major faults parallel to the Osburn fault.

The structural evolution of the district began in Precambrian time and continued through Early Tertiary. The major folding has been established to be older than uraninite veins which have been dated at 1250 million years. The late great strike slip faults have been established as younger than the Gem stocks which have been dated at 100 million years.

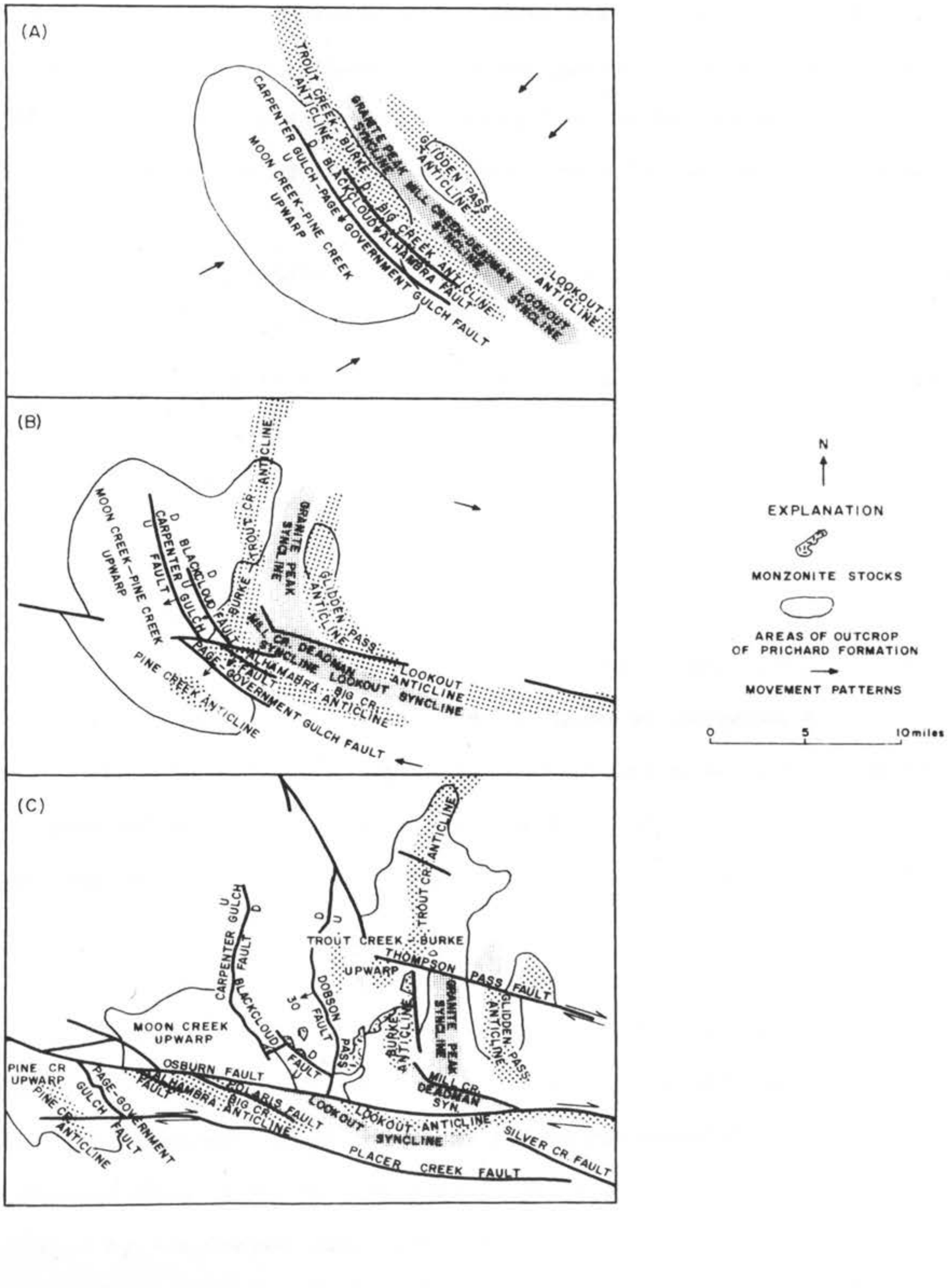

Figure 3. Structural evolution of the Coeur d'Alene district. (After Hobbs, <u>et al.</u>, 1965)

The complexity of structural stresses has created a corresponding complexity of faulting. These faults are grouped chronologically as follows: (a) low angle reverse faults, (b) steep reverse and normal faults, (c) strike slip and associated normal faults, and (d) late normal faults.

The effects of rotational stresses are evidenced by the northerly trend of folds north of the Osburn fault and the westerly trend of folds south of it. The folds south of the fault have been highly compressed and sometimes overturned at steep angles to the north. The Sunshine mine is located in the overturned northern flank of such a fold—the Big Creek anticline.

D. Ore Deposits

A diversity of veins and ore shoots occurs in the Coeur d'Alene district. Fryklund (1964) lists several types of deposits as given in Table 4. Of the deposits listed, the Precambrian uranium bearing veins and disseminated arsenopyrite and the Tertiary deposits are of limited extent and importance. Only the hydrothermal bleaching and the "main period" veins will be considered in this discussion.

The main period veins of the district are clustered into sub-parallel linear zones called "mineral belts". The strike of the veins is generally N65°-85°W and their dip varies from nearly vertical to about 50°S. The strike of the veins generally parallels the trend of the mineral belt in which they occur. These belts occur in two groups separated by the Osburn fault (Figure 4). Reconstruction of the geological setting prior to displacement on the Osburn fault would align the principal productive belts into roughly a north-south trend in which

Table 4. Sequence of mineralization in the Coeur d'Alene district. (After Fryklund, 1964)

Precambrian Mineral Deposits

- Disseminated arsenopyrite and pyrite
- Hydrothermal alteration (bleaching) of country rocks

Late Cretaceous Mineral Deposits--Main Period of Mineralization

- Country rock recrystallization (quartz)
- Silicate stages (biotite, garnet, amphiboles)
- Carbonate stage
- Barite stage
- Iron oxide stages (hematite, magnetite)
- Sulfide stages
  - Pyrite stage
  - Arsenopyrite stage
  - Sphalerite stage
  - Tetrahedrite-chalcopyrite stage
  - Galena stage
  - Late sulfosalt stage

Tertiary Mineral Deposits

- Veins formed during the first period of mineralization:
  - Sphalerite-galena veins
- Veins formed during the second period of mineralization (quartz, carbonate, scheelite, and sulfide stages can be recognized):
  - Stibnite veins
  - Stibnite-scheelite veins
  - Scheelite-gold veins
- Veins formed during the third period of mineralization:
  - Quartz-dolomite-arsenopyrite-gold veins
- Veins formed during other periods of mineralization:
  - Quartz veins
  - Calcite-pyrite veins

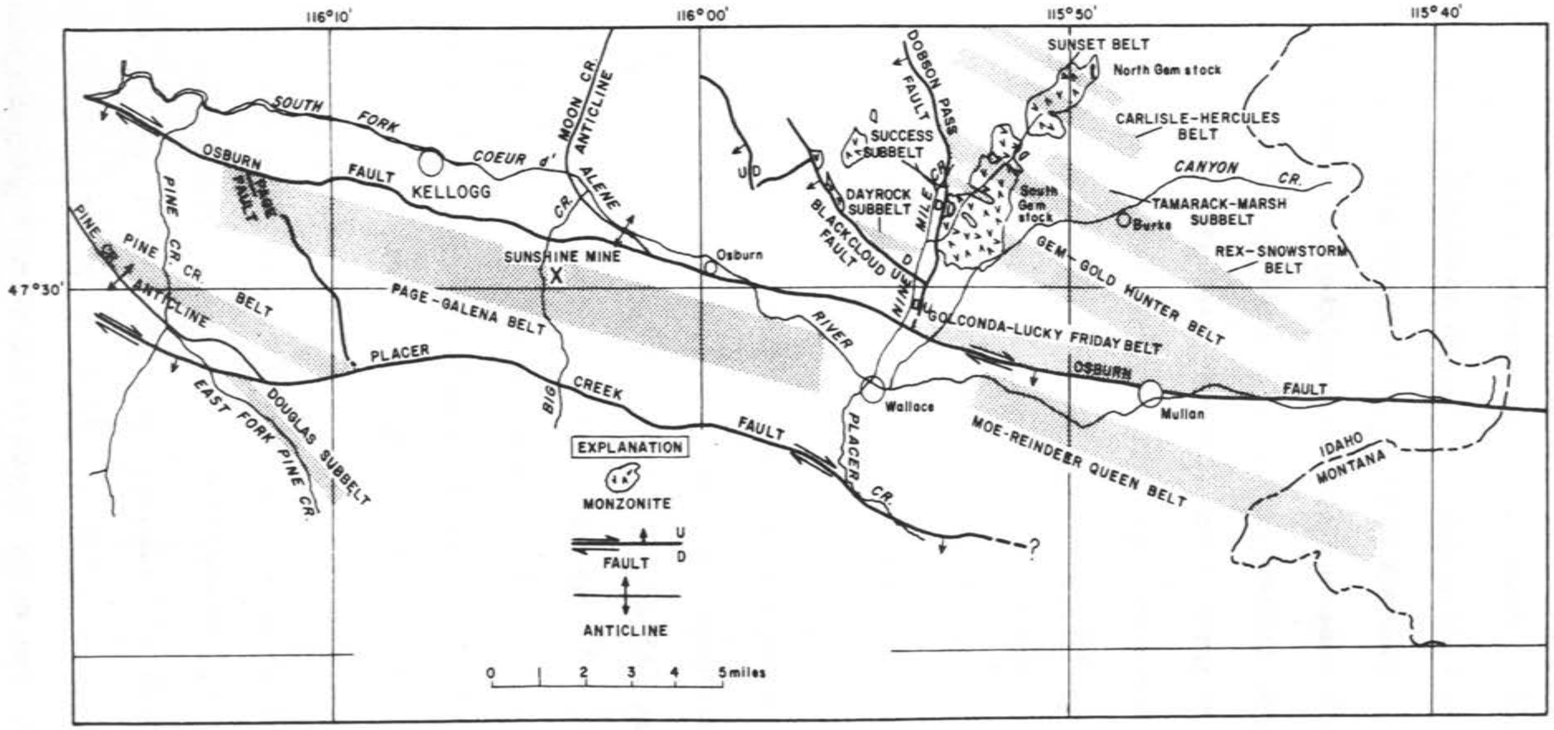

Figure 4. Mineral belts of the Coeur d'Alene district. (After Fryklund, 1964)

individual belts would strike west-northwest. The relatively nonproductive Moe - Reindeer Queen belt would then be associated with similar deposits now located in western Montana.

The fractures containing the main period veins appear to be related to the early stages of stress which ultimately produced the Osburn and related strike slip faults. Displacement along the fractures is generally slight; in some veins further slight movement after ore emplacement is evidenced by the occurrence of schistose or steel galena.

The rake of ore shoots in the veins is 90° or nearly so. The ore shoots vary in breadth from less than 100 feet to 4000 feet. As a rule the vertical dimension is greater than the breadth. There seems to be no relationship between the tenor of the ore and depth, nor does the angular relationship of vein and strata appear to influence the location of ore shoots, except for local vagaries. Hobbs and Fryklund (1968, p. 1426) state "...no apparent relationship to...any particular geologic datum plane" exists for ore shoots. Crosby, G. (1971, oral communication) concluded that the ore shoots are all located about the contacts between the upper and lower parts of the Prichard Formation, the Prichard and Burke Formations, and the Revett and St. Regis Formations. These are gradational zones in which lithology changes from predominantly quartzite to predominantly argillite or vice versa. A specific case of stratigraphic control was encountered in the system of veins in the Sunshine mine and is further discussed in Chapter III.

The minerals which occur in the veins are listed in Table 5. Crude but obvious zoning within the mineral belts and within the entire district has been demonstrated (Fryklund, 1964, pl. 4 and 5). The silicate gangue minerals are found in a zone concentric to the Gem stocks. The carbonate gangue minerals are linearly zoned in the Great Coeur d'Alene Mineral Belt. Siderite predominates in the veins of the Coeur d'Alene district whereas ankerite predominates in veins both to the southeast and northwest along the Great Coeur d'Alene Mineral Belt. Within the individual mineral belts, the general observed zoning is linear with copper (chalcopyrite of tetrahedrite) on the east, lead (galena) in the center, and zinc (sphalerite) on the west. Reconstruction of the pre-Osburn fault geological setting aligns the linear zones of the mineral belts into a planar pattern. The implicit cause of this pattern of zoning has not been postulated by any student of the district.

Table 5. Mineralogy of the main period veins of the Coeur d'Alene district. Principal ore minerals are denoted by upper case letters. (After Fryklund, 1964)

GALENA
SPHALERITE
TETRAHEDRITE
Chalcopyrite
Pyrrhotite
Pyrite
Arsenopyrite
Magnetite
Hematite
Gersdorffite
Boulangerite
Polybasite
Pyrargyrite
Bournonite
Barite
Quartz
Siderite
Ferroan-Dolomite and Ankerite
Calcite
Grunerite
Chlorite
Hornblende
Biotite
Garnet

Fryklund (1964) developed the generalized paragenetic sequence shown in Figure 5. He further subdivided the sulfide stage of Figure 5 into six stages which are listed in Table 4. Deviations from this sequence have been observed in many individual ore shoots (for example, Stringham, *et al.*, 1953, p. 1281). Fryklund subscribed to the view of Umbleby and Jones (1923, p. 134) that the stages resulted from distinct pulses of mineralizing fluids of different composition. Opening and closing of fractures during structural adjustments between stages would then account for the extreme variation of mineral assemblages found in veins throughout the district. This hypothesis explains the differences between veins within mines (for example, Kerr and Robinson, 1953, p. 511) and it is plausible as an explanation for some of the early stages of gangue mineralization. It is difficult, however, to reconcile this concept with the planar zoning observed in the district. No apparent structural evolution of the district could account for this pattern of zoning through the processes inferred above. Hence, it seems unteneable to attribute all variations of ore assemblages among the different ore shoots to changes in the plumbing of the mineralizing fluids.

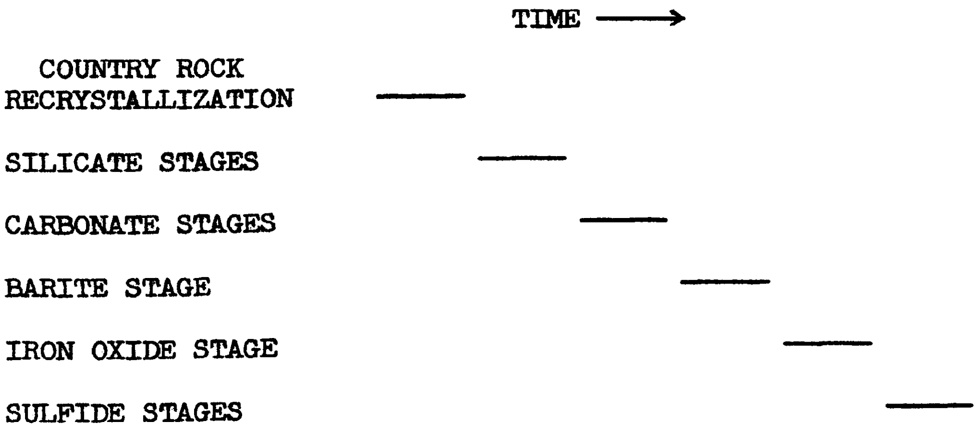

Figure 5. General paragenesis of the main period veins of the Coeur d'Alene district. (After Fryklund, 1964)

Associated with the mineral belts are broad zones of bleaching caused by hydrothermal alteration. The change in color of the rock is from dark green, gray, and purple to much lighter shades of green and gray. The altering fluids moved through the same fractures as the mineralizing fluids which formed the veins. Early researchers erroneously concluded that the bleaching was the result of massive sericitation of the wall rock, because this mineral is more readily observed in bleached rocks than in unbleached rocks. Anderson (1949) concluded that this supposed large scale potassic alteration represented by bleaching resulted from potassium rich fluids from the same source as the fluids which caused the endomorphic alteration that he observed in the Gem stocks. Mitcham (1952) concluded that there was no detectable difference in sericite content between bleached and unbleached rocks. Weis (1964) concluded on the basis of chemical analyses of three pairs of bleached and unbleached rocks that no significant chemical differences existed between the two types of rocks. He attributed the causes of bleaching to alteration of hematite to goethite, degradation of green chlorite, and the destruction of unidentified carbonaceous material. Magnetite was also altered to goethite, but the small concentrations involved did not contribute noticeably to color change.

The bleaching does not affect the fine grained hematite found in alteration haloes about Precambrian uraninite veins which occur in bleached rocks. The bleaching is therefore presumably of Precambrian age and precedes the main period mineralization by a great expanse of time. This conclusion is supported by the facts that large volumes of bleached rocks are barren and many ore shoots occur outside bleached rocks. One difficulty of this interpretation is that it places a very early age and long duration for the shearing stresses to which the fractures that carried the bleaching fluids are related. This does not seem to be consistent with the otherwise complex structure of the area.

Two opposing hypotheses concerning the age of the main period ore deposits are unresolved at the present time. One school of thought considers the deposits as postdating the Gem stocks and cites examples of veins encroaching upon monzonitic material (Fryklund, 1964, p.33). Proponents of the opposing view cite the low radiogenic lead content of the ore deposits (Table 6) which corresponds to a single stage model age of Precambrian (Long, et al., 1960; Zartman and Stacey, 1971). Recent work by Gott and Botbol (1971) indicates that anomalous concentrations of sulfur in rocks are coincident with the mineral belts. These anomalous zones cross the Gem stocks as a pyrite rich zone whereas the mineral belts do not cross the stocks. Gott and Botbol hypothesize that the monzonite assimilated the preexisting sulfide deposits, converting what would have been igneous magnetite to pyrite. What happened to any preexisting ore metals is a matter left unconsidered. Of course, the alternative view could be taken that emplacement of pyrite was favored in the monzonite during post-Gem stock mineralization along the mineral belts. Anderson (1949) concluded that the pyrite in the stocks was the last mineral to be deposited during post-magmatic endomorphic alteration of the stocks.

Table 6. Lead isotope data for ore leads of the Coeur d'Alene district. (a) Average of 15 observations by Long, et al. (1960, p. 651). (b) Average of 7 observations by Zartman and Stacey (1971, p. 854).

ISOTOPE RATIOS	206/204	207/204	208/204
(a)	16.44	15.58	36.52
(b)	16.249	15.389	35.957

Model Lead Age: Precambrian

The crosscutting relationships described by Fryklund are strong evidence for a post-Gem stock age for the ore deposits. Even in a situation where a monzonite appears to cut a vein in gross pattern, careful examination demonstrated that "...irregular veinlets of galena and sphalerite penetrate the dike for as much as 6 inches...in a delicate network that seems no different from other replacement veinlets" (Fryklund, 1964, p. 33).

Of course, the model lead isotope age mentioned above is based on the assumption that the ore lead was derived from a source of uniform uranium, thorium, and lead content and was transported to the ore deposit without interruption or mixing with other lead. This assumption is accepted by Zartman and Stacey (1971) in their discussion of mineralization ages in this and surrounding districts, and they recomment the use of lead isotope ages of the ore deposits as a tool for unraveling the complex structural history of this area. Alternate interpretations are possible. For example, Reynolds and Sinclair (1971) proposed a multistage model for ore leads emplaced 150 million years ago in the Kootenay Arc area that required the separation of lead from its primary source into the upper crust in a system closed with respect to lead, uranium, and thorium at about 1500 million years ago. In short the inferences drawn from single stage model lead age determinations are not irrefutable.

Fryklund (1964, p. 49) postulated three different sources for the Coeur d'Alene vein minerals, (1) a "shallow point" source, (2) a "deep linear" source, and (3) a "deep point" source. The shallow point source, presumedly the roots of the monzonite stocks, was the source of the silicate vein minerals which exhibit concentric zoning around these stocks. The carbonate gangue minerals, hematite, and barite found throughout the Great Coeur d'Alene Mineral Belt were produced from the deep linear source for which "...in keeping with tradition, a magmatic sources is suggested" (Fryklund, 1964, p. 50). The deep point source was the source of the sulfide stages found in the Coeur d'Alene district, the only notable concentration of sulfides along the Osburn shear zone. Supposedly, in this structural knot the deep, throughgoing shear zone tapped a non-magmatic (for consistency with lead isotope data) source at great depth (mantle?).

An alternate hypothesis, which incidentally is consistent with lead isotope data, was proposed by Hershey (1916) who thought that the lead and zinc could be traced to the Upper Prichard Formation where it occurred as disseminated mineralization. He hypothesized that the metals were mobilized by fluids derived from the monzonite stocks during their emplacement. Sorensen (1972) has recently elaborated on Hershey's concept outlining some additional evidence for this hypothesis.

III. GEOLOGY OF THE SUNSHINE MINE

A. General Geology

The Sunshine mine is located in the western end of the "Silver Belt", a subdivision on the eastern end of the larger Page - Galena mineral belt in which silver bearing tetrahedrite is the predominant ore mineral. The Silver Belt is bounded on the north by the Osburn fault and on the south by the Placer Creek fault. The area is transected by a series of sub-parallel west-northwest trending faults. Blocks between faults are folded and tilted to diverse orientations. Rocks of the Wallace, St. Regis, and Revett Formations outcrop within the Silver Belt. The surface geology of the western Silver Belt is outlined in Figure 6.

Veins of the Sunshine mine occur in rocks of the Revett and St. Regis formations in the crumpled northern limb of the overturned Big Creek anticline. The veins tend to parallel the axial plane of this fold which trends west-northwest and dips approximately 60° to the south. The block containing the veins of the Sunshine mine is a structurally depressed portion of the Big Creek anticline which is bounded on the north by the Osburn fault and on the south by the Big Creek fault (Figure 7).

B. Description of the Sunshine Ore Deposits

A plan view of the 3100 level of the Sunshine mine (Figure 8) outlines the important veins within the mine. Ore shoots on these veins consist of massive argentian tetrahedrite with lesser amounts of galena and chalcopyrite. The major gangue mineral is siderite in which the

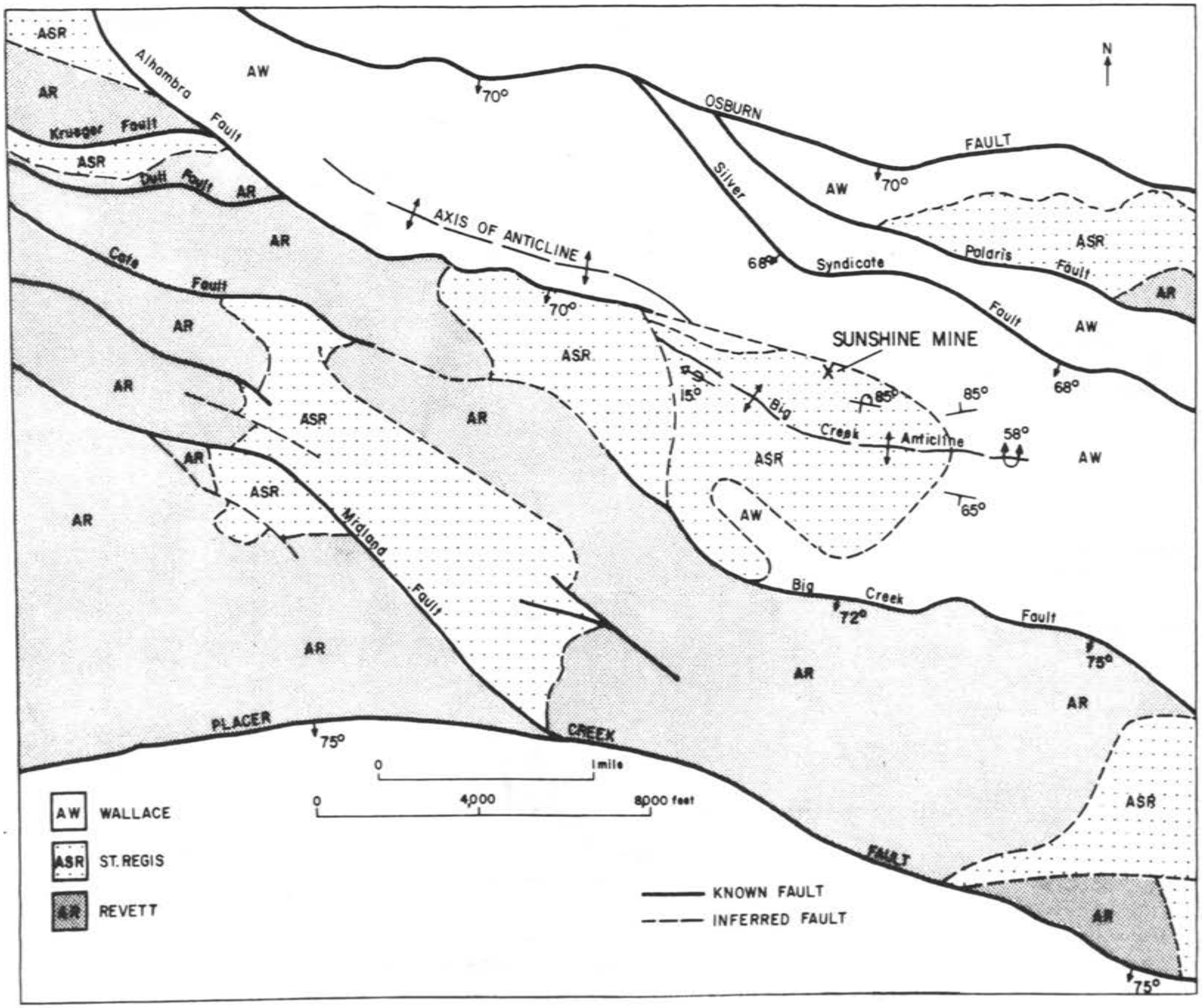

Figure 6. Surface geology of the western Silver Belt. (After Colson, 1961)

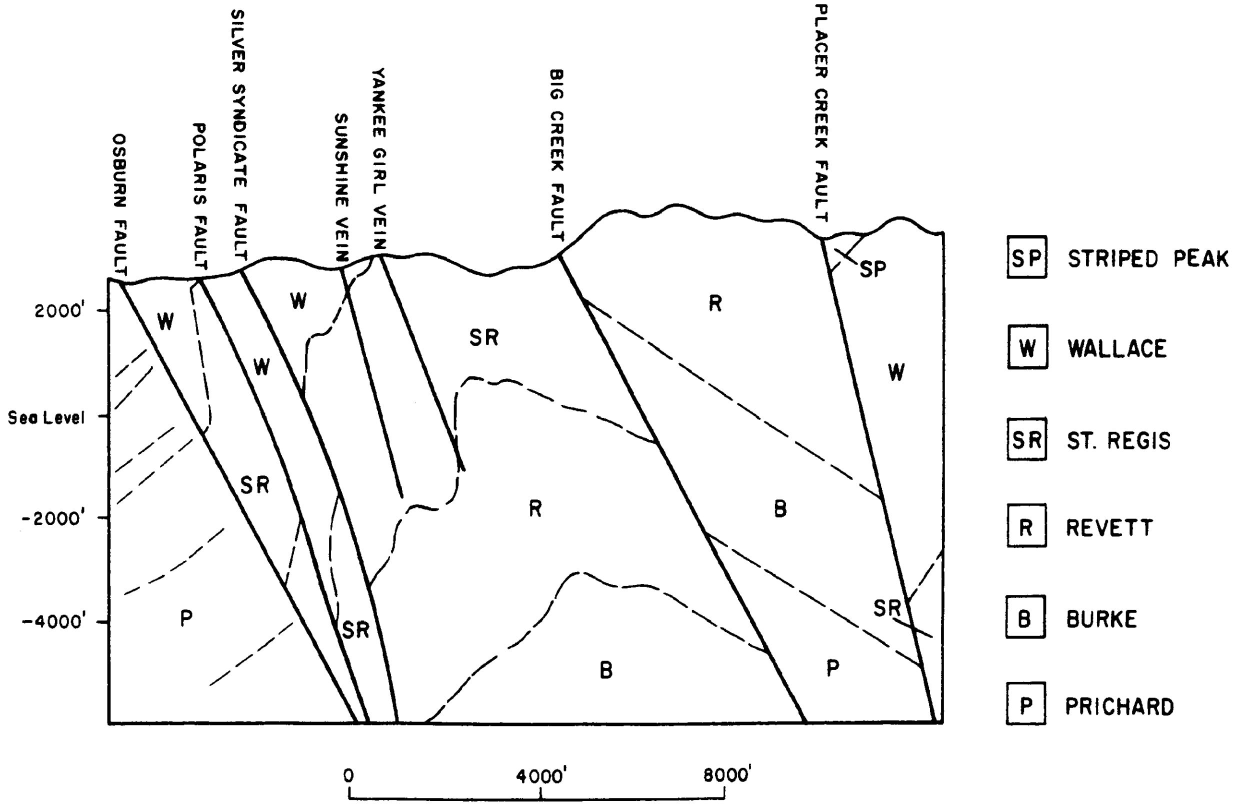

Figure 7. Cross section looking east through the Big Creek anticline. (After Colson, 1961)

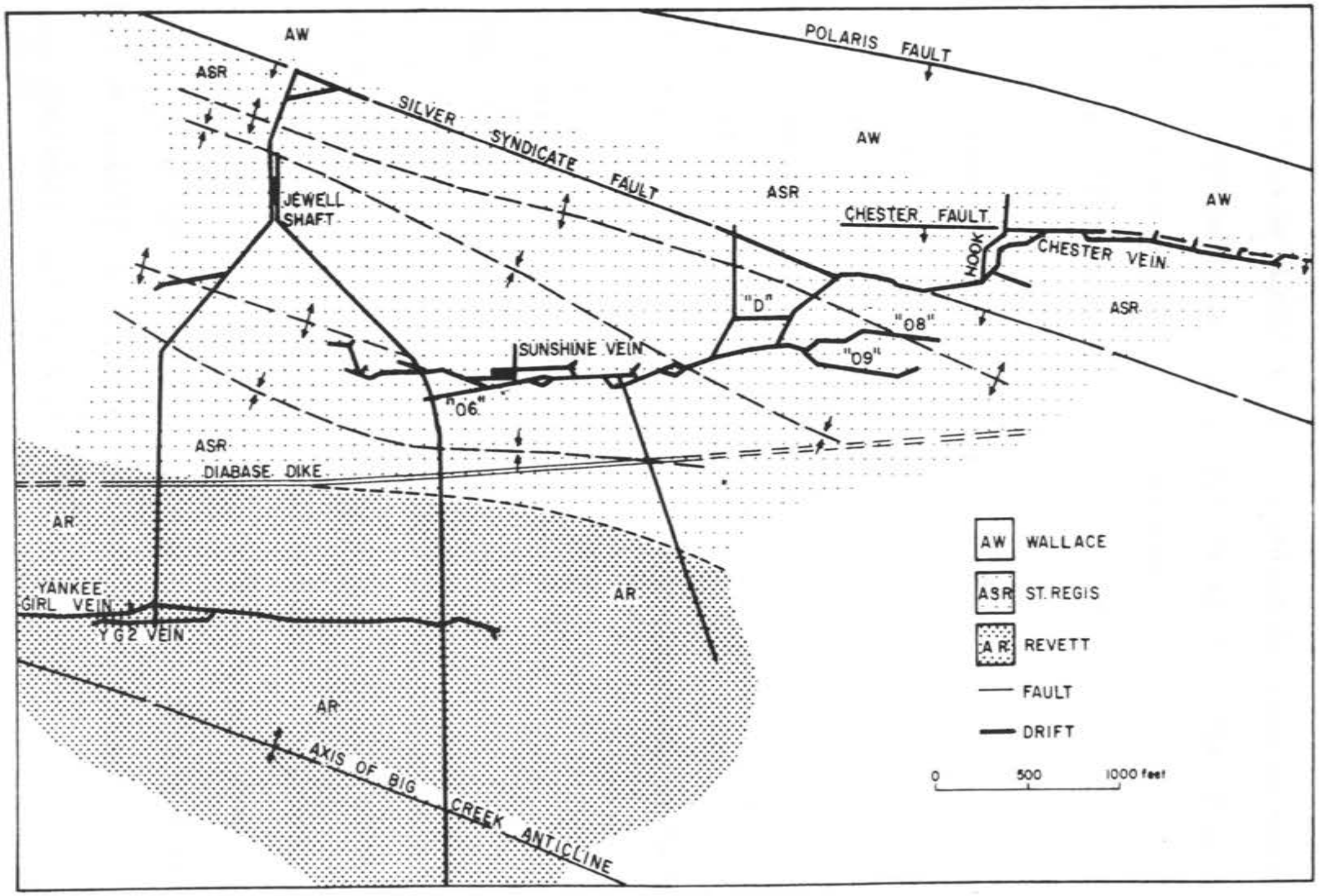

Figure 8. Plan view of the 3100 level of Sunshine mine. (After Colson, 1961)

sulfides occur as stringers. Quartz which occurs in varying amounts, is the second most abundant gangue mineral. Pyrite also occurs in large masses in the vein.

Kerr and Robinson (1953) in a discussion of uranium mineralization in the Sunshine mine postulated the following sequence of events in the development of the ore deposits in the mine:

1. Regional deformation; formation of Big Creek anticline; complex faulting.

2. Early uranium mineralization; some early siderite emplacement.

3. Deformation; changes in vein openings; segmentation of uraninite veins.

4. Main tetrahedrite-siderite mineralization, forming the major silver bearing veins.

5. Deformation resulting in minor cross faulting of tetrahedrite bearing veins.

6. Quartz-galena mineralization.

7. Further deformation.

Kerr and Robinson discussed the occurrence of bleaching in the Sunshine mine and concluded that bleaching preceded the early uranium mineralization and was therefore of Precambrian age.

R. J. Anderson (1940) described the microscopic features of the Sunshine ore, using samples presumedly obtained from the Sunshine vein (Figure 8). He concluded that siderite was the earliest mineral formed in the vein, and that this mineral continued to form throughout the deposition of other minerals in the vein. Pyrite and arsenopyrite were next in the sequence of deposition followed by quartz which also continued to be deposited throughout subsequent mineralization. Argentian tetrahedrite was deposited after pyrite and arsenopyrite. Galena then followed tetrahedrite mineralization. Galena occurred in a separate vein which intersected the main tetrahedrite vein and followed it in some areas and in other areas if present it was found in the immediate hanging wall. Bournonite sometimes occurred as a reaction product between galena and tetrahedrite. Minor chalcopyrite mineralization was described as the final stage of sulfide deposition in the veins.

Twenty polished sections of the Chester vein were prepared and studied by the writer to determine if the paragenesis reported for the Sunshine vein was valid for the Chester vein. The same sequence of deposition as reported by R. J. Anderson was observed with the following exceptions.

Siderite did not appear to precede pyrite in any section. The relationship between pyrite and arsenopyrite was established, pyrite having been deposited first as demonstrated by distinct veining of that mineral by arsenopyrite. Some boulangerite was observed in hand specimens collected from the lowest levels of the mine. It was observed to be deposited subsequent to tetrahedrite, and it is considered to be the final stage of metallic mineralization in the Chester vein.

It was noted that siderite was formed throughout sulfide emplacement, but it is the author's opinion that crosscutting relationships are the result of remobilization of previously existing siderite in the vein, and that the bulk of the siderite was emplaced early in the formation of the Chester vein.

C. Structural Control of Ore Shoots

Structural control has been demonstrated for many of the ore shoots in the Sunshine mine. Ore shoots on the Silver Syndicate fault are controlled by branching of that fault. Where no branching is present, only gouge is present (Colson, 1961, p. 31). But, when the Sunshine vein passes from beds of parallel strike into beds divergent from the vein in strike, branching of the vein occurs and the grade of the ore shoot decreases (Colson, 1961, p. 33). The Chester vein follows the Silver Syndicate fault east for a distance then diverges from it in a northerly direction until it intersects the Chester fault which it again follows in an easterly direction. The northerly divergence is a zone of tension fracturing known as the "Hook" and contains the richest part of the ore shoot.

D. Stratigraphic Control of Ore Shoots

Several instances of stratigraphic control of ore shoots in the Sunshine mine have been described by D. Long (oral communication, 1970). The bottoming of the Sunshine vein ore shoot occurred when the vein passed from the St. Regis into the Revett Formation. Conversely, the top of the ore shoot on the Yankee Girl vein is located at the line where the vein passes from the Revett into the St. Regis Formation. The ore shoot on the Chester vein apexes at the 2300 level near the contact of the Wallace and St. Regis Formations and as this contact rakes easterly at lower levels on the vein, the border of the ore shoot also rakes easterly.

E. Previous Investigations of Wall Rock Alteration in the Sunshine Mine

Kerr and Robinson (1953) discussed the occurrence of hematite haloes about uranium bearing veins. The occurrence of these haloes superimposed on bleached rocks which elsewhere contained goethite as an alteration product of hematite was cited as evidence for a Precambrian age for bleaching.

Mitcham (1952) in his study of the "Silver Belt" included some results of studies conducted on samples from the Sunshine mine. He observed from mineralogical analyses that there was a coincidence between bleaching and low concentrations of calcite. He also conducted a study of ore grade versus sericite content of the wall rock immediate to the vein. He concluded that an inverse relationship existed between sericite content and ore grade. Mitcham also concluded that bleaching was not a result of intensive sericitation as had previously been accepted in the district, and stated that the sericite content of the wall rock was the result of mild regional metamorphism prior to mineralization.

IV. SAMPLING PROCEDURE

A. Location and Geology of Sampled Traverses on the Chester Vein

Samples were collected from the 4400, 4600, and 4800 mining levels on the Chester vein from diamond drill hole cores and crosscuts. On these levels the main haulage drifts parallel the vein. Crosscuts permit access to the vein at regular intervals and diamond drilling on a regular spacing provides assay information. Figure 9 shows the location of the traverses in the plane of the vein. The projection of 10 shaft is included and would be approximately coincident with the "Hook" portion of the Chester vein in which occur the tension fracturing and the resultant very rich ore shoot. To the east of the "Hook" where the vein joins the Chester fault, tension fracturing becomes much less important. In this area the productive parts of the vein rarely exceed 10 feet. Unbleached rocks are exposed on the 4400 and 4800 levels. The unbleached rocks are generally about 100 feet north of the vein on these levels, but in DDH 4400-806 unbleached rocks were encountered about 60 feet south of the barren vein at that point.

This less complicated area was chosen for sampling. Plan views of the levels are included in Figures 10 through 12. The location of the vein and unbleached rocks are outlined in these Figures. Minor faults and fractures were prevalent and are not included. Only those diamond drill holes which were sampled are included in the Figures.

B. Collection of Samples

Previous investigations (E. Bolter, oral communication, 1969) indicated that variations in the geochemistry of the wall rocks would

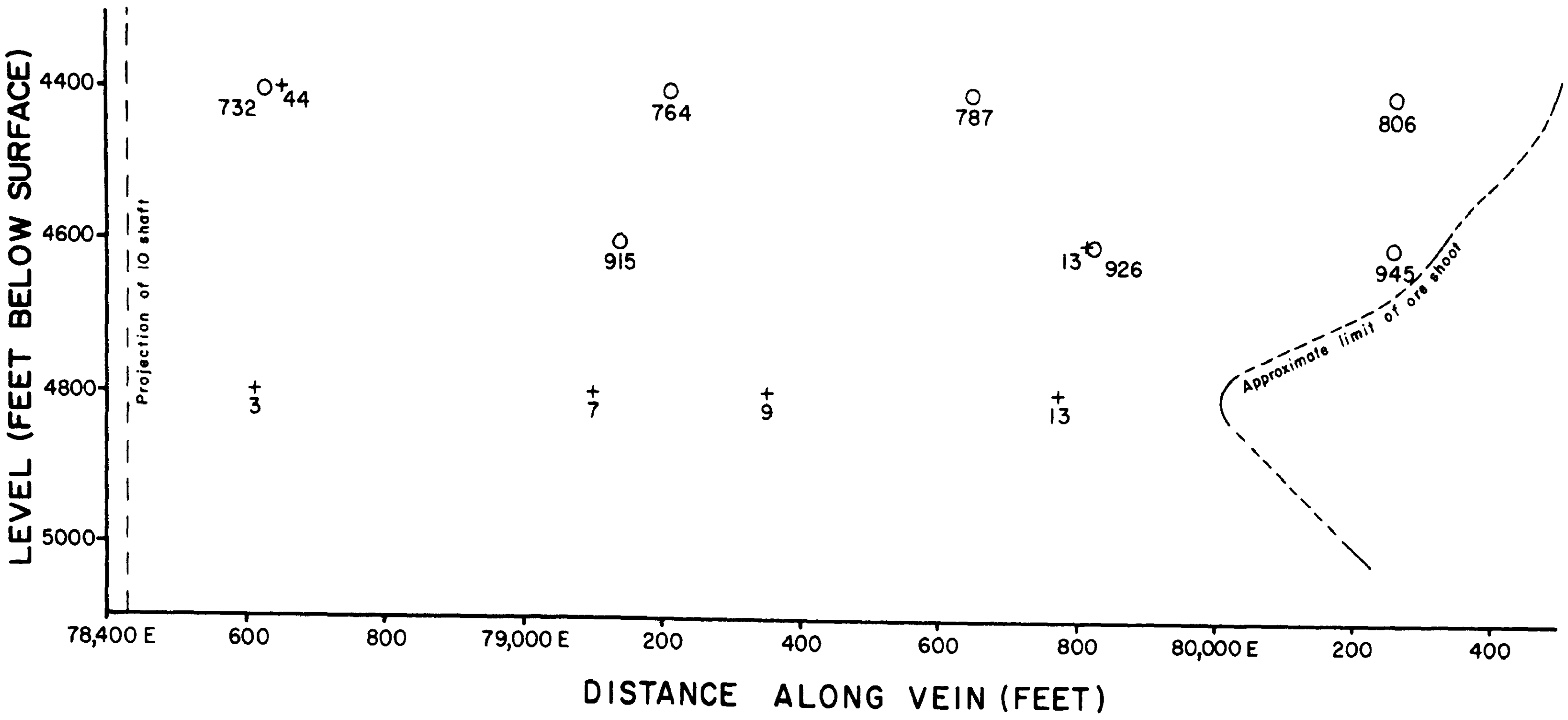

Figure 9. Location of sample traverses projected onto the plane of the Chester vein, looking north. Circles represent diamond drill holes; crosses represent crosscuts. The mine level in conjunction with the traverse number completes the identification of the traverse.

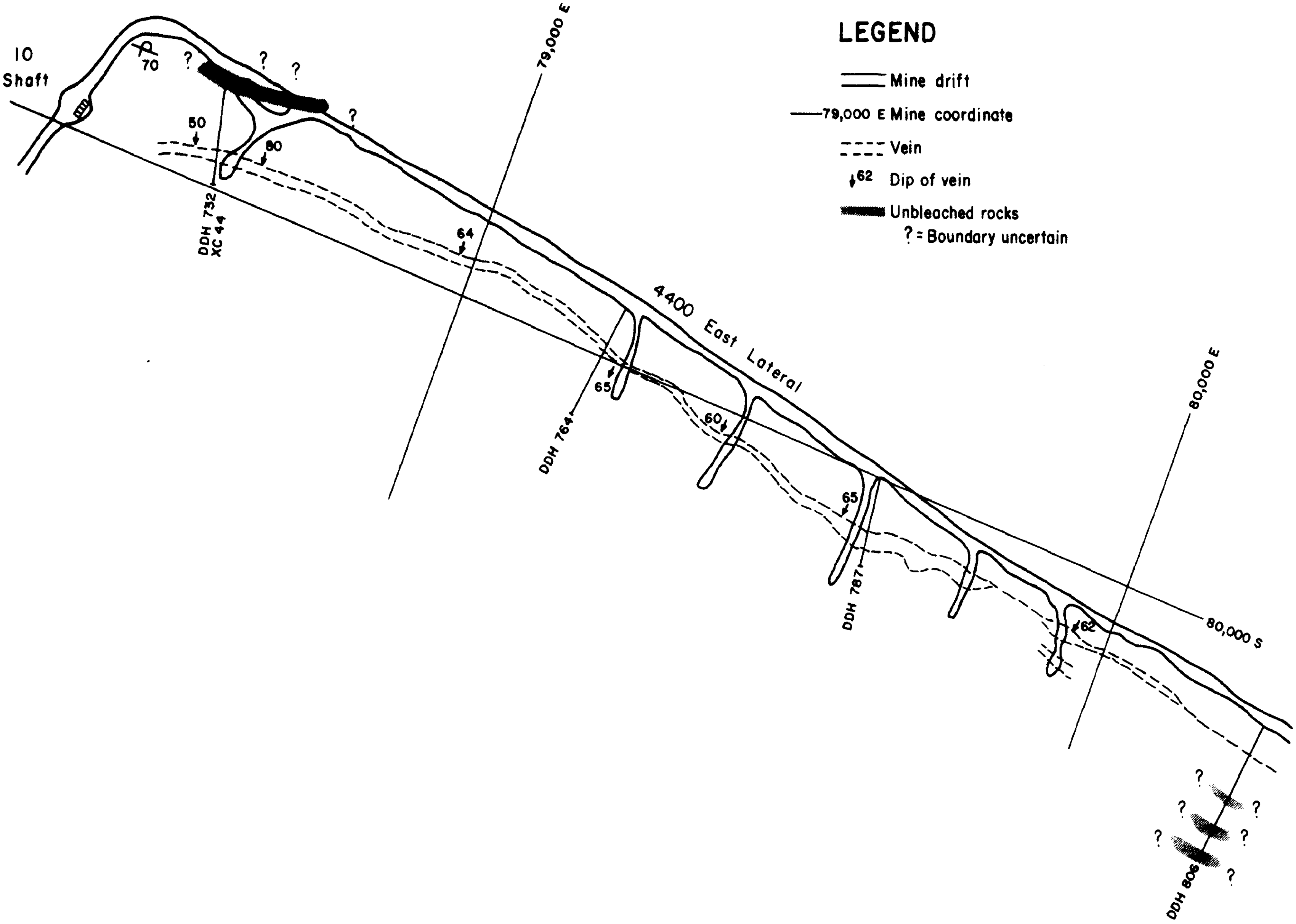

Figure 10. Location of traverses sampled on the 4400 level of the Sunshine mine.

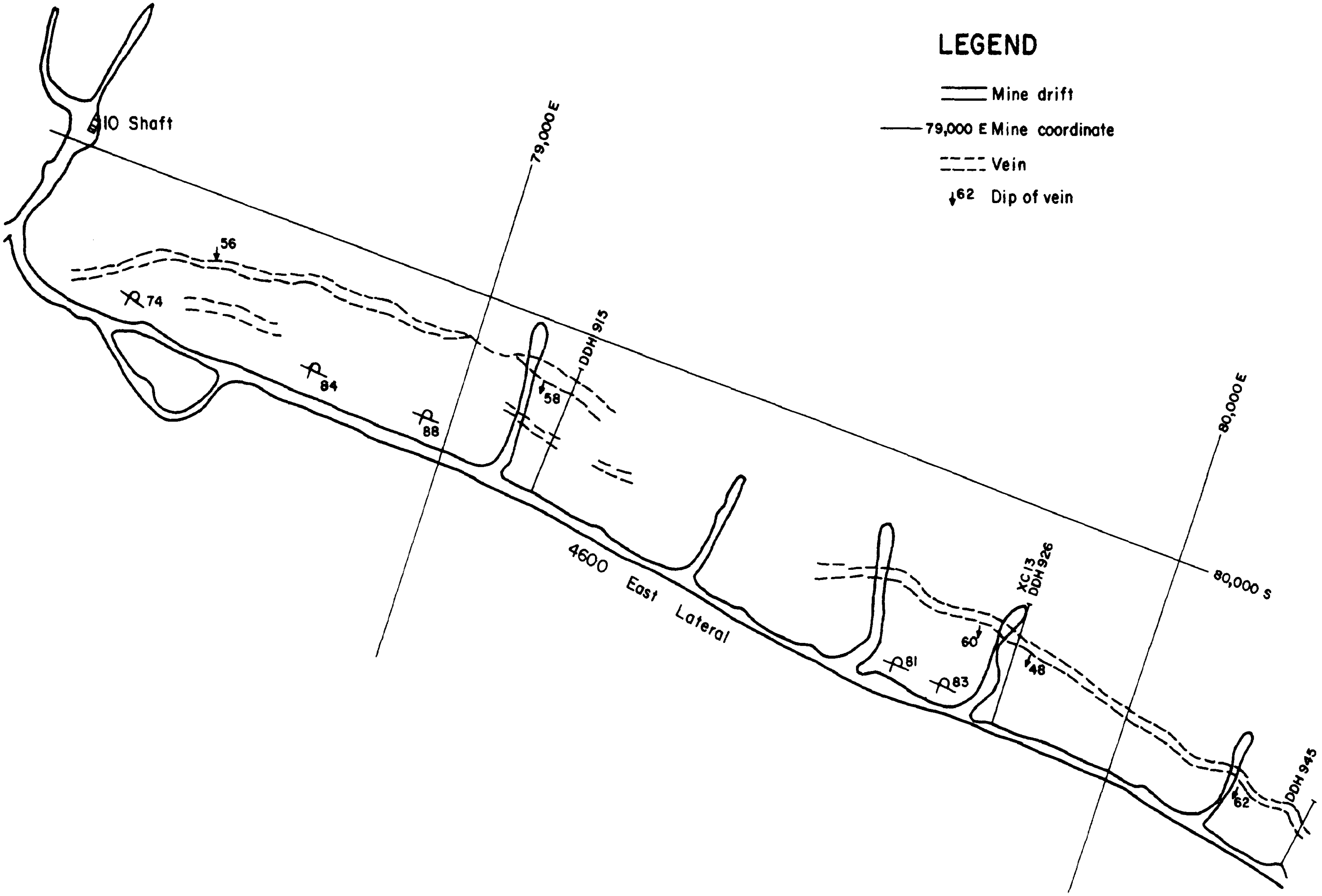

Figure 11. Location of traverses sampled on the 4600 level of the Sunshine mine.

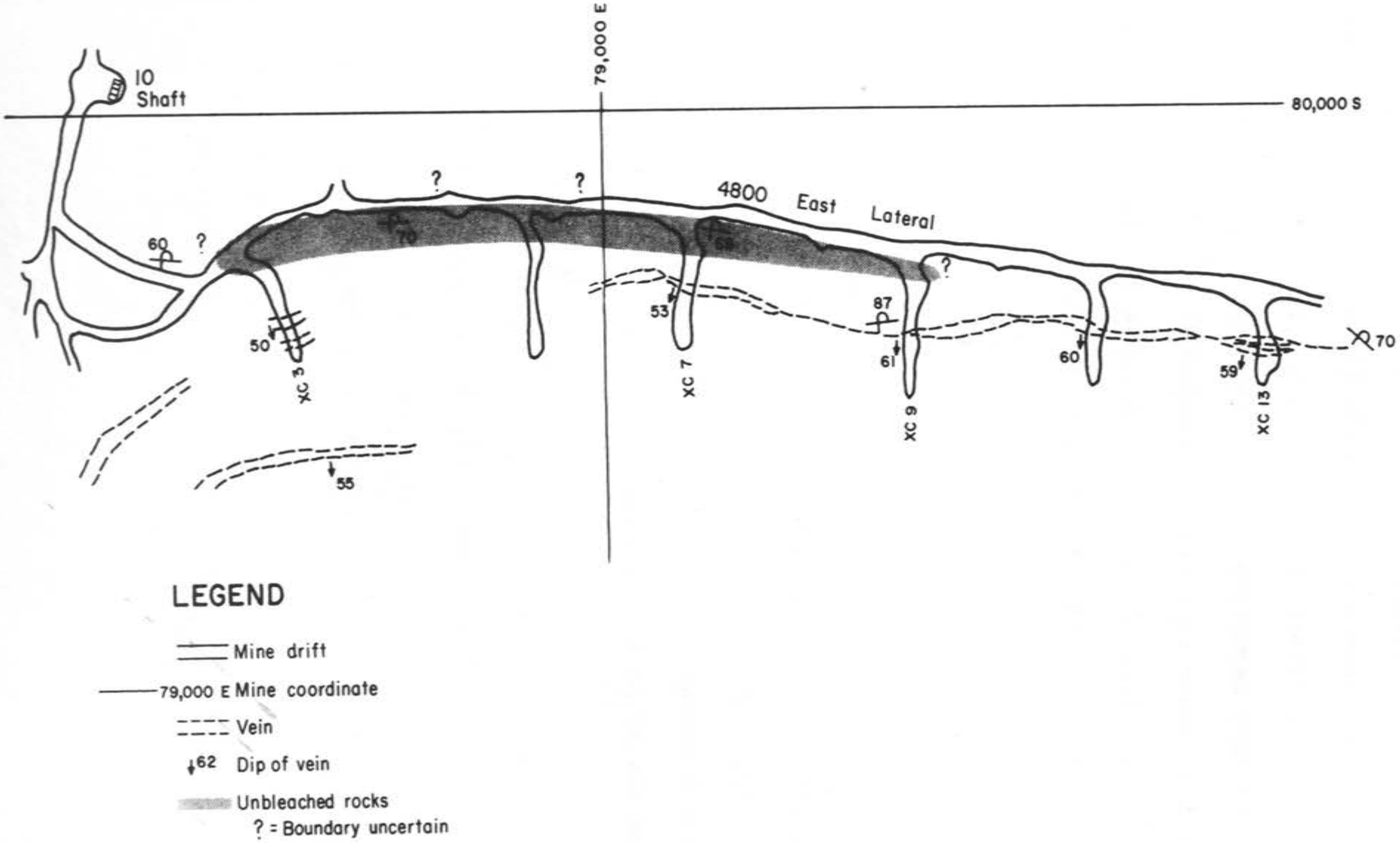

Figure 12. Location of traverses sampled on the 4800 level of the Sunshine mine.

be most pronounced in the immediate vicinity of the vein. Accordingly, samples were collected at close intervals near the vein, and at increasing intervals as distance from the vein increased.

Samples were collected from two different sources, (a) crosscuts (labeled "XC"), and (b) diamond drill hole cores (labeled "DDH"). From mine level maps traverses were selected to give optimum coverage of the portion of the mine being sampled. In the actual sampling, modification of the sampling plan was necessary because of inaccessibility of some crosscuts and the unavailability of all or parts of some cores.

Crosscuts were sampled by measuring along the drift with a tape measure and sampling at intervals with a crack hammer and pick. Approximately one square foot was sampled by chipping. Geologic information was noted when feasible. Lagging and raise timbering frequently obscured the vein and dust on walls further hampered observations. Temperatures in the dead end crosscuts were in excess of 100°F, hampering sampling and data recording.

Sampling of cores was done in the core storage shed of the Sunshine surface plant. Approximately one foot sections of core were sampled by splitting with a core splitter. Geologic observations other than lithology and the presence of gouge or mineralization were not feasible.

V. ANALYTICAL PROCEDURES

A. Sample Preparation

Samples were allowed to dry at room temperature in the sample bag. From each sample a representative fraction sufficient to provide at least 10 grams of powder was selected. This was initially reduced by hand to minus ¼ inch in a steel mortar. Final reduction was accomplished by grinding in a mechanical reciprocating steel ball mill for 10 minutes. The final powder was determined to be more than 90 percent minus 200 mesh by sieving.

Dissolution of the sample for analysis by atomic absorption spectroscopy was accomplished by a procedure modified after Belt (1967, p. 676).

> Weigh 1 g. ± 1 mg. of rock powder into a 100 ml. teflon beaker. Wet with distilled water, then add 20 ml. 48 % HF, 10 ml. conc. HNO_3, and 2 ml. 60 % $HClO_4$. Digest at least 4 hours. On a sand bath evaporate to dryness and continue heating till fuming ceases. Add 10 ml. conc. HCl and boil for 5 minutes. Then add 20 ml. distilled water and boil an additional 5 minutes or until solution is clear. Cool to room temperature, dilute to 50 ml. in a volumetric flask, transfer to a small linear polyethylene bottle for storage.

Initially, an attempt was made to effect final solution with concentrated nitric acid. Several samples yielded a voluminous quantity of flocculent brown precipitate. This was readily dissolved by addition of concentrated hydrochloric acid. It was concluded that this precipitate was $Fe(NO_3)_3 \cdot 9H_2O$ which is only slightly soluble in nitric acid (Handbook of Chemistry and Physics, 1966, p. B-185). Subsequent analyses demonstrated high iron concentrations in samples which had yielded heavy precipitates in nitric acid.

The use of hydrochloric acid presented no problems with precipitates. Lead chloride was observed in only one sample solution and it redissolved completely after a matter of minutes. The characteristic curdy silver chloride was not observed in any sample solution. Apparently, these metals were maintained in solution through complexing by excess chloride ions.

Solution by the method was not complete. Minor residues were observed after treatment. These residues were generally much less than 0.1 percent of the original sample. Examination of the residues by petrographic microscope revealed that the principal mineral in the residue was tourmaline, an ubiquitous accessory mineral in the country rocks. It was then concluded that the small amounts of residues would not have a significant effect on the analytical results.

B. Atomic Absorption Analysis

Aluminum, magnesium, calcium, sodium, potassium, manganese, iron, lead, copper, zinc, and silver were analyzed by atomic absorption spectroscopy. Analysis of the sample solutions was performed on a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer equipped with three-slot Boling burner and Texas Instrument Servo/Riter II chart recorder. The instrument parameters recommended by the Perkin-Elmer handbook (1970) were used except as noted in the following paragraphs. Further details on the general technique of atomic absorption spectroscopy is presented by Slavin (1968).

The analyses of sodium and potassium were performed on the secondary analytical wavelengths 3302.3 Å and 4044.1 Å, respectively. This permitted the direct determination of these metals in the sample solution. Schallis and Kahn (1968) have demonstrated that the characteristic ionization interference observed for sodium and potassium at their primary analytical lines is not observed at the higher concentrations analyzable at the less sensitive secondary analytical lines.

Iron was analyzed on the 3824.4 Å line which is 87 times less sensitive than the primary line at 2483.3 Å (Slavin, 1968, p. 116). By crossing the burner perpendicular to the hollow cathode beam, sample path length was shortened permitting analysis of iron up to 6000 ug/ml in solution.

Magnesium and calcium were analyzed by diluting an aliquot of the sample solution 1:5 to reduce the concentration into the working range of the instrument. The analyses were performed using a nitrous oxide-acetylene flame. This prevented chemical interferences by aluminum and other elements which combine with calcium and magnesium in the lower temperature air-acetylene flame and form refractory compounds. Ionization in the high temperature flame was controlled by adding 1000 ug/ml sodium to the samples when making the dilutions.

A portion of the above dilutions was made in glass sample vials. Apparent high concentrations of calcium were present in these solutions. Extraction of clean vials for one minute with five milliliters of concentrated hydrochloric acid leached as much as 2.5 micrograms of calcium from the vial walls. Magnesium was not leached. Subsequently, the contaminated calcium values were isolated and discarded. Analysis of calcium for these samples was performed on the original sample solutions using the nitrous oxide-acetylene flame and a crossed burner. Tests on standard calcium solutions with varying amounts of potassium established that ionization of calcium was controlled by the concentrations of potassium present in the sample solutions.

Except in vein samples, silver was not present in concentrations high enough to permit direct determination by atomic absorption spectroscopy (above 1 µg/g in the rock). The similarity of the values that could be determined with the zinc and copper values for those samples in proximity to the vein indicated that silver would not yield significant distributions in the altered wall rock. E. Bolter (oral communication, 1971) has since indicated that silver is highly mobile in the wall rock zone and that an aureole may exist at concentrations below the present detection limits of standard atomic absorption methods which is about 5 µg/l in solution under optimum conditions (Slavin, 1968, p. 60).

Precision of the analyses was checked by independent preparation and analysis of 13 duplicate samples selected at random. For each element, the average coefficient of variation was calculated from the 13 duplicate pairs. The results of these calculations are included in Table 7. It should be remembered that these results are representative of the entire analytical process from grinding, through weighing and dissolving, to the atomic absorption analysis. Whereas the average coefficient of variation ranges from 1.8 to 8.1 percent for these analyses, atomic absorption determinations on a single sample solution frequently provide a coefficient of variation of less than 1.0 percent. The high coefficients of variation for the trace metals result from the low concentrations present in the wall rocks. The relatively high coefficients of variation reported herein for calcium, potassium, and manganese appear to have resulted from inhomogeneities in specific sample powders. This hypothesis is supported by the high positive correlations that exist between iron and manganese and between aluminum and potassium (discussed in Chapter VI) which indicate relatively constant ratios of these elements in sample solutions.

Table 7. The average coefficients of variation calculated from thirteen duplicate analyses of elements analyzed by atomic absorption.

Element	Average Coefficient of Variation in Percent
Aluminum	1.8
Magnesium	1.8
Calcium	3.1
Sodium	2.5
Potassium	4.3
Manganese	3.1
Iron	3.0
Lead	8.1
Copper	6.7
Zinc	3.9

C. X-ray Emission Analysis

Sample powders from traverses 4400-732 and 4600-915 were analyzed for silicon and sulfur by x-ray emission spectroscopy. The samples were pelletized at 10,000 psi in a LAMCO die assemply from L. A. McDaniel Company, Kansas City, Kansas. Sufficient sample was used to yield a 0.2 inch thick pellet which was enclosed in a 0.1 inch cup of boric acid in the final pelletizing step.

The analyses were performed on a General Electric XRD-5 X-ray Spectrometer using a helium atmosphere and a gas flow proportional counter. A gas of 90 percent argon and 10 percent methane was used in the counter.

Standards for silicon were U. S. Geological Survey standard rocks and previously analyzed quartz monzonite. Standards for sulfur were mixtures of quartz and pyrite ranging from 0.05 to 5.0 percent sulfur (Z. Al-Shaieb, oral communication, 1971).

The range of silicon values compares favorable with previously reported analyses (Weis, 1964, p. 92 and 93). Duplicate analyses provided an average precision of approximately 4 percent. However, no estimate of the accuracy of the analyses was possible.

Duplication of sulfur analyses in two different analytical runs provided very dissimilar results although the relative values did not change appreciably. The reported values are useful only as relative concentrations and should not be considered as absolute values.

VI. DISCUSSION OF THE DATA

A. Presentation of the Data

Appendix A, Tables A-1 through A-13 contain the results of the analyses of aluminum, magnesium, calcium, sodium, potassium, manganese, iron, lead, copper, and zinc. Tables A-14 and A-15 contain the results of analyses for silicon and sulfur. Major element data are reported in terms of weight percent of the element. This is in accordance with the observation of Tooker (1963, p. 40) that the reporting of elemental abundances is a more accurate representation for a discussion of wall rock alteration processes. Trace element data are reported according to standard practice in terms of micrograms of metal per gram of rock.

B. Observations from Concentration Versus Distance Plots

For each of the thirteen traverses, plots of major element concentration versus distance were prepared from the data in Appendix A. This was done by computer program written for the IBM 360/50 Digital Computer with off-line printing done with a Calcomp 566 Plotter.

The concentrations of calcium in unbleached rocks and in immediately adjacent bleached rocks are generally up to two orders of magnitude greater than in bleached rocks closer to the vein. It is concluded that bleaching removed significant quantities of calcium, and that at some distance from the channelway of the bleaching fluids (now the vein) the ability of the bleaching process to remove calcium abruptly diminished although the physical aspects of bleaching are evidenced for a short distance into the wall rock beyond this point. This feature is exhibited in Figure 13 which shows calcium distribution in DDH 4400-732

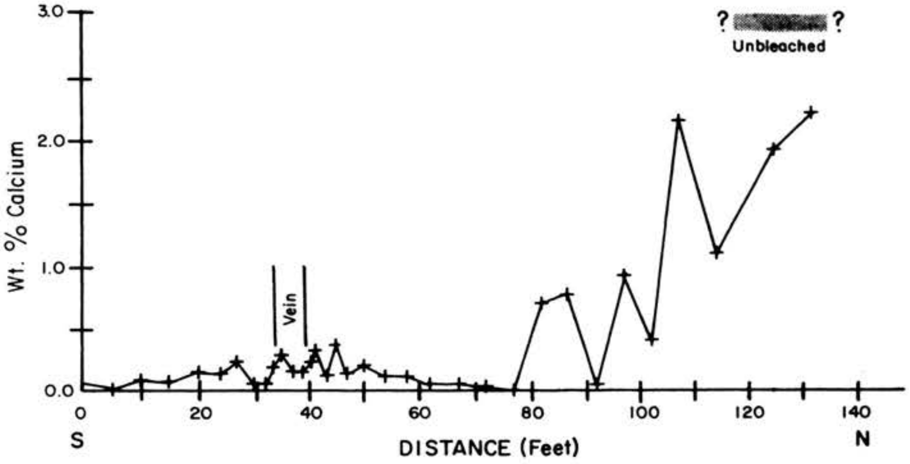

Figure 13. Distribution of calcium in DDH 4400-732.

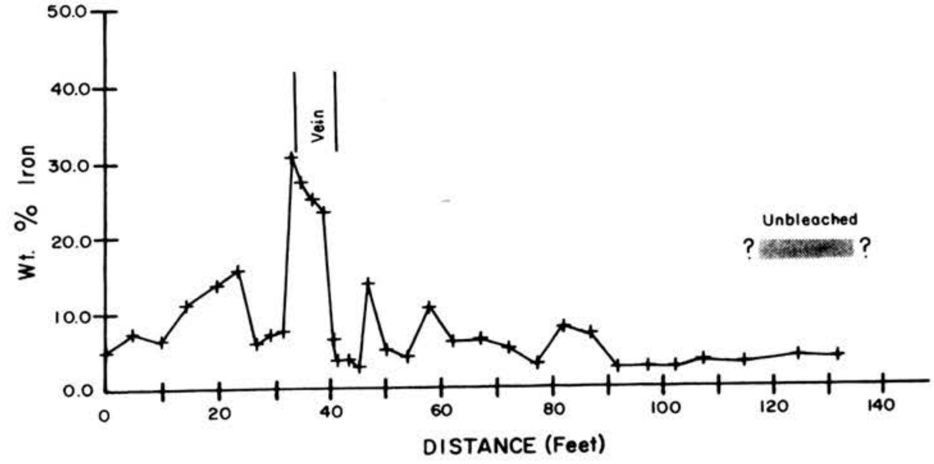

Figure 14. Distribution of iron in DDH 4400-732.

(Table A-1). This feature is also shown by data from XC 4400-44, DDH 4400-787, DDH 4400-806, XC 4800-3, XC 4800-7, and XC 4800-9 as shown by Tables A-2, A-4, A-5, A-10, A-11, and A-12, respectively. It should be noted that DDH 4400-764 and XC 4800-13 (Tables A-3 and A-13, respectively) contained unbleached rocks but did not exhibit high calcium concentrations. DDH 4400-787 (Table A-4) exhibited high calcium concentrations on its northern end but did not contain unbleached rock at this point.

Mitcham (1952, p. 441) reported a much higher content of calcite in unbleached rocks relative to bleached rocks in a traverse across the Sunshine vein. The similar results obtained in two widely separated parts of the Sunshine mine preclude the possibility that the distributions observed for calcium are a result of local variations in original wall rock composition. These observations are contrary to the opinions expressed by Weis (1964, p. 96) in a district wide study.

Iron and manganese are generally present in unbleached rocks in uniformly low concentrations. In bleached rocks, although the concentrations of these metals fluctuate widely, there is a tendency for the concentrations of these elements to increase as the vein is approached. This pattern is exemplified by Figures 14 and 15 which show the distribution of iron and manganese, respectively, in DDH 4400-732.

The distribution of magnesium in individual traverses is somewhat similar to that of iron and manganese as shown by Figure 16, but the tendency to increased concentrations near the vein is not readily discernable. Calcium in bleached rocks in some traverses also exhibits a slight tendency to increased concentrations with proximity to the vein. This feature is observed in DDH 4400-732 (Figure 13).

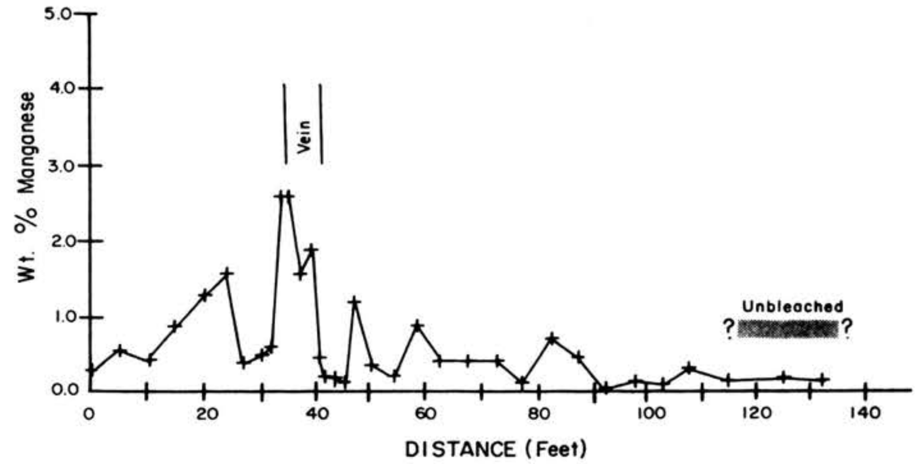

Figure 15. Distribution of manganese in DDH 4400-732

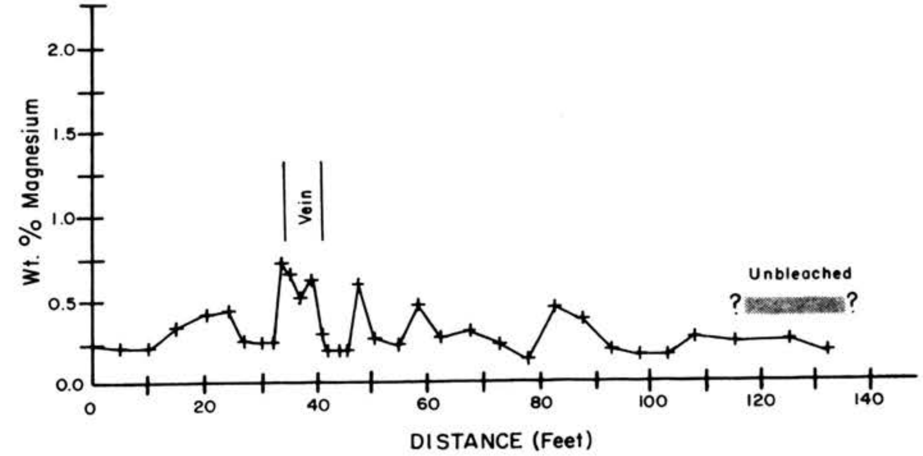

Figure 16. Distribution of magnesium in DDH 4400-732.

It is postulated herein that these aureoles of iron, manganese, magnesium, and calcium are the result of additions of these metals to the wall rock as carbonates. This addition followed bleaching because carbonates, as indicated by the removal of calcium, were not stable in the presence of the bleaching fluids. There is no apparent zonal distribution of these metals that would substantiate the occurrence of a zonal distribution of carbonates as reported by Shaw (1959).

Aluminum and potassium data yield very similar but erratic distributions. These distributions exhibit no apparent relationship to the presence of unbleached rocks or veins other than the very low concentrations observed within the vein. Examples of aluminum and potassium distributions are shown in Figures 17 and 18, respectively.

The distribution of sodium also closely parallels that of aluminum and potassium in individual traverses. However, in some traverses there is a slight enrichment of sodium relative to aluminum and potassium near the vein indicating possible additions of that metal by mineralizing fluids. This is observed in DDH 4400-732 at a distance of 20 feet (Figure 19). It is also exhibited to a greater degree in DDH 4600-915 (Table A-6) at a distance of 5 to 35 feet.

No definitive patterns were recognized for silicon, except that it was present at very low concentrations within the vein. It is postulated that the observed variations in concentration are the result of the actual variation in the content of quartz in the wall rock. An example of silicon distribution is shown in Figure 20 which shows silicon in DDH 4400-732.

The distributions of lead, copper, and zinc were not plotted. The dispersion of these metals into the wall rocks adjacent to the vein

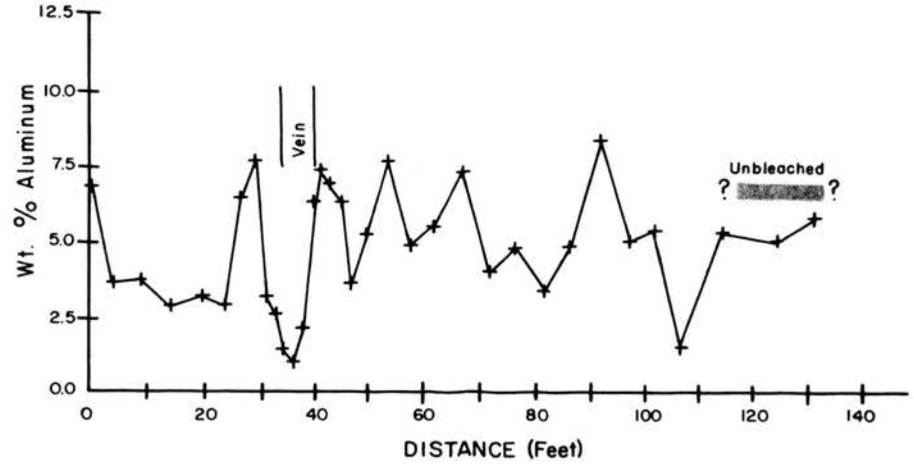

Figure 17. Distribution of aluminum in DDH 4400-732.

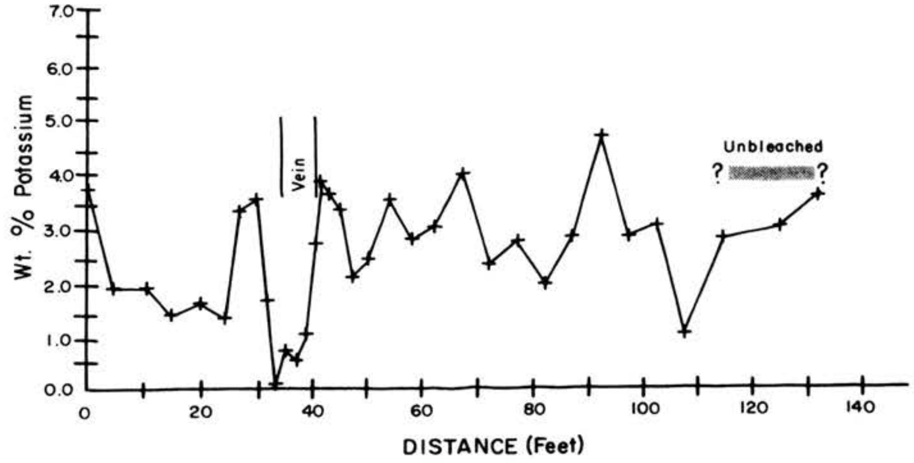

Figure 18. Distribution of potassium in DDH 4400-732.

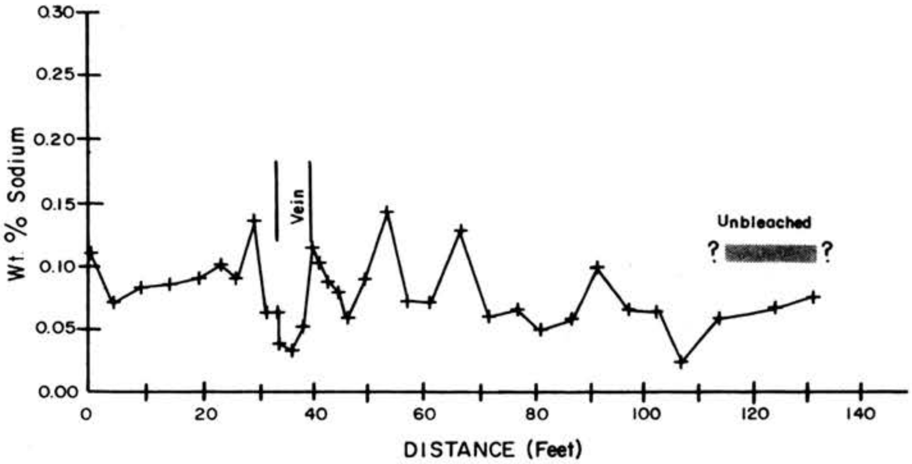

Figure 19. Distribution of sodium in DDH 4400-732.

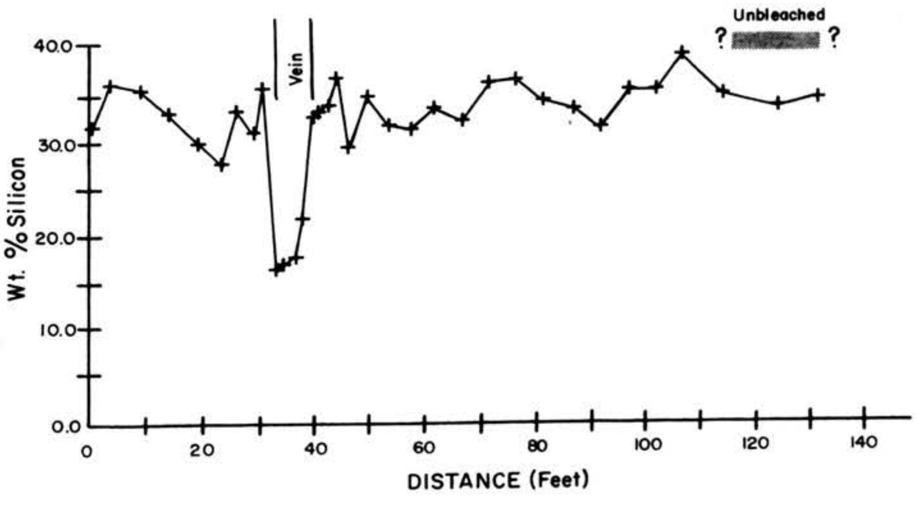

Figure 20. Distribution of silicon in DDH 4400-732.

appears to be limited to a few feet at most. Even this dispersion is difficult to identify because of the impossibility of locating precise vein margins. There are no apparent differences in concentrations of these metals between bleached and unbleached rocks. It is concluded that the concentrations present in the wall rocks are background concentrations existing prior to ore emplacement and bleaching. Bailey (1971) reported relatively large dispersions on the order of 50 feet for these metals into the quartzite wall rocks in the Mayflower mine.

In summary, data distributions indicate that bleaching has removed calcium from the wall rock for distances of up to 100 feet. More extensive leaching of calcium may be present, but the sampling pattern was inadequate to delineate this possibility. Subsequent to bleaching, during emplacement of siderite in the vein, small amounts of iron, manganese, magnesium, and calcium were added to wall rocks adjacent to the vein in the form of carbonates. The distributions indicate that the dispersion of these metals did not exceed the limits of previous calcium leaching. The distributions did not demonstrate that significant removal or addition of aluminum, potassium, or silicon took place in the wall rocks. Some evidence was observed that indicated minor addition of sodium may have occurred immediate to the vein. The dispersion of copper, lead, and zinc into the wall rocks was shown not to extend more than a few feet.

The addition of iron, manganese, magnesium, and calcium is consistant with the carbonatization (ankeritization) reported by Knopf (1929) in phyllites and slates in the Mother Lode system of California. Leaching of silicon has been previously reported in the Coeur d'Alene district (Fryklund, 1964) but was not demonstrated for the Chester vein.

C. Observations from Correlation Coefficient Matrices

The linear correlation coefficient (r) is an estimate of the "goodness of fit" of data to a linear regression line derived by least squares analysis of the data. The coefficient may vary from +1 to -1; these bounding values represent an exact linear relationship. As the coefficient approaches 0, the linear relationship becomes less significant. At r=0 there is no linear relationship evidenced by the data. A discussion of this parameter and examples of its applications are given by Krumbein and Greybill (1965, Chapter 10).

The linear correlation coefficients used in this study were computed by an IBM 360 program preparatory to conducting R-mode factor analysis included in the same program.

Table 8 contains the matrix of linear correlation coefficients for aluminum, magnesium, calcium, sodium, manganese, iron, lead, copper, and zinc for all samples.

A very high positive correlation (0.969) is observed between aluminum and potassium. This degree of correlation is indicative that these elements occur in a stoichiometric ratio in a single mineral. In general this ratio in terms of weight percent varies from 1.9 to 2.2, a value that is consistent with the ratio present in sericite. This ratio has been calculated from one analysis reported in Deer, <u>et al.</u> (1962a, p. 17) to be 1.9. Deer, <u>et al.</u> (p. 16) report an analysis for a single large crystal of muscovite which yielded a calculated ratio of aluminum to potassium of 2.4. It is concluded that aluminum and potassium are in the wall rock principally in the mineral sericite, which is an important rock constituent.

Table 8. Matrix of correlation coefficients for all data from traverses across the Chester vein.

	Al	Mg	Ca	Na	K	Mn	Fe	Pb	Cu	Zn
Al		-0.490	-0.060	0.440	0.969	-0.686	-0.667	-0.177	-0.200	-0.188
Mg	-0.490		0.376	-0.162	-0.502	0.783	0.784	0.110	0.201	0.190
Ca	-0.060	0.370		-0.052	-0.021	0.001	-0.032	-0.007	-0.014	-0.018
Na	0.440	-0.162	-0.052		0.413	-0.254	-0.251	-0.085	-0.109	-0.100
K	0.969	-0.502	-0.021	0.413		-0.689	-0.678	-0.175	-0.202	-0.194
Mn	-0.686	0.783	0.001	-0.254	-0.689		0.945	0.166	0.196	0.167
Fe	-0.667	0.784	-0.032	-0.251	-0.678	0.945		0.209	0.311	0.277
Pb	-0.177	0.110	-0.007	-0.085	-0.175	0.166	0.209		0.232	0.033
Cu	-0.200	0.301	-0.014	-0.109	-0.202	0.196	0.311	0.232		0.793
Zn	-0.188	0.190	-0.018	-0.100	-0.194	0.167	0.277	0.033	0.793	

Iron and manganese also exhibit a similarly high correlation (0.945), providing evidence that these two elements occur in the same mineral, hypothesized to be siderite. Magnesium is correlated to a lesser degree with manganese (0.783) and iron (0.784) indicating that this element is also an important constituent of the siderite. Shaw (1959, p. 1674) obtained the following average composition for siderite from chemical analyses of 100 samples from the Bunker Hill mine of the Coeur d'Alene district:

$$(Fe_{0.75-0.85}Mn_{0.08-0.10}Mg_{0.06-0.10}Ca_{0.02-0.06})CO_3.$$

Deer, et al. (1962b, p. 273) state that there is a complete solid solution between siderite and rhodochrosite and between siderite and magnesite. The maximum calcium permissable in the structure as $CaCO_3$ is 10 to 15 percent. These reports indicate that the sporatic calcium aureoles observed in some traverses may also be contained in siderite. The molar ratios of iron, manganese, magnesium, and calcium in rocks close to the vein do not differ greatly from the average analysis reported by Shaw.

In individual traverses sodium generally exhibits a strong positive correlation with aluminum and potassium (greater than 0.85). This is contrary to the low positive correlations observed for all samples (0.440 and 0.413, respectively). This overall correlation is a result of variation of the concentration of sodium with respect to aluminum and potassium concentrations from traverse to traverse. No orderly pattern is apparent in this variation. It is hypothesized that sodium is substituting for potassium in sericite to varying degrees.

A relatively strong inverse relationship is observed between the group consisting of manganese and iron and the group consisting of aluminum and potassium as illustrated by the corresponding correlation coefficients (between -0.66 and -0.69). This observation is more readily illustrated by the statistical techniques discussed in the following sections.

The high positive correlations between aluminum and potassium and between iron and manganese provide the possibility of simplifying any future geochemical studies of this type in the immediate district through the elimination of two series of analyses. This would be particularly advantageous in the elimination of aluminum analyses because they require the use of the nitrous oxide-acetylene flame which is generally unsatisfactory for reasons of operator safety and comfort.

D. Observations from Factor Analysis

Factor analysis provides a means whereby a complex pattern of correlations, expressed here by the linear correlation coefficient matrix, may be reduced to a simpler pattern of variables and relationships.

In R-mode factor analysis, as used herein, groups of variables are attributed to "factors". The degree to which total variability is expressed by a factor is determined by "eigenvalues" calculated for each factor. A variable may fall under more than one factor; the degree to which it contributes to the variability expressed by a factor is numerically expressed as its "loading" under that factor. Squaring factor loading gives an estimate of the portion of the variance of a variable attributed to a given factor. The "communality" expresses the percent of the variance of a variable explained by the factor solution.

Several different solutions are possible in factor analysis depending on the choice of axes. These can be grouped into solutions using orthogonal axes (principal component and varimax) in which factors are not correlated and solutions using oblique axes (promax) in which factors are correlated proportional to the cosine of the angle between the axes. Promax solutions were not possible with the computer program available for this investigation and were not computed.

The objective of the principal components solution is to attribute the maximum fraction of variance, that is, maximum eigenvalue, to each successive factor. The varimax solution can be considered a rotation of axes derived through principal components analysis such that loadings on the individual factors tend to a maximum (±1) or minimum (0).

Koch and Link (1971, Chapter 10.6) provide a discussion of the mathematical foundation for factor analysis. Reeves and Saadi (1971) give an excellent discussion of different factor solutions.

Results of varimax factor solutions for data from each of the traverses are included in Tables B-1 to B-13 in Appendix B. Factor loadings between 0.50 and -0.50 are not shown in order to improve readability of the matrices. A limiting eigenvalue of 1.0 was chosen.

The varimax solution for all data (Table 9) yielded three factors. The first factor, which accounts for 43.0 percent of the total variability, has high positive loadings for aluminum and potassium and high negative loadings for manganese and iron. Sodium exhibits a low positive loading and magnesium, a low negative loading. A review of the distributions of these metals in the wall rocks indicated that rocks high in aluminum and potassium content (illustrated by Figures 17 and

Table 9. Results of factor analysis of all data from traverses across the Chester vein. Factor loadings of less than ±0.50 are not shown.

VARIABLE	FACTOR 1	 2	 3	COMMUNALITY
Aluminum	0.90			0.82
Magnesium	-0.63		0.67	0.87
Calcium			0.84	0.70
Sodium	0.51			0.31
Potassium	0.91			0.83
Manganese	-0.87			0.84
Iron	-0.85			0.83
Lead				0.12
Copper		0.94		0.90
Zinc		0.92		0.86

Percent of total variability attributed to factor

Factor 1:	43.0
Factor 2:	16.2
Factor 3:	11.8

Table 10. Results of factor analysis of all data from traverses across the Chester vein. Factor loadings of less than ±0.50 are not shown. A limiting eigenvalue of 0.1 was chosen. Communality for all variables is greater than 0.97.

VARIABLE	FACTOR 1	 2	 3	 4	 5	 6
Aluminum						0.90
Magnesium	-0.85					
Calcium			0.99+			
Sodium				0.96		
Potassium						0.90
Manganese	-0.90					
Iron	-0.89					
Lead					0.99	
Copper		0.92				
Zinc		0.95				

Percent of total variability attributed to factor

Factor 1:	42.9	Factor 4:	10.0
Factor 2:	16.3	Factor 5:	9.6
Factor 3:	11.8	Factor 6:	5.6

18) are low in iron and manganese content (illustrated by Figures 15 and 16). From this the conclusion follows that the presence of previous metamorphic sericite is a negative indicator of the presence of siderite.

The second factor, accounting for 16.2 percent of the total variability, exhibits high positive loadings for zinc and copper. This is the result of the occurrence of both of these metals in tetrahedrite in the vein and the generally uniform levels of these metals present at background concentrations in the wall rock.

The third factor, accounting for 11.8 percent of the variability, exhibits a high positive loading for calcium and a lesser positive loading for magnesium. This is interpreted to be representative of the effect of bleaching on the wall rock. The lesser loading for magnesium is attributable to the fact that while magnesium and calcium correlate to a certain extent in bleached rock, in unbleached rocks, the concentrations of calcium are considerably higher than the concentrations of magnesium.

The variability of lead is not explained by the factor matrix as indicated by the low communality (0.12) for that variable. Sodium also exhibits a low communality (0.31) indicating that the variability of that element is not satisfactorily explained by the factor matrix. Choosing a limiting eigenvalue of 0.1 and recalculating the varimax solution revealed that these elements fall individually into factors with high loadings (Table 10). It is interesting to note from Table 10 the difference wrought by the change in eigenvalue. This effect, in which factors are more discreetly separated, is a result of the varimax rotation of the principal components factor axes to maximize the factor loadings. In each case, the initial principal components factor solution was the same for the first three factors.

In an effort to identify spatial patterns related to the shape and intensity of the ore shoot, varimax factor solutions were obtained for each of the individual traverses. Groupings and loadings are only vaguely similar to the solution derived from all data, and no general pattern is apparent. However, specific observations can be made.

Sodium tends to share equal loadings with aluminum and potassium, a reflection of the high correlations shown by that element with these elements in individual traverses.

Lead tends to be included in the zinc-copper factor. This is a result of similarities in mineralization intensities for these metals.

Silicon was not included in Tables B-1 and B-6 because the addition of extra variables would have biased the results obtained for the remaining variables in these tables. Separate factor solutions were derived for these traverse data in which silicon was included in the analysis. In both cases, silicon showed a positive loading with the sericite-siderite factor and a negative loading with the ore metals factor. The former is the result of sericite variation, whereas the latter is the result of low quartz content of the veins.

Sulfur was not included in the original solutions, either. A subsequent solution provided the logical result that sulfur was positively loaded in the ore metals factor.

E. Observations from Cluster Analysis

Cluster analysis provides a technique whereby variables are grouped pictorially according to their similar distributions. Provision is made for linking groups of variables to other variables or groups by computing some average similarity coefficient (average linkage) or by permitting linkages between groups at the level of the lowest similarity displayed between members of the two groups (complete linkage). Cluster analysis has the advantage of providing a display of variable relationships which can be interpreted rapidly. Once the similarity coefficient matrix (in this study, the linear correlation coefficient matrix) is obtained calculation of the linkages by any of the possible methods is simple and can readily be carried out by desk calculator. Parks (1964) in carbonate studies has shown that cluster analysis gives results similar to those obtained by factor analysis.

Sokal and Sneath (1963, chapter 7) discuss the various techniques of cluster analysis as applied to taxonomy. They advocate the use of clustering by average linkage and recommend the pair-group technique for ease in computation. This technique is described in Appendix C.

This method was employed using the linear correlation matrix coefficient matrix for all data (Table 8). The "dendogram" in Figure 21 was constructed as a graphical representation of the clustering. The horizontal bars represent the average linear correlation coefficient between groups as calculated by the formulas in Appendix C.

The dendogram displays two main clusters for the data. Aluminum, potassium, and sodium form one cluster, hypothesized to represent sericite, and the remaining elements form the second cluster, hypothesized to be representative of all stages of mineralization, including bleaching. Within the second cluster, manganese, iron, and magnesium form a cluster representative of siderite; copper and zinc form a cluster representative of their similar distributions.

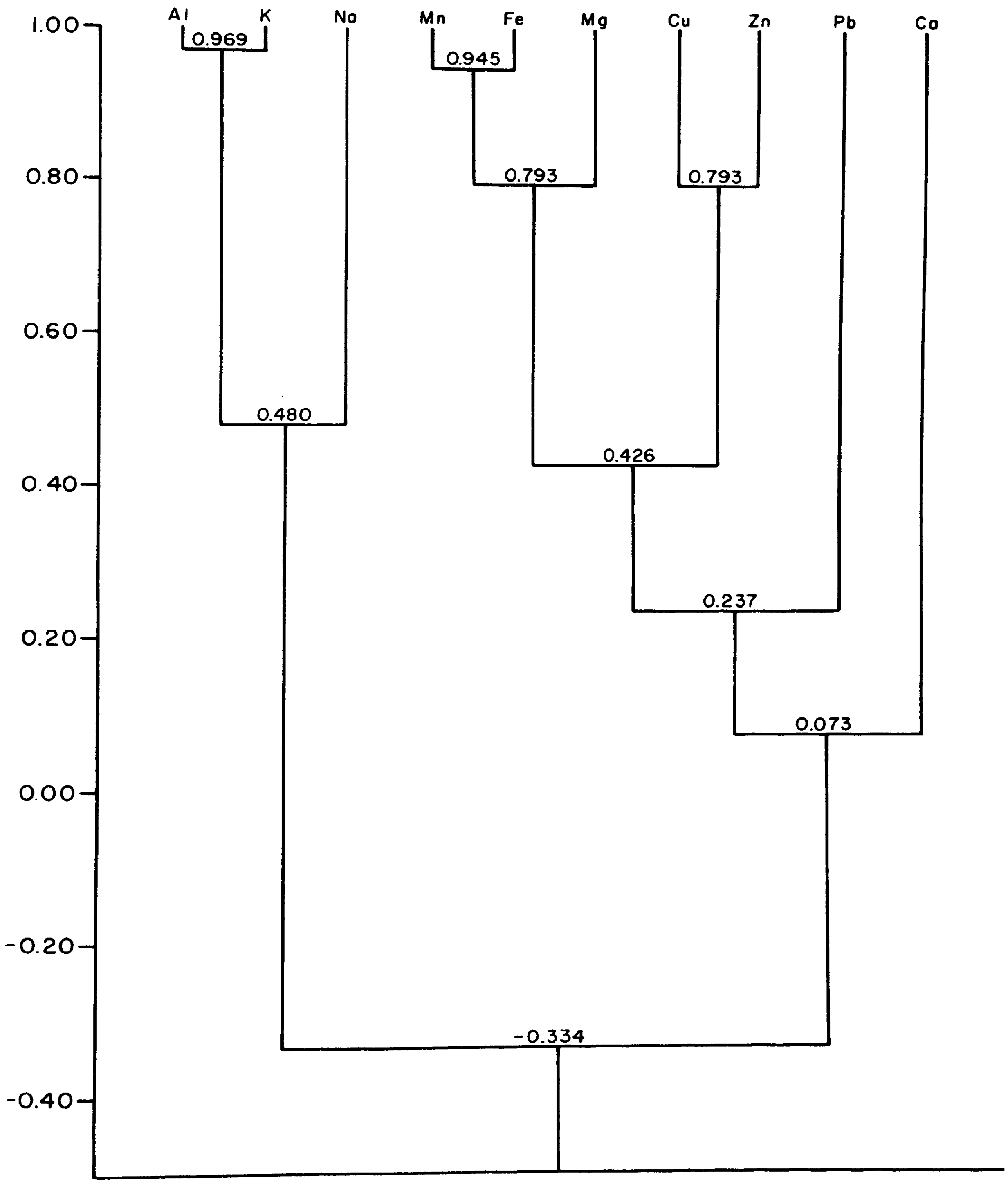

Figure 21. Dendogram derived by cluster analysis of the linear correlation coefficient matrix calculated from all data. Horizontal bars represent average linkages between clusters.

The two main clusters have a weak negative correlation giving the appearance that the presence of sericite is a negative indicator of mineralization. Mitcham (1952, p. 424) reported a similar negative relationship for the Sunshine vein, 3100 level, between silver assay and sericite content of the immediate wall rock.

The above dendogram is misleading in one respect. It places an unequal importance on positive and negative correlations. This is valid in the construction of a taxonomic classification as recommended by Sokal and Sneath, but in the consideration of geochemical processes negative correlations, representing perhaps replacement, should be weighted equally to positive correlations.

Accordingly, the correlation matrix of Table 8 was altered by reversing the signs of the correlation coefficient of the elements in the right cluster of Figure 21 relative to the elements of the left cluster. This yielded the correlation coefficient matrix presented in Table 11. From this matrix the dendogram in Figure 22 was constructed. In Figure 22 and Table 11 variables enclosed in parentheses have correlation coefficients reversed in sign relative to the other variables.

From Figure 22 it is obvious that the weak negative correlation between the mineralization and sericite clusters in Figure 21 is actually the result of a strong correlation (negative) between the siderite cluster and the aluminum-potassium portion of the sericite cluster. For the sampled area, the concentrations of ore metals are not strongly dependent on either the presence of sericite or siderite. It should be added that this does not invalidate the earlier work of Mitcham (1952) as he considered only those wall rocks immediate to the vein as related to ore grade.

Table 11. Matrix of correlation coefficients for all data from traverses across the Chester vein. Correlation coefficients of elements closed in parentheses have been reversed in sign relative to the other elements.

	Al	(Mg)	(Ca)	Na	K	(Mn)	(Fe)	(Pb)	(Cu)	(Zn)
Al		0.490	0.060	0.440	0.969	0.686	0.667	0.177	0.200	0.188
(Mg)	0.490		0.376	0.162	0.502	0.783	0.784	0.110	0.201	0.190
(Ca)	0.060	0.370		0.052	0.021	0.001	-0.032	-0.007	-0.014	-0.018
Na	0.440	0.162	0.052		0.413	0.254	0.251	0.085	0.109	0.100
K	0.969	0.502	0.021	0.413		0.689	0.678	0.175	0.202	0.194
(Mn)	0.686	0.783	0.001	0.254	0.689		0.945	0.166	0.196	0.167
(Fe)	0.667	0.784	-0.032	0.251	0.678	0.945		0.209	0.311	0.277
(Pb)	0.177	0.110	-0.007	0.085	0.175	0.166	0.209		0.232	0.033
(Cu)	0.200	0.301	-0.014	0.109	0.202	0.196	0.311	0.232		0.793
(Zn)	0.188	0.190	-0.018	0.100	0.194	0.167	0.277	0.033	0.793	

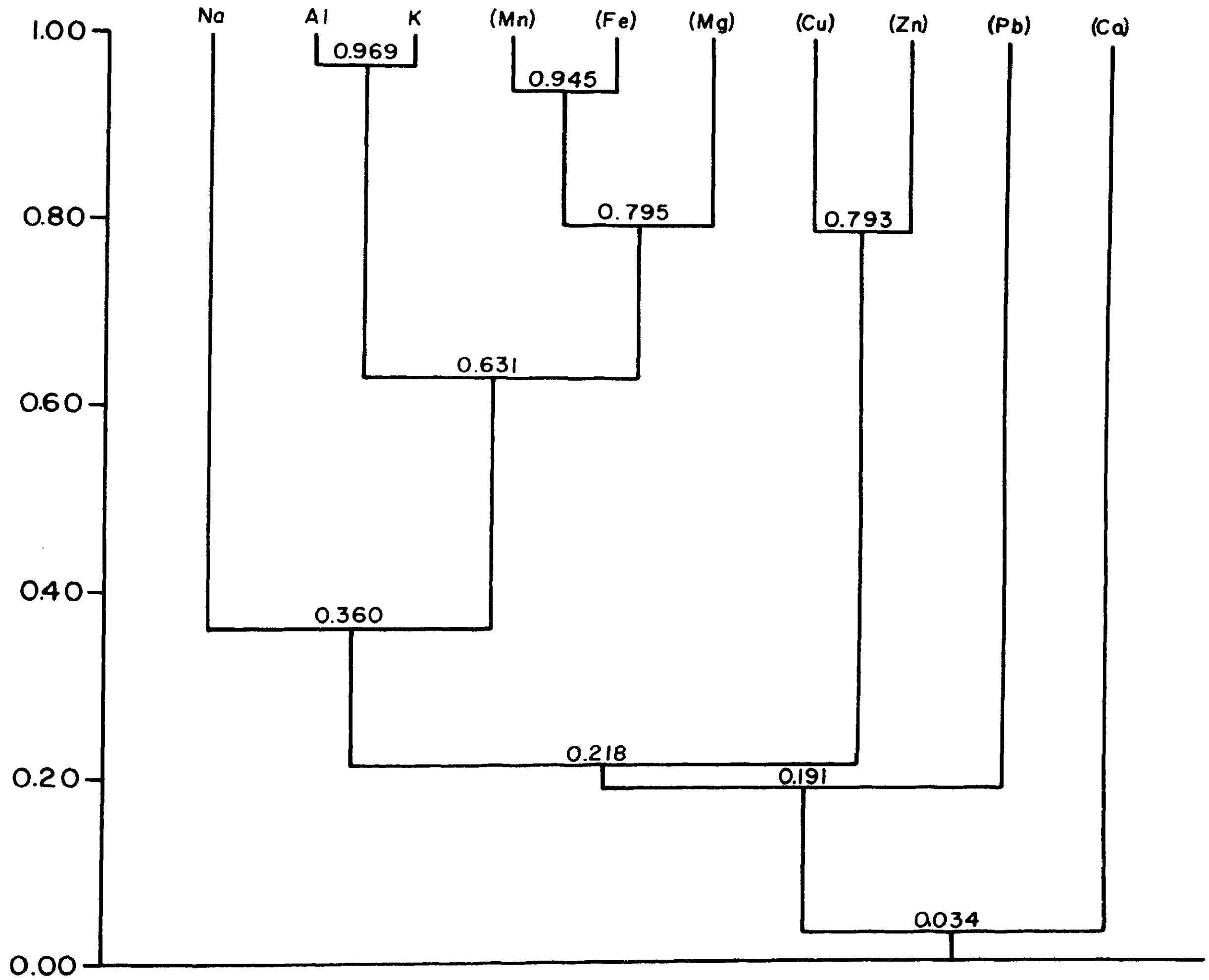

Figure 22. Modified dendogram derived by cluster analysis of the linear correlation coefficient matrix calculated from all data. Correlation coefficients of elements closed in parentheses have been reversed in sign relative to the other elements. Horizontal bars represent average linkages between clusters.

The cause of the inverse relationship between siderite and sericite is not determinable. Such a relationship could have arisen from replacement of sericite by siderite in selected parts of the wall rock. It also may have resulted from the selective emplacement of siderite in sericite poor rocks. Or, quartzitic rocks, being more brittle, would have been more susceptible to fracturing that would have provided the necessary channelways for mineralizing fluids. The resolution of this problem would be possible through an investigation of wall rock mineralogy in order to determine the textural relationships of siderite and sericite. Integration of this type of investigation with the results of this study would contribute additional insight into the geochemical processes which have occurred in the wall rocks of the Chester vein.

VII. CONCLUSIONS

1. Calcium was leached in large quantities during the stage of bleaching in the wall rocks. Leaching of calcium was effective to near the contact of bleached and unbleached rocks. Concentrations of calcium in bleached and unbleached rocks beyond the zone of effective leaching are up to two orders of magnitude higher than in bleached rocks within the zone.

Leaching of calcium and concomitant bleaching preceded the stage of siderite mineralization in the vein. As a result, superimposed on the leached calcium zone are the effects of carbonatization (sideritization) which produced aureoles of iron, manganese, magnesium, and calcium near the vein. Such aureoles could not have survived the effects of calcium leaching had that process postdated sideritization.

2. The concentrations of aluminum and potassium in the wall rocks are representative of the content of metamorphic sericite in the wall rocks. The distributions of these metals do not demonstrate any addition on them by mineralizing fluids. Linear correlation analysis, factor analysis, and cluster analysis have established an inverse relationship between sericite, represented by aluminum and potassium, and siderite, represented by iron and manganese. This inverse relationship is substantiated by the data distributions for individual traverses.

The cause of this inverse relationship cannot be resolved with the available data. Textural relationships between sericite and siderite in the wall rock must be determined to decide if the observed relationship is the result of simple replacement, selective emplacement in sericite poor rocks, or control of fracturing by rock type.

3. Sodium correlated strongly with aluminum and potassium in individual sample traverses. These three elements generally exhibited similar loadings in the same factor in factor analyses of the individual traverses. However, over the entire sampled area sodium did not correlate strongly with aluminum and potassium.

It is concluded that the ratio of sodium to aluminum and to potassium in sericite varies within the sampled area along the ore shoot. No regular pattern is apparent in this variation.

4. Nearly perfect linear correlations exist between aluminum and potassium and between iron and manganese. These pairs each occurred with similar loadings in the same factors derived by factor analysis. In cluster analysis, these pairs formed two of the initial clusters in the first clustering cycle. Future geochemical studies in the immediate district can be simplified through the elimination of analyses for one of the elements in each of the previously mentioned correlated pairs of elements. Elimination of aluminum analyses would eliminate the need for use of the nitrous oxide-acetylene flame.

5. When equal importance is assigned to both positive and negative correlations, cluster analysis provided a graphical display of the interrelationships between elements with essentially the same groupings as determined by factor analysis. In addition, the relationships between groupings were quantified.

It is concluded that cluster analysis, as modified in this study, provides essentially the same information as factor analysis. The ease of calculation, the ability to quantify relationships between variables, and the pictorial representation of these relationships makes the modified cluster analysis a valuable tool for geochemical studies.

6. Because the aureoles of iron, manganese, magnesium, and calcium are in the immediate vicinity of the vein, they effectively widen the exploration target by a factor of approximately 10. Therefore, in exploration, routine analyses for one or more of the above metals in diamond drill cores would demonstrate the proximity of veins. This would be particularly useful where zones of bleaching were too wide to provide accurate indication of proximity to veins.

7. This work has substantiated the work of Mitcham (1952) in establishing the relationship of calcium to bleaching. This study has demonstrated that the opinion expressed by Weis (1964) that chemical changes were not wrought by bleaching is in error, at least, for the Chester vein. This investigation has also demonstrated the value of cluster analysis for geochemical investigations by expanding on the technique of Sokal and Sneath (1963).

It is recommended that future research attempt to integrate this study with a mineralogical study as done by Mitcham. Elaboration of the basic techniques employed by Mitcham such as mineral separation and electron microprobe analyses of individual mineral grains would materially aid in isolating and identifying the modal distribution of elements in the wall rock.

It is further recommended that similar investigations be conducted in other mines of the Coeur d'Alene district to establish the validity of extending the conclusions from this investigation to the entire district.

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VITA

Nicholas Howard Tibbs, son of John and Betty Tibbs, was born a United States citizen on May 31, 1945 in Windsor, England. He received his primary and secondary education in Poplar Bluff, Missouri, and while in high school was elected to the National Honor Society. He entered the University of Missouri, School of Mines and Metallurgy in September, 1962 and received the degree of Bachelor of Science in Geology from that institution (now the University of Missouri - Rolla) in June, 1966. As an undergraduate, he was elected to the honorary fraternity of Phi Kappa Phi. He received his Master of Science in Geology from the University of Missouri - Rolla in May, 1969.

The author served as a Graduate Teaching Assistant from September, 1966 to June, 1967. From that time he has served as a Research Assistant under various federally funded grants.

The author is a member of the Association of Missouri Geologists and AIME. He is married to Mary Susan (Prost) of Perryville, Missouri.

APPENDIX A

DATA

Tables A-1 through A-13 contain chemical data determined by atomic absorption spectroscopy and geologic observations for each of thirteen traverses. Tables A-14 and A-15 contain chemical data determined by x-ray emission spectroscopy for two traverses.

Table A-1. Element concentrations for samples from DDH 4400-732 starting at the south end.
Coordinates of origin: 78,630 E., 79,993 S. Bearing: N 10° W

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	7.6	0.230	0.07	0.111	3.75	0.29	5.0	11	1	14	
2	5	3.7	0.225	0.04	0.071	1.95	0.60	7.2	4	4	12	
3	10	3.8	0.210	0.06	0.083	1.85	0.45	6.0	8	5	10	
4	15	3.0	0.345	0.09	0.084	1.40	0.89	11.0	17	5	20	
5	20	3.2	0.430	0.15	0.091	1.60	1.32	13.8	140	7	22	
6	24	3.0	0.435	0.15	0.101	1.35	1.58	15.5	34	4	21	
7	27	6.5	0.260	0.24	0.091	3.30	0.40	5.7	43	690	69	
8	30	7.8	0.250	0.07	0.140	3.50	0.51	7.0	25	3	15	
9	32	3.3	0.245	0.05	0.062	1.65	0.63	7.5	22	5	14	
10	33.5	2.7	0.730	0.20	0.062	1.35	2.61	30.6	425	21	38	
11	35	1.5	0.650	0.29	0.040	0.70	2.61	27.4	40000	26	42	vein
12	37	1.2	0.515	0.16	0.034	0.50	1.58	25.4	80000	340	54	vein
13	39	2.3	0.635	0.17	0.052	1.05	1.90	23.2	39000	360	66	vein
14	40.5	6.4	0.300	0.25	0.115	2.75	0.47	6.5	45	150	27	
15	41.5	7.5	0.210	0.34	0.105	3.85	0.23	3.5	20	21	14	
16	43	7.0	0.205	0.11	0.089	3.65	0.20	3.5	16	44	15	
17	45	6.4	0.195	0.39	0.080	3.30	0.14	2.4	32	9	14	
18	47	3.8	0.605	0.14	0.060	2.10	1.23	13.8	32	6	39	
19	50	5.3	0.270	0.20	0.090	2.45	0.36	5.1	100	7	18	
20	54	7.8	0.240	0.13	0.143	3.50	0.20	4.0	13	6	15	
21	58	5.0	0.490	0.12	0.073	2.75	0.92	10.6	5	5	30	
22	62	5.7	0.270	0.07	0.073	3.00	0.42	6.0	8	4	16	
23	67	7.5	0.310	0.06	0.130	3.95	0.41	6.3	11	6	30	
24	72	4.0	0.240	0.04	0.063	2.30	0.41	5.1	8	3	14	
25	77	5.0	0.135	0.03	0.069	2.75	0.14	2.7	9	4	8	

Table A-1. (Continued)

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
26	82	3.5	0.445	0.72	0.050	1.95	0.71	7.7	20	6	18	
27	87	5.0	0.375	0.79	0.059	2.80	0.46	6.7	94	5	18	
28	92	8.6	0.180	0.07	0.102	4.65	0.03	2.4	21	4	15	
29	97	5.1	0.170	0.94	0.066	2.75	0.12	2.2	9	2	12	
30	102	5.5	0.155	0.42	0.066	3.00	0.08	2.0	8	2	8	
31	107	1.7	0.270	2.20	0.026	1.00	0.29	3.0	9	11	20	
32	114	5.4	0.240	1.12	0.062	2.75	0.17	2.8	8	3	14	unbleached
33	124	5.2	0.255	1.95	0.069	3.00	0.18	3.6	13	3	12	
34	131	6.0	0.180	2.25	0.079	3.55	0.11	3.4	15	2	10	unbleached

Table A-2. Element concentrations for samples from XC 4400-44 starting at the south end.
Coordinates: 78,640 E., 79,972 S. Bearing: N 30° E

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	3.7	0.410	0.08	0.057	1.75	1.15	14.3	4	2	34	
2	5	3.4	0.110	0.33	0.043	1.45	0.18	2.2	23	5	6	
3	7	6.5	0.160	0.08	0.088	3.00	0.18	3.2	9	2	10	
4	9	3.4	0.490	0.12	0.059	1.65	1.52	16.2	9	5	32	
5	10	3.1	0.525	0.13	0.052	1.45	1.69	18.4	26	3	31	
6	13	2.2	0.485	0.27	0.030	0.95	1.69	17.5	29000	67	42	vein
7	16	0.2	0.810	0.24	0.007	<0.05	2.92	45	40000	72000	490	vein
8	19	7.6	0.310	0.21	0.097	3.80	0.65	8.5	52	160	33	
9	20	6.9	0.280	0.15	0.093	3.40	0.58	7.2	28	12	30	
10	22	5.9	0.310	0.14	0.082	2.85	0.58	7.5	20	23	44	
11	24	8.7	0.195	0.14	0.113	4.70	0.10	2.3	14	16	12	
12	29	9.5	0.190	0.04	0.114	4.60	0.06	2.4	17	35	14	
13	34	5.7	0.230	0.14	0.068	2.70	0.23	4.8	55	42	26	
14	39	5.5	0.155	0.07	0.064	2.60	0.14	2.6	13	5	13	
15	44	5.7	0.155	0.07	0.075	2.75	0.14	2.6	10	5	12	
16	54	5.2	0.125	0.03	0.068	2.70	0.11	2.4	8	6	12	
17	64	3.5	0.315	0.05	0.041	1.90	0.62	6.7	<4	5	23	
18	74	7.9	0.185	0.07	0.094	4.10	0.07	3.0	10	2	20	
19	84	3.8	0.370	0.82	0.050	2.00	0.48	5.8	8	5	14	
20	99	3.7	0.370	0.79	0.053	2.00	0.48	5.8	4	4	14	unbleached
21	118	6.0	0.200	0.83	0.073	3.35	0.08	2.3	12	4	9	unbleached?
22	138	4.9	0.320	2.50	0.063	2.75	0.18	3.7	12	3	13	unbleached

Table A-3. Element concentrations for samples from DDH 4400-764 starting from the south end.
Coordinates: 79,198 E., 80,086 S. Bearing: N 8° E

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	7.4	0.140	0.05	0.101	3.40	0.09	2.4	7	6	11	
2	3	6.7	0.185	0.03	0.082	2.95	0.23	4.0	9	6	11	
3	8	4.9	0.310	0.08	0.074	2.20	0.63	8.6	9	5	20	
4	13	5.8	0.420	0.12	0.080	2.50	0.78	11.4	12	10	23	
5	18	6.0	0.235	0.14	0.060	2.65	0.34	5.7	7	7	13	
6	22	5.7	0.265	0.22	0.054	2.20	0.28	5.4	14	8	13	
7	24	8.0	0.265	0.08	0.066	3.30	0.38	6.6	10	5	14	
8	26	4.0	0.240	0.64	0.039	1.80	0.37	6.1	29	6	14	
9	28	6.4	0.240	0.10	0.082	2.90	0.29	5.7	17	7	14	
10	30	3.7	0.620	0.10	0.057	1.75	1.90	30.4	6	3	21	vein
11	32	<0.05	0.790	0.16	0.010	<0.05	3.71	36.	<4	5	62	vein
12	34	<0.05	1.00	0.25	0.012	<0.05	6.38	46.	6	430	140	vein
13	36	1.2	0.770	0.20	0.027	0.50	3.22	32.0	7	52	57	vein
14	38	2.9	0.315	0.07	0.052	1.35	0.99	12.0	7	5	17	vein
15	40	1.2	0.850	0.28	0.032	0.50	4.46	36.	5	3	24	vein
16	42	1.8	0.840	0.24	0.038	0.75	3.38	33.5	7	1	36	vein
17	44	3.0	0.535	0.16	0.054	1.55	1.56	17.7	8	6	23	vein
18	45.5	4.8	0.180	0.05	0.069	2.30	0.28	4.3	6	10	12	
19	47	3.5	0.320	0.07	0.052	1.70	0.67	8.9	6	3	20	
20	49	8.0	0.190	0.05	0.104	3.70	0.49	3.7	9	5	11	
21	54	3.9	0.270	0.08	0.056	1.80	0.63	9.6	5	6	16	
22	59	6.2	0.270	0.06	0.081	2.75	0.63	8.6	8	2	17	
23	62	4.2	0.230	0.04	0.057	2.00	0.55	7.1	6	4	13	
24	68	2.6	0.450	0.10	0.048	1.40	1.20	18.6	6	4	19	
25	73	2.7	0.325	0.06	0.047	1.40	0.93	11.2	6	6	16	

Table A-3. (Continued)

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb μg/g	Cu μg/g	Zn μg/g	Remarks
26	78	6.5	0.145	0.05	0.081	2.90	0.14	2.6	4	3	7	
27	83	4.5	0.280	0.06	0.062	2.15	0.68	8.6	7	5	16	
28	86	3.9	0.310	0.06	0.047	1.85	0.71	9.9	6	4	17	
29	89	9.8	0.240	0.04	0.114	4.80	0.11	2.4	10	6	12	
30	91	5.1	0.350	0.12	0.069	2.35	0.75	10.1	8	3	20	vein
31	93	7.0	0.205	0.06	0.094	3.55	0.14	3.0	10	3	11	
32	95	2.9	0.200	0.16	0.042	1.35	0.41	3.9	21	8	11	
33	96	3.4	0.610	0.28	0.036	1.40	1.86	20.8	1700	300	87	
34	97	5.5	0.375	0.24	0.065	2.70	0.48	6.6	10	8	25	
35	98	9.3	0.390	0.10	0.113	4.85	0.42	5.4	11	<1	23	
36	100	7.4	0.255	0.20	0.090	3.65	0.15	3.2	7	1	15	
37	102	5.3	0.480	0.12	0.059	2.40	0.65	8.8	7	12	26	
38	104	6.9	0.330	0.13	0.087	3.60	0.29	5.5	8	4	22	
39	109	6.4	0.465	0.12	0.072	2.95	0.60	8.4	8	8	24	
40	114	5.6	0.285	0.06	0.064	2.85	0.43	5.5	8	5	13	
41	118	5.1	0.490	0.18	0.058	2.35	0.94	11.5	8	6	22	
42	123	6.5	0.225	0.04	0.072	3.25	0.18	3.1	8	2	10	
43	128	3.9	0.310	0.06	0.038	1.95	0.43	5.4	3	8	14	
44	133	9.0	0.345	0.12	0.100	4.35	0.10	3.7	11	4	16	
45	138	8.3	0.315	0.05	0.092	3.95	0.17	3.9	9	2	15	
46	142	9.1	0.315	0.08	0.100	4.05	0.10	3.5	9	2	13	
47	147	10.0	0.305	0.04	0.111	5.35	0.10	4.2	6	2	14	
48	152	6.5	0.390	0.10	0.068	3.15	0.47	7.5	8	3	20	unbleached
49	157	9.0	0.315	0.14	0.105	4.35	0.14	5.4	8	2	15	unbleached

Table A-4. Element concentrations for samples from DDH 4400-787 starting at the south end.
Coordinates: 79,653 E., 80,109 S. Bearing: N 11° W

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	10.2	0.310	0.12	0.123	4.70	0.54	6.7	9	47	24	
2	3	7.2	0.300	0.07	0.100	3.25	0.58	7.1	7	4	22	
3	7	6.6	0.185	0.08	0.090	3.15	0.13	2.9	9	2	17	
4	9	8.7	0.205	0.10	0.110	4.25	0.03	2.8	14	2	14	
5	13	4.3	0.140	0.08	0.060	2.00	0.13	2.2	5	4	11	
6	15	1.8	0.485	0.21	0.040	0.80	1.53	17.8	140	28	48	
7	17	4.4	0.110	0.07	0.077	3.25	0.05	1.2	14	3	8	
8	22	0.7	0.890	0.21	0.023	0.25	2.66	38.0	300	460	81	
9	25	8.0	0.315	0.10	0.105	4.00	0.64	9.6	120	30	21	
10	26.5	4.2	0.580	0.19	0.071	1.90	1.62	21.0	9	3	35	
11	27.5	7.0	0.235	0.07	0.103	3.30	0.27	5.0	21	77	22	
12	33	0.2	0.970	0.22	0.019	0.10	3.71	49.	170	9700	1100	vein
13	39	2.5	1.04	0.36	0.048	1.10	3.22	33.2	110	190	110	
14	41	3.4	0.585	0.20	0.055	1.60	1.81	18.4	62	46	48	
15	43	3.8	0.610	0.18	0.064	1.85	1.72	17.2	29	4	47	
16	45.5	1.4	0.765	0.21	0.027	0.50	2.09	31.2	200	240	66	vein
17	49	3.9	0.450	0.12	0.053	1.75	1.15	12.5	9	4000	420	
18	50	2.7	0.435	0.12	0.040	1.10	1.30	12.8	225	1400	150	
19	52	3.8	0.485	0.22	0.053	1.75	1.16	11.7	210	23	40	
20	54	5.6	0.350	0.33	0.077	2.45	0.59	7.0	130	5500	510	
21	56	3.4	0.450	0.15	0.046	1.50	1.12	11.2	69	21	30	
22	57	4.8	0.315	0.16	0.066	2.25	0.61	6.5	86	93	29	
23	62	5.0	0.270	0.14	0.075	2.45	0.39	4.4	22	10	34	
24	67	5.8	0.265	0.13	0.085	2.85	0.29	4.0	8	9	26	
25	69	6.8	0.370	0.38	0.092	3.50	0.56	6.8	33	12	28	

Table A-4. (Continued)

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
26	74	4.4	0.450	0.10	0.052	2.20	0.89	8.6	8	18	33	
27	79	6.8	0.345	0.06	0.091	3.55	0.48	5.2	8	3	28	
28	84	5.9	0.320	0.07	0.081	3.05	0.39	4.6	10	8	28	
29	89	6.7	0.720	1.85	0.084	3.70	0.76	6.0	8	3	26	
30	94	8.2	0.355	0.35	0.109	4.30	0.19	2.4	16	5	20	
31	99	5.1	1.50	5.60	0.074	2.80	0.87	5.2	16	5	26	

Table A-5. Element concentrations for samples from DDH 4400-806 starting at the south end.
Coordinates: 80,241 E., 80,293 S. Bearing: N 6° E

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	7.6	0.165	0.44	0.097	4.30	0.03	3.8	10	2	10	unbleached
2	13	3.8	0.175	2.80	0.052	2.20	0.13	1.9	8	3	7	
3	33	3.9	0.120	2.25	0.061	2.35	0.12	1.5	10	4	59	unbleached
4	53	8.1	0.190	0.71	0.104	4.45	0.07	3.0	12	3	11	
5	67	9.0	0.165	0.24	0.107	4.55	0.03	3.7	8	5	11	unbleached
6	77	7.4	0.205	0.59	0.089	3.90	0.07	2.2	12	4	13	unbleached
7	87	4.5	0.430	0.55	0.057	2.45	0.55	8.0	6	2	20	unbleached
8	97	4.6	0.215	0.04	0.056	2.45	0.28	4.3	8	2	12	
9	102	4.2	0.325	0.06	0.047	2.40	0.55	6.9	4	2	14	
10	107	6.8	0.320	0.15	0.080	3.65	0.33	5.3	16	4	18	
11	112	8.4	0.215	0.12	0.091	4.45	0.08	2.9	10	2	12	
12	117	8.0	0.190	0.32	0.090	3.95	0.03	3.9	10	6	14	
13	122	6.4	0.390	0.57	0.078	3.20	0.63	9.6	4	4	20	
14	127	6.6	0.270	0.08	0.078	3.40	0.37	5.7	4	4	13	
15	132	6.9	0.235	0.10	0.077	3.45	0.23	4.1	6	3	12	
16	137	6.4	0.410	0.12	0.070	3.00	0.70	8.8	6	10	14	
17	142	4.7	0.430	0.14	0.055	2.45	0.83	10.2	6	3	22	
18	147	7.2	0.330	0.24	0.091	3.85	0.46	7.3	16	4	21	
19	149.5	3.5	0.610	0.26	0.055	1.75	1.63	18.1	6	3	35	
20	150.5	3.8	0.395	0.14	0.060	2.00	1.23	11.2	8	5	22	
21	151.5	2.9	0.600	0.18	0.041	1.40	1.46	18.0	10	5	47	vein
22	153	3.9	0.395	0.34	0.050	1.80	0.71	9.0	21	18	30	
23	154	6.4	0.335	0.78	0.082	3.20	0.08	3.2	21	4	11	
24	156	7.9	0.420	0.84	0.094	4.20	0.11	2.3	14	4	14	
25	158	6.6	0.235	0.78	0.081	3.30	0.05	1.5	10	2	10	

Table A-5. (Continued)

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
26	160	4.7	0.460	1.07	0.066	2.35	0.17	2.2	8	4	12	
27	162	4.4	2.19	7.00	0.066	2.30	0.84	6.9	19	4	36	
28	167	4.4	0.340	0.92	0.051	2.45	0.11	1.9	6	4	10	
29	172	8.8	0.300	0.53	0.103	4.45	0.02	2.0	13	3	13	
30	177	4.4	0.655	1.65	0.061	2.15	0.24	2.6	11	3	20	
31	182	8.0	0.330	0.08	0.124	5.20	0.03	3.0	10	4	19	
32	187	7.7	0.385	0.66	0.109	3.75	0.08	2.8	8	3	16	
33	192	6.7	0.345	0.68	0.097	3.30	0.08	2.6	15	4	15	

Table A-6. Element concentrations for samples from DDH 4600-915 starting at the south end. Coordinates: 79,126 E., 80,218 S. Bearing: N 7° E

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	5.3	0.250	0.04	0.097	2.40	0.30	5.4	5	7	13	
2	5	5.1	0.305	0.08	0.168	2.25	0.40	6.8	6	7	14	
3	10	4.7	0.200	0.06	0.160	2.10	0.31	4.9	10	11	10	
4	15	10.4	0.215	0.12	0.188	5.25	0.05	3.1	11	8	11	
5	20	4.3	0.610	0.18	0.233	2.05	1.32	15.0	10	12	33	
6	25	5.4	0.555	0.16	0.238	2.50	0.94	5.3	8	9	24	
7	28	7.8	0.405	0.11	0.234	3.70	0.68	9.9	10	10	18	
8	30	7.1	0.420	0.11	0.265	3.35	0.74	10.3	5	14	21	
9	32	3.1	0.410	0.08	0.209	1.40	1.10	12.6	7	6	20	
10	33	2.7	0.455	0.10	0.208	1.15	1.14	13.2	7	9	23	
11	34	0.7	1.26	0.26	0.366	0.20	3.84	45.6	8	8	38	vein
12	36	7.5	0.345	0.11	0.090	2.60	0.18	4.3	11	13	12	
13	38	9.5	0.380	0.09	0.079	3.75	0.07	2.7	10	11	11	
14	40	8.1	0.535	0.14	0.091	3.05	0.55	8.4	10	6	19	
15	42	2.8	0.815	0.19	0.042	1.10	1.78	20.8	7	9	25	
16	47	2.1	0.740	0.12	0.030	0.80	1.37	15.8	5	8	18	
17	52	7.2	0.230	0.02	0.079	3.00	0.11	2.0	6	7	8	
18	54	5.8	0.245	0.03	0.067	2.25	0.21	3.3	6	8	8	
19	56	5.3	0.510	0.10	0.062	2.15	0.73	10.3	6	11	20	
20	57	2.8	1.34	0.26	0.038	0.95	2.84	52	13	9	29	1' Siderite
21	58	10.6	0.485	0.09	0.111	4.25	0.43	7.8	23	16	17	
22	60	8.3	0.320	0.12	0.089	3.35	0.38	6.9	12	11	18	
23	62	5.3	0.520	0.14	0.059	2.30	1.04	13.2	20	6	25	
24	67	5.8	0.185	0.02	0.072	2.55	0.15	2.6	7	6	8	
25	72	4.0	0.260	0.03	0.051	1.60	0.38	5.4	3	7	11	

Table A-6. (Continued)

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
26	75	4.9	0.400	0.07	0.060	2.05	0.80	10.4	7	7	16	
27	76.5	5.4	0.795	0.16	0.071	2.05	1.58	19.5	9	8	31	vein
28	77.5	7.1	0.260	0.04	0.080	2.80	0.18	3.2	5	9	10	
29	79	9.9	0.345	0.06	0.121	4.35	0.25	4.9	88	200	900	
30	82	4.0	0.180	0.04	0.049	1.85	0.44	6.2	7	9	12	
31	87	5.8	0.260	0.04	0.065	2.60	0.28	4.0	7	7	10	
32	92	4.1	0.505	0.10	0.056	1.85	0.95	11.4	15	14	21	
33	97	3.7	0.500	0.07	0.047	1.55	0.88	10.4	5	22	22	
34	102	4.6	0.260	0.05	0.063	2.10	0.30	4.2	5	8	10	
35	107	4.3	0.335	0.31	0.082	2.65	0.31	5.3	5	10	16	
36	112	3.7	0.265	0.06	0.048	1.60	0.39	5.0	5	10	11	
37	117	4.3	0.270	0.04	0.045	1.70	0.35	4.8	21	10	8	
38	122	4.9	0.190	0.05	0.064	2.25	0.12	2.4	5	12	8	
39	127	5.9	0.215	0.05	0.066	2.05	0.10	2.2	7	9	7	
40	130	4.9	0.430	0.10	0.060	2.20	0.74	9.2	5	5	18	
41	133	4.6	0.245	0.05	0.060	2.10	0.19	3.5	10	8	8	
42	135	4.0	0.625	0.14	0.048	1.60	1.10	12.8	5	9	25	
43	137	5.1	0.425	0.11	0.048	2.15	0.58	8.7	65	270	44	vein
44	140	2.7	0.500	0.13	0.036	1.15	0.99	12.8	250	380	59	vein
45	141	1.4	0.755	0.16	0.024	0.35	1.69	44	1200	9300	970	vein
46	142.5	0.3	1.10	0.13	0.018	<0.05	2.65	42	250	84000	8800	vein
47	143.5	3.7	0.870	0.27	0.049	1.50	1.75	18.8	12	330	66	
48	145	3.8	0.405	0.16	0.043	1.60	0.61	8.0	7	73	22	
49	149	4.3	0.395	0.06	0.052	1.95	0.57	7.2	13	30	15	
50	154	3.4	0.475	0.06	0.051	1.70	0.68	8.2	7	26	18	

Table A-6. (Continued)

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
51	159	8.8	0.340	0.08	0.980	3.70	0.09	2.6	6	4	17	
52	167	7.0	0.545	0.15	0.076	3.25	0.48	8.4	6	4	22	

Table A-7. Element concentrations for samples from XC 4600-13 starting at the south end.
Coordinates: 79,770 E., 80,300 S. Bearing: N 12° E

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	4.3	0.280	0.26	0.054	2.15	0.26	4.6	10	4	10	
2	18	9.2	0.300	0.04	0.120	4.45	<0.02	2.6	5	3	8	
3	38	5 6	0.195	0.06	0.070	2.85	0.08	1.9	5	3	6	
4	48	2.6	0.410	0.10	0.034	1.30	0.74	8.4	12	10	15	
5	58	6.6	0.280	0.08	0.090	3.15	0.18	3.2	7	4	12	
6	68	7.3	0.210	0.03	0.097	3.35	0.03	1.4	5	3	6	
7	78	5.0	0.155	0.02	0.066	2.50	0.12	2.4	5	4	7	
8	80	2.9	0.385	0.07	0.062	2.30	0.74	8.6	100	27	14	
9	88	4.2	0.195	0.03	0.048	2.00	0.15	2.2	84	550	78	
10	93	11.1	0.275	0.04	0.131	5.20	<0.02	1.1	7	3	8	
11	98	4.1	0.275	0.08	0.059	3.20	0.39	5.4	3	5	12	
12	103	6.2	0.275	0.04	0.078	2.85	0.29	3.9	9	6	16	
13	108	6.6	0.200	0.06	0.084	3.05	0.08	1.7	9	4	7	
14	111	4.3	0.310	0.06	0.050	2.15	0.46	7.7	9	7	16	
15	113	8.1	0.235	0.04	0.083	3.80	0.12	2.8	9	5	9	
16	114	6.0	0.350	0.14	0.062	2.70	0.51	8.2	45	33	17	
17	120.5	0.2	0.790	0.12	0.031	<0.05	1.95	20.7	13	1200	170	vein
18	127	3.2	0.650	0.24	0.038	1.15	1.86	16.1	190	250	72	
19	129	5.3	0.425	0.14	0.058	2.30	0.49	8.0	100	160	40	
20	133	3.9	0.315	0.59	0.064	1.70	0.57	6.7	98	88	26	
21	138	4.5	0.385	0.26	0.065	2.10	0.43	5.5	28	260	27	
22	143	4.8	0.470	0.19	0.080	2.40	0.56	8.0	9	5	18	
23	148	4.9	0.580	0.13	0.070	2.45	0.67	8.6	3	18	21	
24	153	5.2	0.560	0.12	0.069	2.45	0.66	8.8	7	8	19	
25	163	12.3	0.420	0.06	0.124	6.70	0.02	2.4	8	2	12	

Table A-7. (Continued)

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
26	173	10.5	0.405	0.06	0.099	5.55	0.07	3.3	8	3	17	
27	182	8.4	0.430	0.12	0.096	3.90	0.20	3.9	9	3	15	

Table A-8. Element concentrations for samples from DDH 4600-926 starting at the south end.
Coordinates: 79,818 E., 80,288 S. Bearing N 1° E

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	5.6	0.330	0.28	0.067	2.40	0.32	5.2	5	5	15	
2	9	6.3	0.395	0.08	0.080	3.10	0.71	9.5	7	5	24	
3	19	5.2	0.330	0.08	0.091	2.50	0.66	9.0	<4	6	18	
4	24	5.3	0.320	0.08	0.070	2.60	0.60	8.3	7	6	22	
5	29	8.0	0.210	0.09	0.103	3.35	0.16	3.4	11	6	14	
6	34	3.8	0.385	0.14	0.061	1.95	0.90	11.3	5	5	21	
7	39	3.7	0.185	0.04	0.054	1.95	0.29	4.3	5	6	10	
8	44	5.3	0.340	0.09	0.080	2.75	0.36	8.8	7	6	17	
9	49	3.4	0.345	0.07	0.052	1.85	0.71	9.0	7	6	18	
10	54	3.3	0.225	0.05	0.084	1.70	0.45	6.1	14	5	16	
11	59	2.5	0.220	0.04	0.036	1.05	0.45	6.5	9	5	12	
12	64	3.4	0.170	0.02	0.052	1.50	0.29	4.3	9	6	11	
13	69	7.9	0.170	0.03	0.109	4.05	0.05	1.9	11	7	8.5	
14	74	3.1	0.455	0.10	0.036	1.60	0.77	12.0	7	4	19	
15	78	5.3	0.195	0.08	0.067	2.55	0.34	4.8	4	5	14	
16	82	5.1	0.925	0.30	0.072	2.45	1.69	22.0	29	11	55	
17	85	5.7	0.310	0.12	0.082	3.00	0.66	8.3	7	6	20	
18	87	5.1	0.415	0.17	0.071	2.30	1.08	12.6	14	4	22	
19	89	7.2	0.230	0.13	0.100	3.35	0.42	6.5	10	10	14	
20	91	5.1	0.195	0.13	0.071	2.65	0.39	5.5	44	15	14	
21	92	3.5	0.475	1.70	0.057	1.80	1.73	18.0	70	62	36	
22	94	2.1	0.810	0.30	0.042	1.00	3.28	32.0	300	180	74	vein
23	96	<0.05	0.960	0.30	0.012	<0.05	4.93	46	26	9	74	vein
24	98	<0.05	1.18	0.35	0.018	<0.05	4.52	46	8	2	97	vein
25	100	<0.05	1.06	0.30	0.021	<0.05	4.55	48	8	2	72	vein

Table A-8. (Continued)

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
26	102	0.1	1.00	0.26	0.018	<0.05	3.69	46	8	850	175	vein
27	104	0.4	1.00	0.30	0.035	0.10	3.62	45	240	3700	650	vein
28	106	2.7	0.410	0.16	0.041	1.10	1.24	13.3	150	110	47	vein
29	108	2.0	0.250	0.10	0.026	0.70	0.62	20.8	3900	32000	5600	vein
30	110	3.0	0.335	0.18	0.038	1.25	0.70	8.1	200	810	150	vein
31	112	2.5	0.300	0.20	0.035	1.15	0.70	7.4	60	96	28	vein
32	114	4.0	0.500	0.20	0.050	1.80	1.14	12.0	300	600	125	vein
33	116	3.4	0.570	0.18	0.041	1.50	1.24	13.0	120	500	115	vein
34	118	4.3	0.660	0.32	0.051	1.90	1.54	15.0	275	6400	760	vein
35	120	6.7	0.290	0.18	0.081	3.05	0.38	5.0	8	3	16	
36	122	3.9	0.360	0.21	0.054	1.95	0.62	7.1	28	550	75	
37	124	6.4	0.380	0.17	0.079	3.00	0.54	7.3	12	2	22.5	
38	127	4.9	0.490	0.16	0.062	2.40	1.14	13.6	14	390	70	
39	130	8.5	0.245	0.07	0.098	4.10	0.21	3.4	10	2	16	
40	133	5.7	0.385	0.10	0.068	2.55	0.55	7.5	10	13	20	
41	137	6.2	0.405	0.16	0.068	2.95	0.63	8.7	8	2	25	
42	142	7.0	0.295	0.08	0.075	3.30	0.34	5.0	8	2	20	
43	147	5.5	0.540	0.28	0.056	2.65	0.71	9.2	8	2	31	
44	152	8.3	0.350	0.11	0.092	3.30	0.23	4.6	12	1	14	
45	156.5	8.5	0.310	0.09	0.090	4.10	0.20	4.2	12	1	20	

Table A-9. Element concentrations for samples from DDH 4600-945 starting at the south end.
Coordinates: 80,239 E., 80,337 S. Bearing: N 12° E

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	4.3	0.135	0.05	0.060	2.50	0.30	4.1	4	6	18	
2	6	5.8	0.130	0.04	0.075	3.15	0.12	2.6	4	5	8	
3	11	4.4	0.235	0.05	0.056	2.30	0.56	6.9	8	5	14	
4	16	3.7	0.160	0.06	0.055	2.00	0.25	3.9	4	7	8	
5	21	4.8	0.160	0.03	0.067	2.45	0.28	4.0	<4	17	10	
6	26	7.8	0.120	0.03	0.103	4.25	0.02	1.4	8	21	12	
7	31	3.0	0.325	0.07	0.051	1.55	1.02	10.2	<4	6	18	
8	36	6.4	0.250	0.69	0.065	3.40	0.60	7.4	12	8	17	
9	39	5.7	0.230	0.06	0.081	3.40	0.54	6.7	6	6	16	
10	41	7.8	0.140	0.03	0.106	4.30	0.10	2.6	12	5	8	
11	43	1.2	0.650	0.20	0.026	0.55	2.46	22.8	75	65	51	
12	45	3.6	0.500	0.11	0.058	1.85	1.32	14.4	24	7	18	
13	47	2.7	0.555	0.14	0.034	1.25	1.52	15.8	89	45	26	
14	48	1.1	0.990	0.34	0.023	0.20	2.77	45	1600	3000	415	vein
15	49	7.4	0.305	0.16	0.077	3.75	0.13	4.0	8	6	34	
16	50	8.3	0.310	0.11	0.096	4.55	0.13	3.8	6	4	19	
17	52	7.4	0.305	0.14	0.086	3.75	0.16	4.2	6	4	20	
18	54	4.2	0.285	0.62	0.067	2.90	0.23	4.3	8	10	18	
19	56	4.5	0.585	1.50	0.059	2.35	0.49	5.8	13	4	28	
20	59	9.5	0.305	0.13	0.105	5.50	0.12	3.2	6	2	22	
21	69	6.0	0.505	0.22	0.075	3.40	0.47	6.0	6	2	28	
22	74	9.4	0.365	0.13	0.107	5.35	0.18	3.4	11	2	22	
23	79	8.6	0.260	0.09	0.105	4.65	0.06	2.0	8	2	22	
24	84	8.2	0.275	0.07	0.096	4.55	0.11	2.4	11	1	16	

Table A-10. Element concentrations for samples from XC 4800-3 starting at the south end. Coordinates: 78,650 E., 80,295 S. Bearing: N 12° W to No. 19, N 60° W to end.

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	10.9	0.150	0.01	0.111	5.15	0.02	1.9	8	2	8	
2	6	5.2	0.245	0.05	0.079	2.55	0.32	5.9	8	8	12	
3	16	7.6	0.200	0.07	0.101	3.65	0.05	2.1	6	3	16	
4	26	6.0	0.180	0.07	0.082	2.65	0.17	3.6	6	3	12	
5	31	7.4	0.240	0.10	0.094	3.20	0.27	5.1	6	6	16	
6	36	7.7	0.215	0.09	0.097	3.45	0.18	3.7	4	4	11	
7	41	8.8	0.160	0.07	0.109	3.85	0.03	1.5	8	4	8	
8	46	3.4	0.290	0.07	0.059	1.55	0.55	7.6	4	4	15	
9	49	8.5	0.200	0.08	0.116	3.90	0.18	3.5	6	2	10	
10	50	6.5	0.160	0.07	0.100	3.05	0.16	3.1	6	3	10	
11	51	4.1	0.235	0.08	0.071	1.95	0.46	6.3	6	4	14	
12	66	3.1	0.285	0.08	0.038	1.45	0.95	10.8	30	35	24	vein
13	81	3.5	0.200	0.05	0.073	1.70	0.37	4.4	4	51	22	
14	83	2.6	0.150	0.04	0.061	1.30	0.27	3.6	6	11	12	
15	85	5.1	0.095	0.14	0.090	2.55	<0.02	1.1	8	6	6	
16	90	9.2	0.195	0.09	0.136	4.20	0.05	2.7	12	2	12	
17	95	5.1	0.210	0.15	0.082	2.20	0.20	3.5	6	130	24	
18	100	8.9	0.190	0.07	0.124	4.20	0.05	4.0	12	5	10	
19	105	6.1	0.155	0.08	0.080	2.70	0.10	2.3	6	4	8	
20	115	7.3	0.130	0.04	0.086	3.35	0.02	1.5	12	2	8	
21	125	7.1	0.140	0.07	0.089	3.35	0.02	1.7	6	2	8	
22	140	6.7	0.275	0.26	0.080	3.05	0.22	4.7	8	4	14	unbleached
23	155	5.2	0.305	1.95	0.065	2.35	0.24	3.5	6	2	15	unbleached
24	162	5.9	0.175	1.16	0.080	2.80	0.09	3.1	8	2	10	unbleached

Table A-11. **Element concentrations for samples from** XC 4800-7 **starting at the south end.**
Coordinates: 79,090 E., 80,271 S. **Bearing:** N 12° E to No. 29, N 15° W to end.

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	5.7	0.175	0.10	0.075	2.90	0.20	3.5	6	5	11	
2	5	9.3	0.145	0.03	0.122	4.90	0.02	1.1	7	6	8	
3	10	12.0	0.230	0.10	0.140	5.70	<0.02	1.8	8	4	11	
4	15	4.7	0.150	0.07	0.101	2.20	0.19	3.5	6	4	10	
5	17	3.6	0.205	0.04	0.083	1.55	0.39	5.5	4	3	14	
6	19	4.3	0.170	0.06	0.097	2.15	0.30	5.3	7	4	12	
7	20	5.0	0.190	0.05	0.103	2.45	0.31	4.8	4	3	11	
8	22	0.2	1.075	0.13	0.025	<0.05	3.76	50	5	4	55	vein
9	24	7.3	0.145	0.04	0.091	3.40	0.06	2.3	6	5	11	
10	25	3.6	0.380	0.22	0.053	1.80	0.91	11.9	5	4	24	
11	27	7.9	0.140	0.06	0.106	4.05	0.03	1.4	8	4	9	
12	29	6.6	0.180	0.08	0.094	3.65	0.05	1.8	6	4	9	
13	34	8.9	0.160	0.04	0.114	4.45	0.03	1.5	12	4	10	
14	39	4.6	0.355	0.19	0.064	2.10	0.75	9.6	7	4	22	
15	44	5.1	0.205	0.15	0.068	2.45	0.20	3.4	6	4	14	
16	49	4.3	0.330	0.07	0.065	2.30	0.98	10.3	6	2	21	
17	54	5.9	0.205	0.18	0.082	3.10	0.28	3.8	6	4	13	
18	59	2.9	0.250	0.05	0.046	1.50	0.68	7.8	8	4	17	
19	61	3.4	0.215	0.05	0.053	1.55	0.48	5.6	7	4	11	
20	63	2.5	0.160	0.06	0.038	1.20	0.40	4.7	7	11	12	
21	65.5	1.6	0.555	0.18	0.037	0.70	1.93	18.1	350	200	68	vein
22	66	2.6	0.185	0.04	0.047	1.25	0.43	5.6	170	1700	250	
23	67	6.8	0.315	0.17	0.085	3.20	0.37	5.3	10	6	17	
24	69	5.9	0.185	0.07	0.075	2.80	0.10	2.1	12	7	9	
25	74	5.4	0.200	0.04	0.070	2.45	0.15	2.5	17	62	17	

Table A-11. (Continued)

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
26	79	3.6	0.605	0.12	0.053	1.75	1.50	16.0	10	9	34	
27	84	2.6	0.325	0.06	0.041	1.30	0.66	6.8	5	5	14	
28	89	4.4	0.205	0.04	0.061	2.30	0.29	4.0	5	6	11	
29	99	3.9	0.355	0.06	0.052	1.90	0.71	8.0	5	5	16	
30	109	5.7	0.300	0.05	0.064	2.75	0.32	5.5	5	2	16	
31	119	8.2	0.230	0.04	0.101	4.05	0.08	4.0	9	2	12	unbleached
32	139	5.2	0.250	0.58	0.060	2.25	0.10	2.7	<3	3	9	unbleached
33	150	5.6	0.575	3.30	0.071	2.60	0.32	4.4	9	2	16	unbleached

Table A-12. Element concentrations for samples from XC 4800-9 starting at the south end. Coordinates: 79,347 E., 80,340 S. Bearing: approximately N 5° E

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	9.6	0.225	0.02	0.133	5.30	<0.02	1.6	5	3	7	
2	18	6.7	0.165	0.04	0.098	3.30	<0.02	1.1	8	4	6	
3	28	5.2	0.410	0.14	0.068	2.05	0.60	8.0	27	8	19	
4	33	3.8	0.395	0.12	0.056	1.90	0.73	9.5	9	7	18	
5	38	3.2	0.605	0.14	0.048	1.35	1.43	15.6	9	8	18	
6	40	3.3	0.330	0.09	0.051	1.45	0.79	9.2	8	8	14	
7	40.5	0.4	0.735	0.15	0.026	0.15	1.82	47	875	7300	970	vein
8	41	6.9	0.250	0.06	0.093	3.40	0.13	3.4	200	43	13	
9	52	3.3	0.320	0.08	0.050	1.55	0.90	9.4	36	55	22	
10	54	2.3	0.235	0.05	0.037	0.80	0.49	10.8	230	2700	340	
11	56	2.7	0.570	0.12	0.051	1.05	1.35	18.8	78	49	31	vein
12	58	3.7	0.860	0.22	0.069	1.60	2.30	22.7	47	4	37	
13	61	8.3	0.255	0.09	0.093	3.75	0.25	4.7	10	5	12	
14	63	5.7	0.490	0.18	0.063	2.65	1.30	12.3	10	24	22	
15	65	7.7	0.410	0.08	0.083	3.35	0.44	6.8	6	11	16	
16	67	6.9	0.375	0.08	0.075	3.20	0.48	6.9	99	350	66	
17	71	2.5	0.690	0.18	0.051	1.20	1.63	17.4	67	7	24	vein?
18	73	4.6	0.315	0.05	0.064	2.10	0.46	6.1	9	10	17	
19	76	7.5	0.275	0.05	0.103	3.80	0.07	2.1	14	480	53	
20	79	6.5	0.215	0.04	0.103	3.35	0.10	2.3	8	10	11	
21	83	4.1	0.190	0.15	0.071	2.25	0.21	3.6	6	75	16	
22	88	5.3	0.280	0.09	0.084	2.85	0.39	5.4	6	32	15	
23	93	7.3	0.235	0.05	0.106	3.80	0.10	2.2	14	30	11	
24	103	7.3	0.240	0.05	0.113	3.85	0.09	2.1	11	20	11	
25	113	4.8	0.295	0.16	0.077	2.60	0.77	10.9	7	4	26	

Table A-12. (Continued)

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
26	128	5.2	0.565	0.12	0.081	2.70	0.23	4.1	5	3	11	unbleached
27	148	7.0	0.380	1.36	0.087	3.60	0.16	4.4	9	5	12	unbleached
28	158	11.6	0.335	0.120	0.126	6.05	<0.02	5.3	7	2	13	unbleached
29	173	6.5	0.420	2.80	0.097	3.25	0.19	3.7	8	2	13	unbleached

Table A-13. Element concentrations for samples from XC 4800-13 starting at the south end. Coordinates: 79,770 E., 80,340 S. Bearing: approximately due N.

No:	Dist. feet	Al wt%	Mg wt%	Ca wt%	Na wt%	K wt%	Mn wt%	Fe wt%	Pb µg/g	Cu µg/g	Zn µg/g	Remarks
1	0	3.4	0.235	0.04	0.063	1.75	0.52	5.8	<4	5	13	unbleached
2	7	3.3	0.190	0.04	0.064	1.55	0.37	4.3	13	500	57	unbleached
3	17	2.7	0.235	0.09	0.048	1.30	0.51	5.7	6	5	22	
4	27	5.0	0.125	0.02	0.080	2.35	0.14	2.0	6	3	9	
5	42	4.1	0.270	0.06	0.066	1.85	0.49	5.4	7	7	14	
6	47	6.3	0.125	0.04	0.117	3.55	0.08	1.8	7	10	10	
7	52	4.5	0.245	0.09	0.074	2.35	0.86	6.3	7	3	18	
8	57	7.9	0.165	0.09	0.123	5.00	0.11	2.2	7	4	13	
9	60	7.3	0.140	0.10	0.110	4.55	0.05	1.4	9	7	13	
10	61	5.6	0.085	0.15	0.086	3.25	0.03	0.7	4	6	10	
11	62	7.0	0.155	0.04	0.096	3.50	0.19	2.8	7	4	16	
12	73	<0.05	0.910	0.27	0.035	<0.05	4.37	48	30	240	130	vein
13	84	3.4	0.290	0.56	0.054	1.30	0.88	9.4	24	200	60	
14	85	4.5	0.305	0.75	0.061	2.05	0.88	9.4	15	130	55	
15	87	2.9	0.455	0.12	0.048	1.45	1.02	15.6	29	720	140	
16	89	1.7	0.695	0.16	0.028	0.75	1.42	22.2	140	8700	1600	
17	94	4.4	0.325	0.08	0.066	2.20	0.61	4.1	9	59	20	
18	99	6.2	0.245	0.14	0.076	3.35	0.24	3.2	7	7	18	
19	104	9.0	0.295	0.11	0.107	4.85	0.16	3.2	11	14	23	unbleached
20	109	10.5	0.315	0.08	0.110	5.20	0.10	2.4	9	6	21	unbleached?
21	123	9.7	0.245	0.08	0.110	4.65	0.06	1.9	9	3	13	unbleached?

Table A-14. Concentrations of silicon and sulfur in samples from DDH 4400-732 starting at the south end.

No:	Dist. feet	Si wt%	S ug/g
1	0	31.2	700
2	5	36.6	1300
3	10	35.9	1200
4	15	33.1	800
5	20	30.1	2800
6	24	27.7	2300
7	27	33.3	900
8	30	31.0	1700
9	32	37.6	2600
10	33.5	16.5	5800
11	35	17.2	18000
12	37	17.5	52000
13	39	21.6	18000
14	40.5	32.9	500
15	41.5	33.6	600
16	43	34.0	990
17	45	37.4	660
18	47	29.6	440
19	50	35.0	590
20	54	31.8	1600
21	58	31.6	950
22	62	33.6	1100
23	67	32.3	1100
24	72	36.5	30
25	77	37.1	230
26	82	34.6	180
27	87	33.8	1800
28	92	31.4	160
29	97	35.5	530
30	102	35.5	690
31	107	39.4	810
32	114	34.9	450
33	124	33.5	350
34	131	34.7	120

Table A-15. Concentrations of silicon and sulfur in samples from DDH 4600-915 starting at the south end.

No:	Dist. feet	Si wt%	S ug/g
1	0	36.6	420
2	5	34.8	1200
3	10	37.5	1400
4	15	31.7	2200
5	20	27.6	1300
6	25	31.0	1200
7	28	29.2	1600
8	30	28.5	2400
9	32	32.5	1400
10	33	31.0	730
11	34	6.2	1200
12	36	32.6	4500
13	38	31.5	2700
14	40	29.5	2700
15	42	24.6	1300
16	47	28.4	1100
17	52	34.3	1200
18	54	34.8	1400
19	56	30.7	1900
20	57	12.3	2200
21	58	28.1	4800
22	60	31.5	3600
23	62	29.0	2800
24	67	36.2	1600
25	72	35.9	1400
26	75	31.1	1800
27	76.5	22.2	1600
28	77.5	34.4	2200
29	79	28.4	3900
30	82	35.6	1900
31	87	33.9	760
32	92	30.3	2200
33	97	31.9	1200
34	102	36.6	1500
35	107	34.7	2100
36	112	37.8	1100
37	117	36.5	1100
38	122	37.4	1500
39	127	35.9	1700
40	130	40.7	1400
41	133	37.7	1200
42	135	30.8	1800
43	137	32.3	4300
44	140	32.1	5500
45	141	14.8	—
46	142.5	0.7	—
47	143.5	25.9	1800
48	145	34.9	1700
49	149	34.4	1400
50	154	34.2	1300
51	159	33.8	1400
52	167	30.8	1600

APPENDIX B

RESULTS OF FACTOR ANALYSIS

Tables B-1 through B-13

Table B-1. Results of factor analysis of data from DDH 4400-732. Factor loadings of less than ±0.50 are not shown.

VARIABLE	FACTOR			COMMUNALITY
	1	2	3	
Aluminum	0.81			0.91
Magnesium	-0.88			0.85
Calcium			0.81	0.72
Sodium			-0.77	0.84
Potassium	0.88			0.89
Manganese	-0.94			0.95
Iron	-0.92			0.95
Lead	-0.50	0.59		0.62
Copper		0.96		0.93
Zinc		0.86		0.94

Percent of total variability attributed to factor

Factor 1:	55.2
Factor 2:	18.1
Factor 3:	12.7

Table B-2. Results of factor analysis of data from XC 4400-44 Factor loadings of less than ±0.50 are not shown.

VARIABLE	FACTOR		COMMUNALITY
	1	2	
Aluminum		0.87	0.98
Magnesium	-0.80		0.81
Calcium			0.11
Sodium		0.85	0.94
Potassium		0.85	0.96
Manganese	-0.84		0.88
Iron	-0.93		0.96
Lead	-0.86		0.79
Copper	-0.93		0.87
Zinc	-0.96		0.92

Percent of total variability attributed to factor

Factor 1:	68.8
Factor 2:	13.4

Table B-3. Results of factor analysis of data from DDH 4400-764. Factor loadings of less than ±0.50 are not shown.

VARIABLE	FACTOR 1	FACTOR 2	COMMUNALITY
Aluminum	0.95		0.90
Magnesium	-0.77		0.77
Calcium			0.26
Sodium	0.91		0.84
Potassium	0.94		0.88
Manganese	-0.84		0.87
Iron	-0.87		0.87
Lead		0.78	0.61
Copper		0.88	0.87
Zinc	-0.55	0.78	0.90

Percent of total variability attributed to factor

Factor 1: 62.2
Factor 2: 15.5

Table B-4. Results of factor analysis of data from DDH 4400-787. Factor loadings of less than ±0.50 are not shown.

VARIABLE	FACTOR 1	FACTOR 2	FACTOR 3	COMMUNALITY
Aluminum	0.94			0.90
Magnesium		0.84		0.97
Calcium		0.96		0.94
Sodium	0.93			0.90
Potassium	0.95			0.93
Manganese	-0.83			0.86
Iron	-0.82			0.85
Lead	-0.78			0.62
Copper			0.97	0.98
Zinc			0.96	0.99

Percent of total variability attributed to factor

Factor 1: 59.1
Factor 2: 16.2
Factor 3: 14.2

Table B-5. Results of factor analysis of data from DDH 4400-806. Factor loadings of less than ±0.50 are not shown.

VARIABLE	FACTOR 1	FACTOR 2	FACTOR 3	COMMUNALITY
Aluminum	0.89			0.86
Magnesium		0.83		0.79
Calcium		0.97		0.95
Sodium	0.87			0.80
Potassium	0.90			0.87
Manganese	-0.89			0.82
Iron	-0.83			0.76
Lead			0.80	0.87
Copper			0.88	0.82
Zinc	-0.62			0.55

Percent of total variability attributed to factor

Factor 1:	46.2
Factor 2:	20.4
Factor 3:	14.3

Table B-6. Results of factor analysis of data from DDH 4600-915. Factor loadings of less than ±0.50 are not shown.

VARIABLE	FACTOR 1	FACTOR 2	FACTOR 3	COMMUNALITY
Aluminum			0.79	0.85
Magnesium	-0.92			0.92
Calcium	-0.85			0.74
Sodium			0.70	0.54
Potassium			0.80	0.88
Manganese	-0.91			0.94
Iron	-0.85			0.91
Lead				0.26
Copper		0.97		0.97
Zinc		0.98		0.98

Percent of total variability attributed to factor

Factor 1:	49.7
Factor 2:	16.9
Factor 3:	13.4

Table B-7. Results of factor analysis of data from XC 4600-13. Factor loadings of less than ±0.50 are not shown.

VARIABLE		FACTOR		COMMUNALITY
	1	2	3	
Aluminum		-0.92		0.96
Magnesium	-0.86			0.85
Calcium			0.84	0.73
Sodium		-0.90		0.92
Potassium		-0.90		0.96
Manganese	-0.78			0.93
Iron	-0.80			0.92
Lead			0.71	0.60
Copper	-0.81			0.81
Zinc	-0.87			0.89

Percent of total variability attributed to factor

Factor 1: 60.5
Factor 2: 14.4
Factor 3: 10.9

Table B-8. Results of factor analysis of data from DDH 4600-926. Factor loading of less than ±0.50 are not shown.

VARIABLE	FACTOR		COMMUNALITY
	1	2	
Aluminum	0.91		0.87
Magnesium	-0.89		0.80
Calcium			0.15
Sodium	0.84		0.77
Potassium	0.90		0.87
Manganese	-0.95		0.90
Iron	-0.94		0.89
Lead		0.99	0.98
Copper		0.99	0.98
Zinc		0.99	0.98

Percent of total variability attributed to factor

Factor 1: 52.3
Factor 2: 29.7

Table B-9. Results of factor analysis of data from DDH 4600-945. Factor loadings of less than ±0.50 are not shown.

VARIABLE	FACTOR 1	2	3	COMMUNALITY
Aluminum		0.96		0.96
Magnesium	-0.70			0.82
Calcium			0.99	0.98
Sodium		0.94		0.97
Potassium		0.95		0.97
Manganese	-0.58	-0.74		0.89
Iron	-0.80	-0.58		0.97
Lead	-0.96			0.97
Copper	-0.96			0.96
Zinc	-0.97			0.98

Percent of total variability attributed to factor

Factor 1: 67.3
Factor 2: 17.2
Factor 3: 10.4

Table B-10. Results of factor analysis of data from XC 4800-3. Factor loadings of less than ±0.50 are not shown.

VARIABLE	FACTOR 1	2	3	4	COMMUNALITY
Aluminum	0.96				0.98
Magnesium		0.63	0.63		0.88
Calcium			0.90		0.85
Sodium	0.89				0.90
Potassium	0.95				0.98
Manganese	-0.57	0.77			0.96
Iron		0.84			0.94
Lead		0.77			0.64
Copper				0.95	0.94
Zinc				0.76	0.94

Percent of total variability attributed to factor

Factor 1: 52.4
Factor 2: 14.4
Factor 3: 12.8
Factor 4: 10.5

Table B-11. Results of factor analysis of data from XC 4800-7. Factor loadings of less than ±0.50 are not shown.

VARIABLE		FACTOR		COMMUNALITY
	1	2	3	
Aluminum	0.88			0.89
Magnesium	-0.79		0.58	0.95
Calcium			0.78	0.61
Sodium	0.84			0.79
Potassium	0.88			0.88
Manganese	-0.90			0.89
Iron	-0.87			0.84
Lead		0.71		0.56
Copper		0.96		0.93
Zinc		0.95		0.94

Percent of total variability attributed to factor

Factor 1:	49.5
Factor 2:	22.1
Factor 3:	11.2

Table B-12. Results of factor analysis of data from XC 4800-9. Factor loadings of less than ±0.50 are not shown.

VARIABLE		FACTOR		COMMUNALITY
	1	2	3	
Aluminum	0.88			0.87
Magnesium	-0.75			0.77
Calcium			0.90	0.81
Sodium	0.88			0.87
Potassium	0.90			0.90
Manganese	-0.90			0.86
Iron	-0.69	0.66		0.92
Lead		0.95		0.97
Copper		0.97		0.99
Zinc		0.97		0.99

Percent of total variability attributed to factor

Factor 1:	60.9
Factor 2:	17.9
Factor 3:	10.6

Table B-13. Results of factor analysis of data from XC 4800-13. Factor loadings of less than ±0.50 are not shown.

VARIABLE	FACTOR 1	 2	COMMUNALITY
Aluminum	0.87		0.80
Magnesium	-0.74		0.77
Calcium			0.21
Sodium	0.84		0.81
Potassium	0.87		0.81
Manganese	-0.90		0.83
Iron	-0.86		0.82
Lead		0.96	0.98
Copper		0.99	0.99
Zinc		0.98	0.99

Percent of total variability attributed to factor

Factor 1: 59.6
Factor 2: 20.5

APPENDIX C

CLUSTER ANALYSIS

The following describes the technique of pair-group cluster analysis as used in this investigation.

First, a full matrix of similarity coefficients is calculated. This is examined by column and by row and the highest coefficient noted in each case. The first clusters are derived by locating these variables which have the highest mutual correlation. For example, in Table 8, aluminum is most highly correlated with potassium and vice versa. They therefore form a cluster. Calcium is most highly correlated with magnesium, but magnesium is most highly correlated with iron. Calcium does not enter a cluster in the first cycle.

After the first clustering cycle, a new average similarity coefficient matrix is calculated between clusters and between clusters and single variables by Spearman's sums of variables method according to the formula

$$r_{qQ} = \frac{\square qQ}{\sqrt{q+2\Delta q} \cdot \sqrt{Q+2\Delta Q}},$$

where $\square qQ$ is the summation of similarity coefficients between clusters, Δq is the summation of similarity coefficients within the first cluster, ΔQ is the summation of similarity coefficients within the second cluster. q and Q are the number of members in the clusters, respectively. In the pair-group method only one variable may join a cluster in any given cycle. Hence, when calculating an average similarity coefficient between two clusters, q and Q are always equal to two. In the special case of calculating an average similarity coefficient between a cluster and a single variable, the general formula is reduced to

$$r_{xq} = \frac{\sum r_{xq}}{\sqrt{q+2\Delta q}},$$

where $\sum r_{xq}$ is the summation of similarity coefficients between members of the cluster and the single variable.

This cyclic computation and formation of similarity matrices are continued until all clusters and single variables are joined into one cluster. This is then displayed graphically in the form of a "dendogram". A detailed account of this technique is also provided by Sokal and Sneath (1963, Appendix A.3).