PARAGENETIC RELATIONSHIPS, ZONING, AND MINERALOGY OF THE BLACK PINE MINE, GRANITE COUNTY, MONTANA

by

Gregory Douglas Zeihen

A Thesis Submitted to the Faculty of the

DEPARTMENT OF MINING AND GEOLOGICAL ENGINEERING

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN GEOLOGICAL ENGINEERING

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 8 5

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotations from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate School when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Gregory Douglas Zeihen

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Charles E. Glass

C. E. GLASS
Associate Professor of Mining
Geological Engineering

AUGUST 5, 1985
Date

ACKNOWLEDGMENTS

I wish to extend my sincere thanks to Mr. Daniel McLaughlin, mine manager of the Black Pine mine, for allowing me to collect data for this thesis. I am indebted as well to the mine geologist, Mr. Albert Silva, for his time, help, and ideas that contributed to my work.

I am grateful to Dr. Jerry Bartholomew of the Montana Bureau of Mines and Geology for arranging financial support of this project and to Drs. Timothy Loomis, Michael Drake, and Thomas Teska of the Department of Lunar and Planetary Sciences at The University of Arizona for the use of the electron microprobe.

My thanks also go to my thesis committee members, Drs. Charles E. Glass. William D. Payne, Christopher J. Eastoe, and John M. Guilbert, for their time and ideas as well as for their critical review of the manuscript.

I especially wish to thank my father, Lester G. Zeihen, for his suggestions and guidance during all phases of this work.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS--Continued

LIST OF ILLUSTRATIONS--Continued

LIST OF TABLES

ABSTRACT

Ore from the Black Pine mine near Philipsburg, Montana, is won from the Combination vein, a flat-dipping quartz vein that cuts across the quartzite of the Mount Shields 2 unit of the Missoula Group. Normal-grade, quartz–tetrahedrite–pyrite ore and high-grade, quartz–tetrahedrite–galena–sphalerite–pyrite ore are the two separate ore types in the mine. This suggests two mineralizing events, but only one stage of tetrahedrite was observed, and fluid-inclusion homogenization temperatures for both ore types were nearly the same. Electron microprobe analysis of the tetrahedrite revealed a positive correlation between silver and antimony and detected several ore shoots along the main haulage drift but failed to outline a central, high-arsenic conduit. Mineralogical and elemental zoning, vein flattening, and lateral high-angle fault movement appear to localize high-grade zones. If the dike to the north is considered a possible fluid source, high-grade zones may trend N. 60° E.

CHAPTER 1

INTRODUCTION

The Black Pine mine, owned and operated by Inspiration Development Company, was located in 1882 as the Combination mine. It exploits a shallowly dipping quartz vein by room-and-pillar methods. A steady silver producer in recent years, the mine is located in the eastern portion of the Sapphire Mountains of southwestern Montana (Fig. 1).

Ore consists of argentiferous tetrahedrite with other minor sulfides, sulfosalts, and huebnerite, and it assays an average of 5.7 oz/ton Ag. Rubber-tired vehicles truck the ore to the surface where it is shipped to a custom mill in Philipsburg, 11 miles to the southeast. Concentrates are shipped to ASARCO's smelter in East Helena, Montana.

The present work was undertaken because of the relative lack of mineralogical or other detailed geologic information on the property. It was thought that a study of the paragenetic relationships, mineral and ore zoning and mineralogy, and the relationship of these to megascopic features of the mine might give valuable information on ore trends. If this information could be gathered quickly and inexpensively from assays and underground mapping and observations, it might prove important in predicting the occurrence and location of higher grade ore zones for mine exploration. Some of these characteristics may also apply to regional exploration for similar deposits of this type.

Figure 1. Aerial view of the Black Pine mine looking west. -- Photograph courtesy of Hugh Dresser, Montana College of Mineral Science and Technology.

To examine the relationships of ore to both structure and oxide mineralogy of the deposit, work was separated into two parts. First, two drill holes 1,030 feet apart were logged to examine microscopic structural and lithologic features both above and below the vein. An attempt was made to identify marker beds, and samples from the core were retained for examination under reflected and transmitted light. An underground plan map at the scale of 1" = 100' was then compiled by using available mine survey ground lines, with the strike and dip of the bedding, vein, and major faults noted. From this information, two roughly orthogonal cross sections were constructed. Minor field checking using an existing surface map (Hughes, 1970) was also conducted.

The second portion of work entailed microscopic examination of thin and polished sections. Two suites of specimens were collected, one from random locations throughout the mine, and the other from along the two cross-sectional planes. All polished sections were examined under reflected light to identify minerals, determine paragenetic relationships and determine if recently located high-grade ore was a result of supergene enrichment or hypogene mineralogy. All samples from the cross-sectional planes were polished and examined under a reflected light microscope. An electron microprobe was used to analyze the tetrahedrite in these specimens for Cu, Ag, Fe, Zn, Sb, As, and S to determine element zoning in the deposit. A brief and general fluid-inclusion study was undertaken on samples from two mine locations in the low- and high-grade zones, respectively. The purpose was to determine any differences in salinity and temperature of the ore fluids at the two locations and thus to establish if two different ore fluids could have been responsible for the two ore types.

X-ray identification of submitted specimens of oxide minerals from the mine is being undertaken by L. G. Zeihen in conjunction with the Montana Bureau of Mines and Geology. Thus far, 33 mineral species have been identified. Several thin sections of the hanging wall, footwall, and vein were examined for the presence of alteration and to ascertain general mineralogy.

Data and interpretation of each of the preceding portions are presented in Chapters 2 through 6. This work presents a detailed study of ore mineralogy, the paragenetic relationships, and mineralogical and elemental zoning in the mine. From this information, conclusions were drawn regarding the factors controlling high-grade ore trends.

Location and General Information

The Black Pine mine is located in western Montana in secs. 16, 17, and 21, T. 8 N., R. 14 W., 10 miles northwest of the town of Philipsburg and roughly 70 miles northwest of Butte, as shown in Figure 2. Situated near the southern end of the John Long Mountains, the Combination Number 2 adit entrance is on National Forest land at an elevation of 6,219 feet (Fig. 3). Access to the mine is via a dirt road leading west from Highway 10A about 2 miles north of Philipsburg.

Surrounding terrain consists of broad, rolling hills with grass and sage on the lower slopes. Upper slopes near the mine are timbered with lodgepole and occasional yellow pine. Topographic relief is

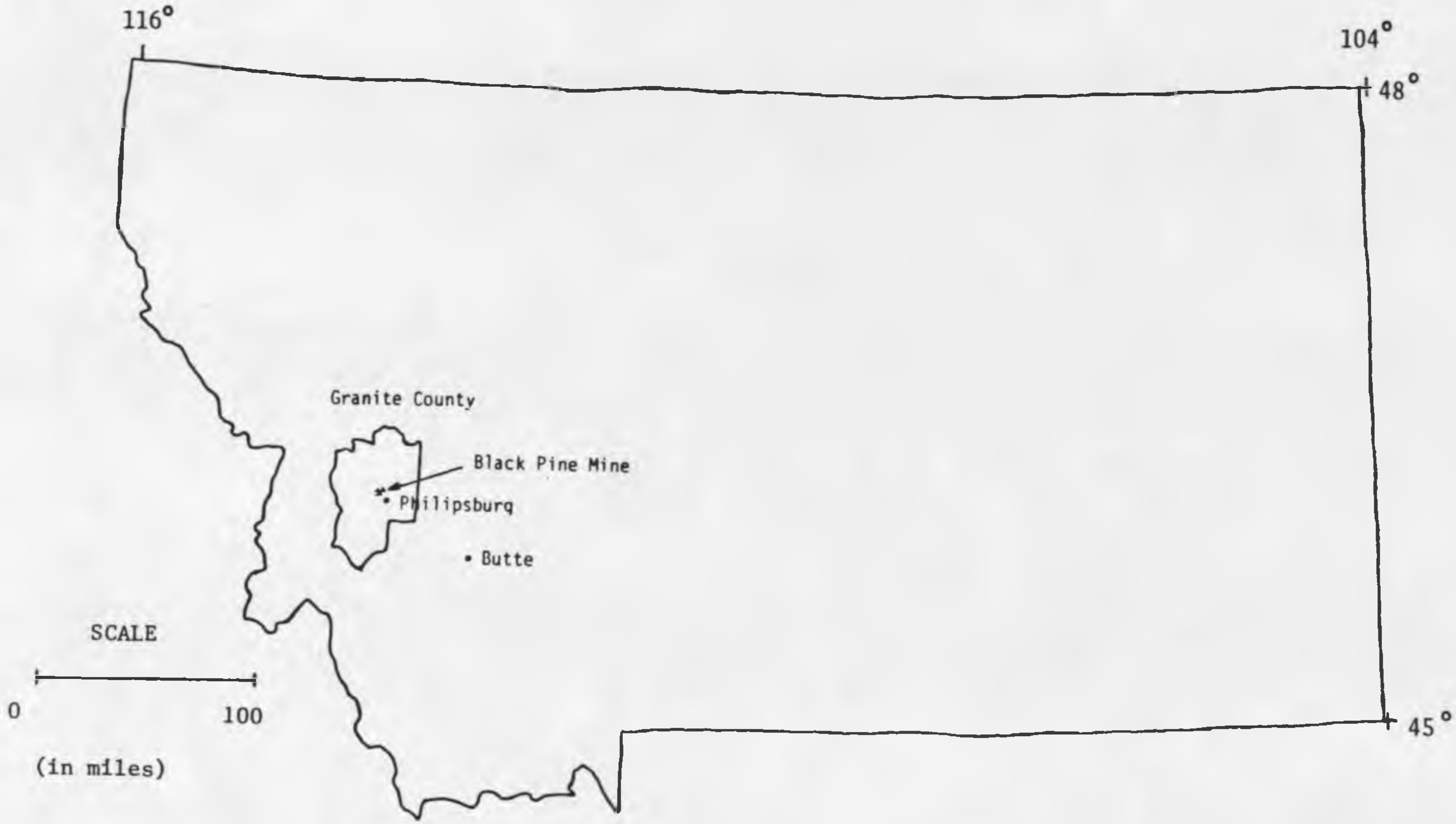


Figure 2. Map of The State of Montana showing the location of the Black Pine mine

Figure 3. Combination Number 2 adit entry

Figure 4. A typical small outcrop of one of the units of the Missoula Group

moderate, with valley elevations around 5,600 feet, and the highest elevation nearby is 7,937 feet at the Black Pine lookout. Outcrops are generally small and sparse, due to the gentle dips of the country rocks. Figure 4 shows an example of a typical outcrop.

The climate in the vicinity of the mine is semiarid, cool, and temperate, with summer high temperatures around 70°F and winter high temperatures in the 20°-30°F range. Snowpack at the mine can be moderate to heavy, as much as 6 feet, but more commonly less than 2 feet are on the ground at any one time.

Although mining was, and still is, the principal industry of the area, lumbering is an important business and logging is carried on in nearby mountains. Hay and alfalfa are common crops in the Flint Creek valley, and livestock raising makes up a minor commercial industry.

History of the Black Pine Mine

Previous and Current Work

Published detailed reports on the Black Pine mine are quite limited. A considerable amount of early data on the mine is found in a U.S. Geological Survey Professional Paper by Emmons and Calkins (1913). Because the paper deals with the mines and geology of the entire Philipsburg quadrangle, the discussion of the Black Pine mine is understandably brief.

Due to the presence of tungsten in some of the Black Pine ore, a post-World War II study of the property was undertaken by the U.S. Bureau of Mines. The report of this work by Volin, Roby, and Cole (1952) briefly describes the location and extent of the workings as they were at that time and reports the results of 16 diamond drill holes and 10,732 linear feet of trenches. Average grade indicated by that work was 0.32 to 0.42% WO_3 and 12.70 to 13.82 oz/ton Ag. It is interesting to note that the "average" silver value is heavily skewed toward only four holes. Subsequent assaying in this area seems to show grades on the order of half of these values.

The tungsten potential of the Black Pine mine was again examined by the U.S. Bureau of Mines as a part of a districtwide tungsten evaluation project (Walker, 1960). No new exploration was involved in that study.

A short report on mining operations by White (1976) provides in a brief discussion of the geology and mining practices at the Black Pine mine as they were in that year. Production figures through 1964 are reported in the Montana Bureau of Mines and Geology Special Publication 75 (Krohn and Weist, 1972). This publication also contains general information on the mine. Two other U.S. Bureau of Mines reports by Cole (1950) and Hundhausen (1949) deal with nearby mineralization located about 3 miles northeast of the Black Pine mine.

Hughes (1970) attempted to correlate the rock units in the area with similar units to the northwest and to tie igneous bodies and observed structures into the structural and tectonic framework of the district. A similar attempt by Waisman (1984) examined the structural relation of the Black Pine mine to regional tectonics.

Billingsley (n.d.) addressed the detailed mineralogy of the vein as well as paragenetic relationships, factors influencing sulfide transport and deposition, and the presence of elemental and mineralogical zoning in the Black Pine mine.

Historical Summary

The Black Pine mine was originally located as the Combination mine in 1882. A small amount of ore from the property was milled in 1885, and in that same year, James A. Pack organized the Black Pine Mining Company. In 1887, a newly built stamp mill was put into production, but the company went bankrupt within a few months of its acquisition, and the property was purchased at auction and organized under the Combination Mining & Milling Co. C. D. McLure, one of the new owners, expanded the mill and both mine and mill were in continuous operation from 1888 to 1897. Both low ore grade and low silver prices forced closure, leaving production figures at 2,185,000 oz Ag and 1,411 oz Au, a ratio of Ag to Au of 2000 to 1. In 1928, Calumet and Hecla Mining Company held the property under option and carefully evaluated the project, but they declined to purchase, and in 1932 Black Pine Inc. was organized in Seattle. From 1885 to 1945 some 40,000 combined tons of tailings and minor new ore were processed. In 1964, Montana Climax leased the property and produced 4,826 tons of ore averaging 0.171 oz/ton Au and 11.37 oz/ton Ag, and 1.27% Cu. Total production from 1885 to 1964 is given in Table 1.

Inspiration Development Co. obtained a lease on the property in 1970. They subsequently opted to purchase the mine, and development proceeded in April 1974 (White, 1976). Ore shipments began 5 months later and have continued to the present, with a brief interruption in

Table 1. Production of base and precious metals from the Black Pine mine, 1885-1964. -- After Krohn and Weist, 1977

Commodity	Estimated Cumulative Production		Grade
Gold	3,000	oz	0.02 oz/ton
Silver	2,572,000	oz	16 oz/ton
Copper	2,120,000	lb	0.7%
Lead	260,000	lb	
Zinc	27,000	lb	
Tungsten trioxide	460	lb	0.3%

the summer of 1980 due to low silver prices. Current mining is done using room-and-pillar methods with a mining height of 7.5 feet. Ore reserves in August 1983 totaled 1.7 million tons of 6 oz/ton silver ore. Ore is shipped to a custom mill in Philipsburg, Montana, and concentrates are sent to the ASARCO smelter in Helena, Montana. Production under Inspiration has been 784,000 tons at 5.80 oz/ton Ag, 0.8% Cu, and 0.009 oz/ton Au as of October 1983. Current production is approximately 1,000 tons per day.

CHAPTER 2

GEOLOGY

This first part of this section provides a brief overview of the regional lithology and structure as observed and interpreted by Hughes (1970). It is included because of the importance of regional structure to the detailed structure of the mine. The general geology of the area is presented in Figure 5 (in pocket).

Detailed geologic structure in the mine is important to assessing mineral zoning and ore grade.

Regional Geology

Lithology

Sedimentary Rocks. The sedimentary rocks of the Belt Supergroup are host to the Combination vein of the Black Pine mine. A generalized geologic map of the vicinity is presented in Figure 6. Stratigraphic nomenclature used by Hughes (1970) was adopted from Nelson and Dobell (1961) and places the vein outcrops in the Bonner Quartzite. More recent work by Harrison (1972) divided the Miller Peak Formation into the Snowslip Formation and the Mount Shields Formation. The Mount Shields Formation, in turn, has been divided into the Mount Shields 1, 2, 3, and 4. Recent mapping of units in the area by the U.S. Geological Survey has reassigned the Combination vein host rock to the Mount Shield 2 (Fig. 7). Although individual formations in the

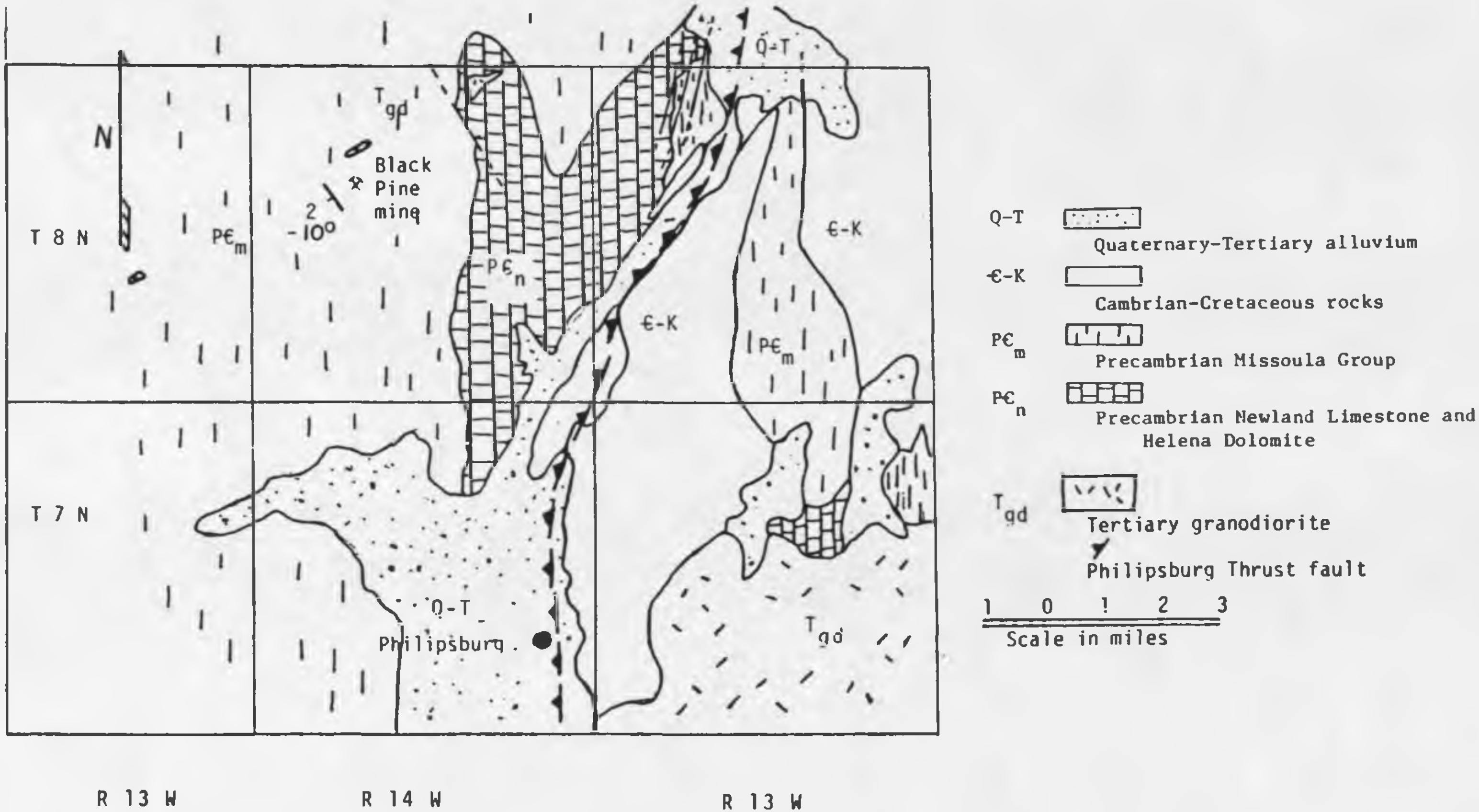


Figure 6. Generalized geologic map of the Philipsburg areas. -- Modified from Volin and others (1952) and Winston (1973).

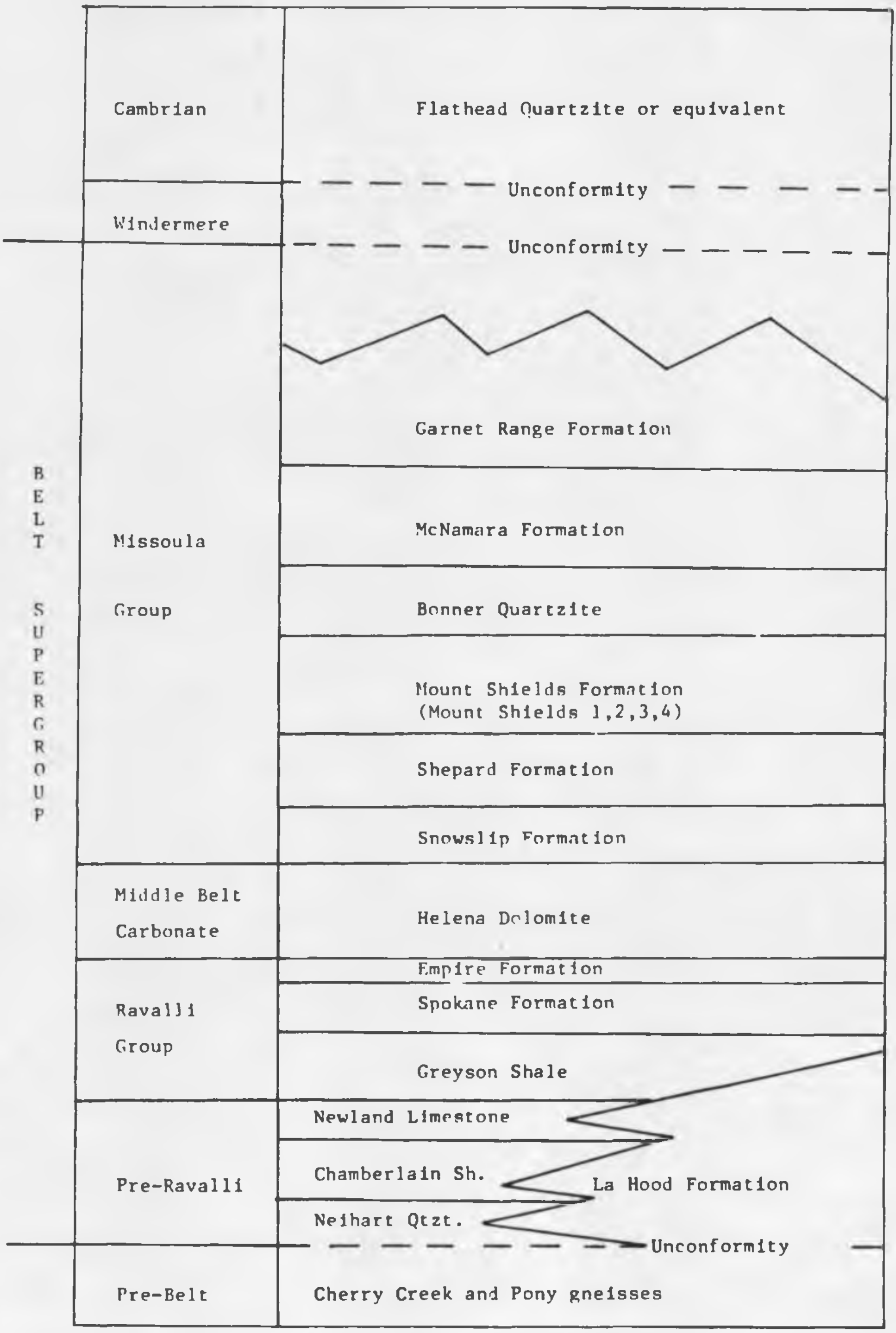


Figure 7. Composite section showing Belt Supergroup terminology. -- No scale implied. After Harrison (1972) and Wallace and others (1981).

Belt Supergroup have not been dated, deposition of these sediments probably occurred between 1,200 and 1,600 m.y ago (Giletti, 1969).

An isopach map of the Belt rocks in Montana is shown in Figure 8. This also shows the Belt embayment running northwest to southeast, which was probably bordered by an active fault along the southwest margin (Hughes, 1970).

Megascopically, the Mount Shields 2 is a buff-to-pink quartzite with beds ranging from 1 to 3 inches to several feet thick. It also contains thin, red, shaly zones. Figure 9 shows typical Mount Shields 2 in outcrop. The Combination vein is outlined and shows oxide staining. Joints in the mine vicinity are commonly manganese stained, and a red argillic unit, the Mount Shields 3 (mapped by Hughes as the McNamara Argillite) crops out 300 feet up section from the Combination Adit No. 2.

The sedimentary rocks of the Belt Supergroup are made up of many different lithologies in different areas where they occur. In the vicinity of the Black Pine mine, Hughes (1970) suggested a regressive sequence beginning with the deep-water deposition of calcareous rocks of the Helena Formation up through the shallow-water clastics of the Garnet Range Quartzite. In particular, he noted that the Bonner Quartzite (now reassigned to the Mount Shields Formation) probably included a different source area for coarser sediments, possibly as close as the Anaconda Range to the south. This fits well with the fresh, angular microcline and plagioclase and angular quartz fragments seen in thin sections of this rock. Winston (1983) enlarged upon this and interpreted the clastics as part of a transgressive-regressive sequence

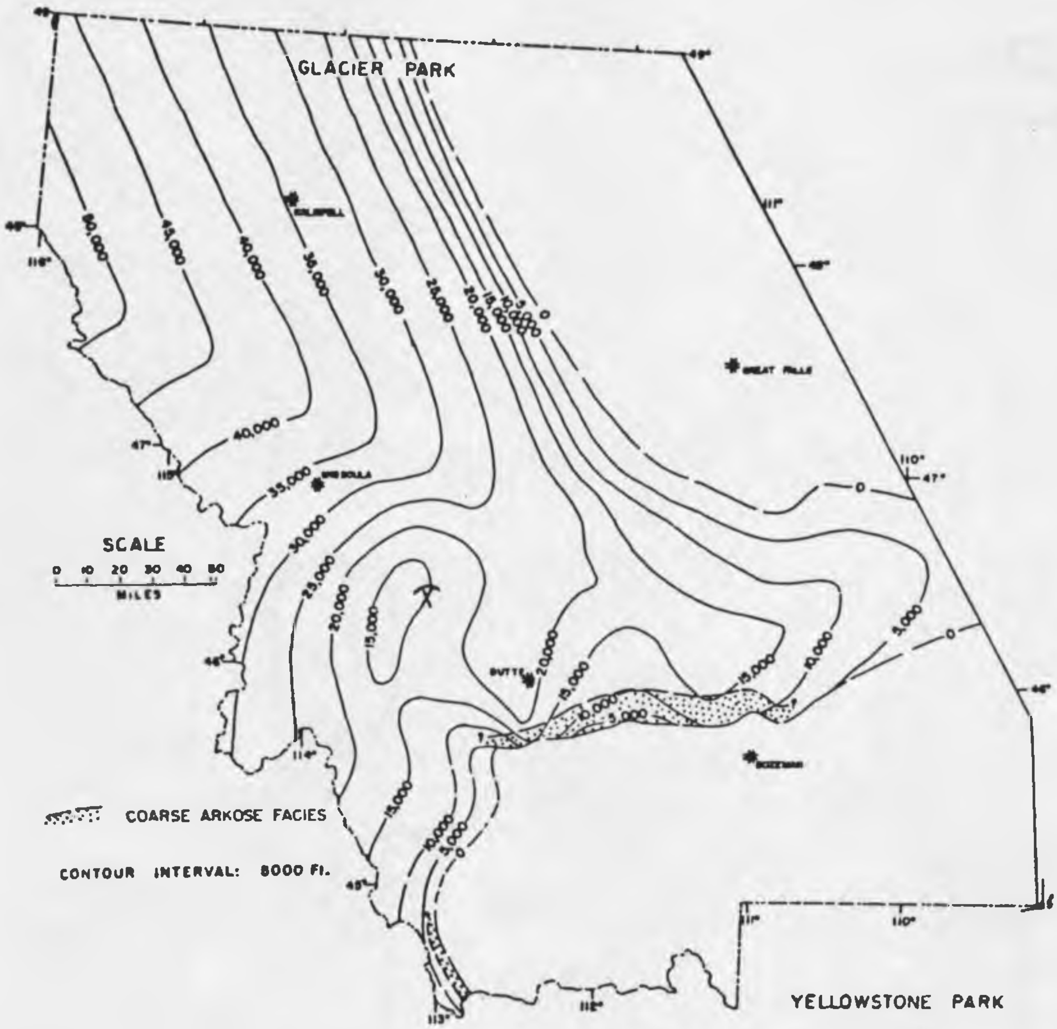


Figure 8. Generalized isopach map of Belt Series, western Montana. -- After McMannis (1965). The Black Pine mine location is shown by mine symbol.

Figure 9. Mount Shields 2 unit showing outcrop of Combination vein

with deposition of coarse, cross-bedded strata due to braided streams. He also invoked a southern sediment source made up of Precambrian crystalline rocks of the Pony and Cherry Creek gneisses.

There is considerable evidence of high-energy sediment deposition in and near the Black Pine mine. Cross-bedding and scattered mud chips are common in drill core, and symmetric and asymmetric ripples with wavelengths ranging from 1-2 inches to 2-3 feet are visible in the workings.

Composition of the quartzite, as determined from several thin sections, is 90-95 percent quartz, 1-2 percent feldspar (about 50 percent microcline and 50 percent plagioclase), and 1 percent accessory minerals. The grains are subangular to angular and are strongly bimodal in size, ranging from 88-125 microns and 125-250 microns.

Igneous Rocks. In the immediate vicinity of the Black Pine mine, only three igneous bodies are found. On a hill almost due north of the adit entrance, Hughes mapped a a dike-shaped body. During a cursory examination, the rock was found to be composed of a coarsely crystalline feldspar groundmass supporting quartz phenocrysts up to half an inch in diameter. It was described as a granodiorite by Hundhausen (1949), and the general trend of this body is N. 60° E.

Another dike with a similar strike is located 3,000 feet north and west of the Lewis shaft. It was not examined during this study but was mapped by Hughes as a Tertiary intrusive rock similar to the outcropping dike to the north.

The third igneous body crops out 2 miles east of the first on Sunrise Mountain. This unit was not examined in the course of this study, but owing to low-grade tungsten values (averaging 0.03% WO_3) in the form of disseminated scheelite, it was investigated by a U.S. Bureau of Mines group as a potential tungsten deposit (Hundhausen, 1949). This unit is also a granodiorite and is probably continuous at depth with the dikelike masses along the N. 60° E. trend. A recent aeromagnetic survey showed a N. 60° E. anomaly, about 30-40 gammas in magnitude, that matched the trend of the intrusive rocks (Silva, 1983, personal commun.).

The Henderson Creek pluton on Sunrise Mountain has been dated near 70.1 m.y. B.P. by potassium-argon dating of biotite, whereas the dike to the west yielded a K-Ar date of about 73.7 m.y. B.P. from muscovite (Daniel and Berg, 1981). The Philipsburg batholith, 18-20 miles south of the mine area, is dominantly granodioritic. The age of this batholith is 50 m.y. (Chapman, Gottfried, and Waring, 1955).

Structural Geology

Faults. The Combination vein occupies one of four shallowly dipping, geologically similar structures cutting the quartzites of the Mount Shields 2 unit. Most early structures are low angle and appear the result of compressional forces directed generally east-northeast. Principal among these is the Philipsburg thrust, which crops out on the eastern side of the Flint Creek valley, as shown in Figure 6. The upper plate of this thrust is referred to as the allochthonous portion of the Sapphire tectonic block (Emmons and Calkins, 1913).

Recent district-level mapping by the U.S. Geological Survey (1978) has revealed two smaller thrust faults just below the veins, as shown on Figure 5 (in pocket). Hughes (1970) stated that considerable thrusting has taken place in the area and indicated that siliceous infilling of larger structures is common.

Hughes (1970) described the Placer and Sunrise faults as major, north-striking reverse faults. The Placer fault dips steeply westward and forms the eastern contact between the Helena Formation of Henderson Mountain and the Belt rocks to the east. It lies to the east of Figure 5. The Sunrise fault forms the western contact between the Mount Shields 2 unit and the Helena Formation and dips steeply eastward. One set of normal faults described by Hughes strikes N. 30°-55° W. in the mine vicinity. The amount of movement on these is not specified. A highly generalized structure map is presented in Figure 10.

Tension fractures in the mine area strike N. 65°-75° E. and dip vertically. They show little or no offset and are occasionally intruded by porphyry dikes. Transverse faults form a conjugate set with a poorly developed group striking northwest and a better developed group striking northeast.

The youngest structural features noted by Hughes are north-south-striking normal faults. These may dip either east or west, 55 to 60 degrees, and typically have several hundreds of feet of displacement. The only example of this fault type in this area truncates the intrusion as shown in the northeastern portion of Figure 5.

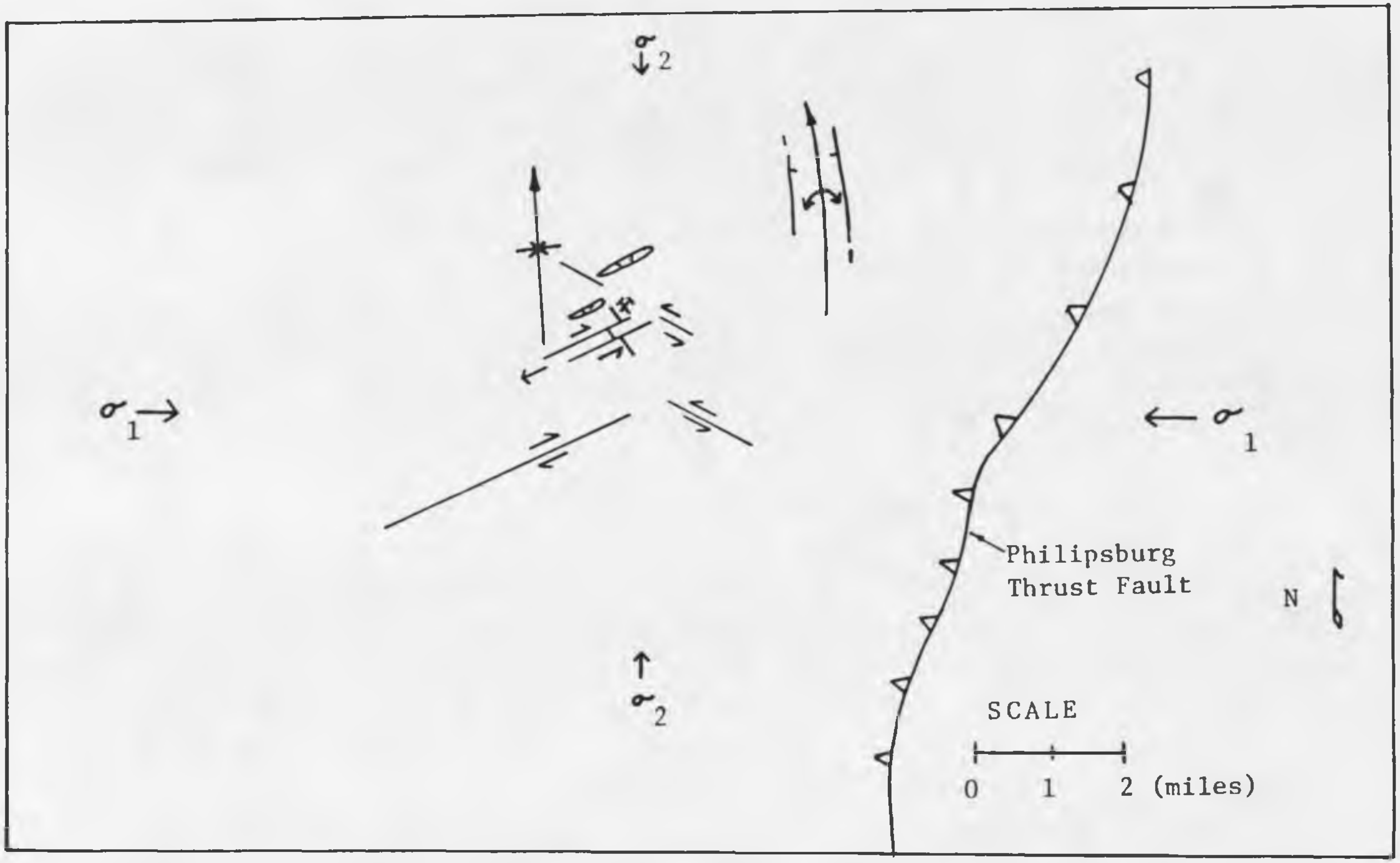


Figure 10. Highly generalized structure map of mine area prior to block faulting. --Modified from Hughes's (1970) discussion. Late Cenozoic normal faults may have added normal components to some lateral structures.

Folds. The broad Marshall Creek syncline trends north-south and plunges gently northward. In the mine area, the east flank dips from 2 to 10 degrees westward, and this structure is in fault contact with the Helena Formation along the Sunrise fault (Fig. 5).

The Henderson Mountain anticline is a structure of very short wavelength and is bounded by a reverse fault to the east and a thrust fault to the west. It also plunges shallowly northward and trends generally north-south.

Hughes (1970) interpreted the normal faults striking N. 30°-55° W. as belonging to an early set because they are cut by the Willow Creek stock, which is to the west of Figure 5 (in pocket). They represent graben-and-horst faults resulting from differential movement of a gravity slide block and would develop roughly perpendicular to the principal stress direction. The generally north-striking normal faults he explained as a result of late Cenozoic block faulting.

The two reverse faults, the Sunrise and the Placer, may be the result of compression-induced uplift of the Helena Formation. This uplift was the result of high compressional stresses creating concentric folds in close vertical proximity to a décollement surface, possibly the Philipsburg thrust fault (Fig. 11). There is no room for the strata near the center of a concentric fold, so beds force their way in the direction of the least principal stress, which is usually perpendicular to bedding. The Sunrise fault, which forms the contact between the Helena Formation and the Mount Shields 1 unit has also been interpreted as a thrust fault dipping shallowly west. In view of the above

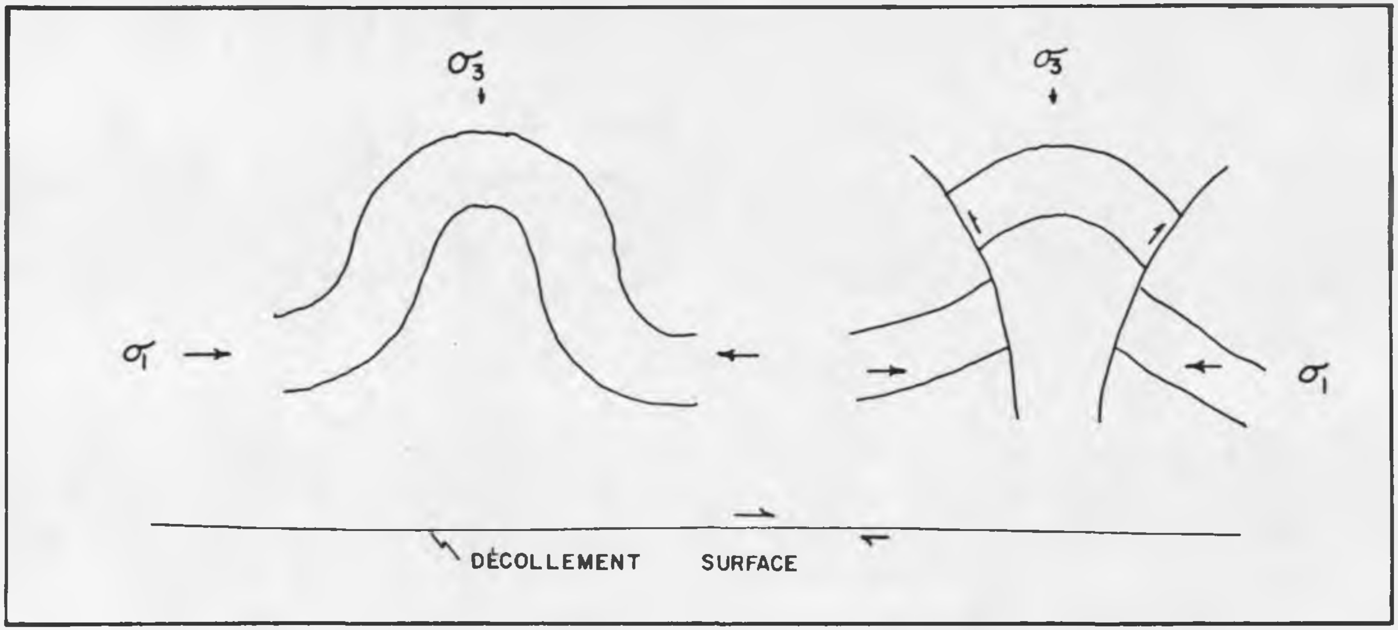


Figure 11. Diagram showing compression-induced faulting and uplift above a décollement surface, -- After De Sitter (1956).

discussion and the interpretation of Hughes, the Sunrise fault has been portrayed as a reverse fault (Fig. 5).

The broad open nature of the Marshall Creek syncline also supports concentric folding above a décollement surface, as does the short-amplitude fault-bounded Henderson Mountain anticline. Hughes (1970) interpreted the porphyry dikes as occupying tension fractures. These developed subparallel to the principal horizontal stress directions as seen in Figure 10. Hughes further interpreted the cause of these features to be the result of radial displacement of sediments on a décollement surface. Doming of the sediments over the Idaho batholith initiated slippage on this surface and caused the eastward gravity slide of a large block of sediments.

On a large scale, the arcuate nature of the thrust faults and folds, which gradually trend west farther north toward the Clark Fork River, suggests eastward translation and imbricate thrusting as a result of doming to the south and west. This also supports Hughes's ideas.

Mine Geology

The Combination vein is one of four major subparallel structures in the mine vicinity, all of which occur in the allochthonous portion of the Sapphire tectonic block. Highest in the section is the Upper vein, which is not currently economical. Below that is the Tim Smith vein from which Inspiration is producing silver-gold siliceous ore. Four hundred feet below the Tim Smith vein is the Combination vein, which is the major producer. The Onyx vein is 700 feet below the Combination vein and is currently under feasibility study and acquisition status. A very generalized projected cross section of these veins is shown in Figure 12. The location of the Upper vein was obtained from a general cross section in Inspiration's files. These veins are all very similar in appearance, containing coarsely crystalline, locally vuggy quartz, tetrahedrite, huebnerite, pyrite, and sparse sphalerite and galena (Walker, 1960).

A pinkish-tan quartzite of the Mount Shields 2 unit is the only rock encountered in the present workings. Bedding in the mine strikes from N. 20° W. to N. 20° E. and commonly dips from 2° to 10° W. The Combination vein strikes from N. 10° W. to N. 30° W. and commonly dips from 10° to 25° W. (Fig. 13, in pocket). It consistently cuts bedding in the mine, but this crosscutting can be obscure due to the lenses in the host-rock quartzite. Megascopically, both the footwall and hanging wall appear identical.

In the mine workings, two sets of steeply dipping postore faults cut the vein. One set strikes roughly orthogonally to the main haulage, striking generally N. 55° E. and dipping around 80° N. This set consists of four faults with varying amounts of relative normal displacement, ranging from less than 8 to 35 feet across the fault zones (Fig. 13, in pocket). The other fault set strikes roughly N. 40° W., but one of the faults horsetails north and dies out. The faults have minor normal relative displacement of about 2 feet and dip steeply to the north.

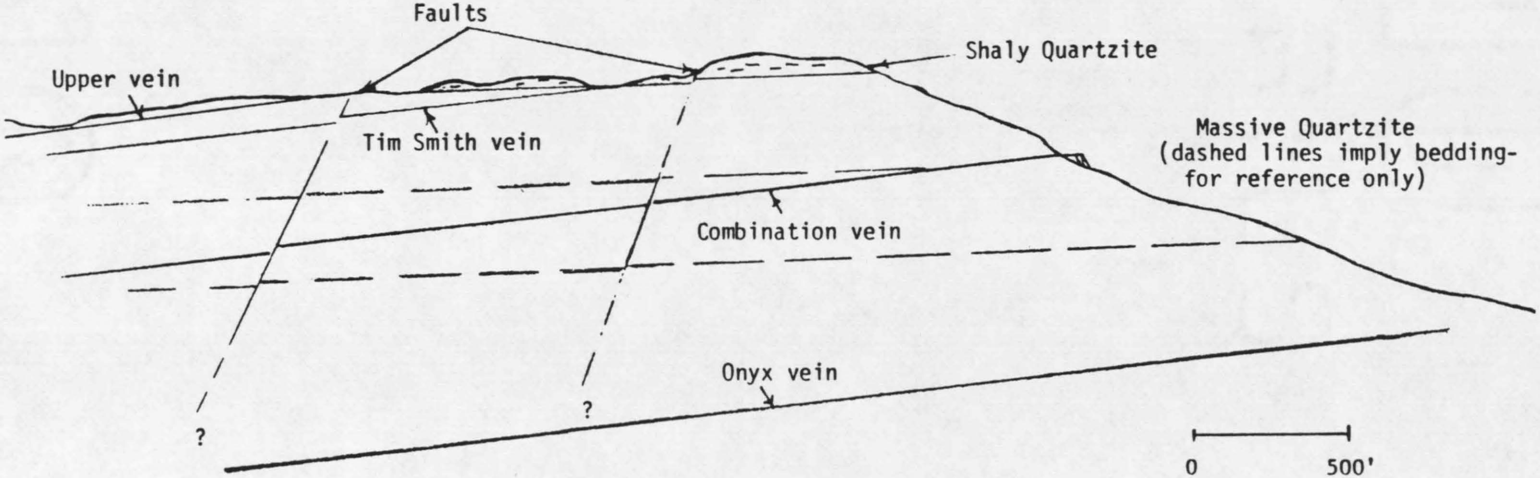


Figure 12. Diagrammatic cross section of the Combination and related veins, looking north. -- Veins and faults have been projected for clarity, and dashed lines imply dip of bedding relating to the veins.

Interpretation

The following observations suggest that the Combination vein has features of a thrust fault as well as a fissure filling. They also indicate that it is not a simple bedding-plane fissure as reported by Emmons and Calkins (1913). Siliceous infilling of structures that are undoubtedly thrust faults, as noted by Hughes (1970), implies that some thrusting along the vein structures could have occurred. Rotated fragments of wall rock contained in the vein were seen in several parts of the mine, although they were not common. Under the reflected-light microscope, sulfides are seen as a matrix infilling around fragments of broken quartz crystals. The thin section taken from core roughly 2 feet above the vein exhibits clay-filled shears containing pyrite, and definite crushing and aligning of quartz grains as seen in Figure 14. Irregular clay-filled patches with striations trending N. 11° W. are visible west of the 4470 drift near sample location 21 (Fig. 13, in pocket).

There are also strong indications of open-space filling by both sulfides and quartz. Tetrahedrite, sphalerite, and galena commonly fill vugs consisting of quartz crystals and cymoid loop structures as well. In addition, open vugs containing euhedral quartz are found throughout the mine. Thus, there is evidence of both thrusting (amount of displacement unknown) and open-space filling.

Displacement on the steep faults cutting the vein ranges from 4 inches to 35 feet; however, several features strongly indicate some lateral movement on at least one of these structures. The first high-angle fault in the southwestern portion of the workings showed

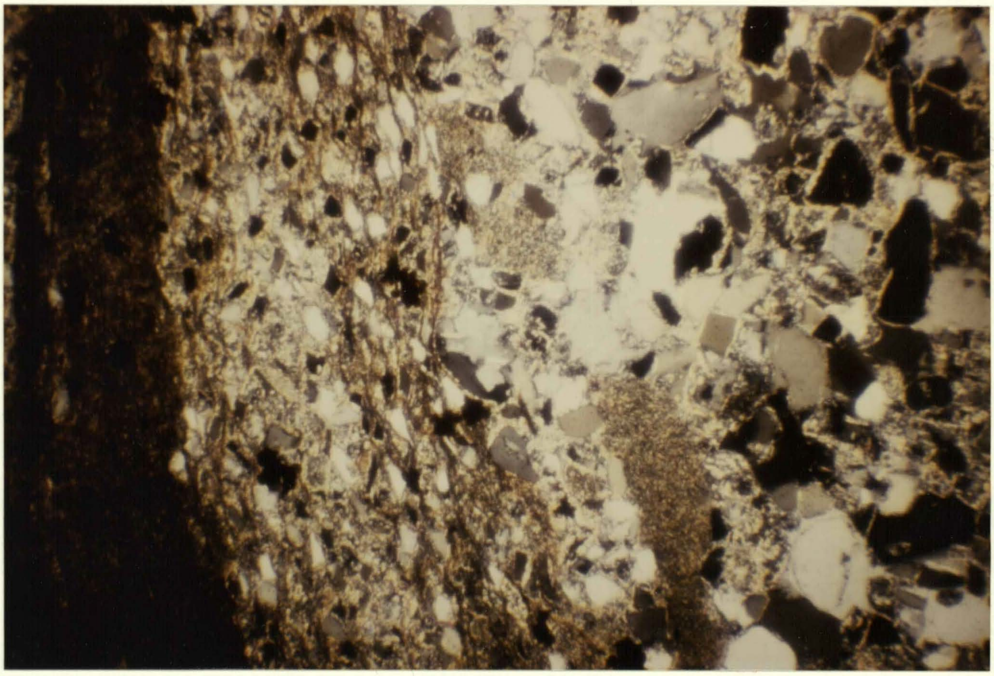


Figure 14. Photomicrograph of a thin section showing progressive shearing of grains in the quartzite as they approach a shear plane. -- Width of field = 2.44 mm.

definite slickensides pitching very shallowly in the plane of the fault, and although structural analysis indicated a slight normal component, a lateral offset of 70 to 80 feet could be possible. The downthrown portion of the vein is on the north side of the fault, and the vein dips to the west. Dextral slip is the only lateral motion that could result in that relation (Fig. 15, in pocket). Dextral slip is supported by assay results that do not match well across the faults (Silva, 1983, personal commun.). This set probably corresponds to Hughes's (1970) set of northeast-striking transverse faults and thus fits well into his structural picture.

The possible offset of one of the porphyry dikes by a northwest-striking fault on the western portion of Figure 5 (in pocket) provides an argument for left-lateral slip on that fault, although Hughes interpreted it as a normal fault.

In the subsurface, a group of en echelon faults generally strikes N. 40° W. subparallel to this structure and would fit well with Hughes's interpretation as the less well developed, northwest-striking transverse faults. The sharp cutting of the vein by these faults suggests that the east-west stress field was still present after the thrusting and mineralization had occurred.

Drill-hole Evaluation

Two drill holes were logged to examine the vein and the hanging-wall and footwall rock to look for alteration. Drill hole TS-40 was collared at an elevation of 6,362 feet and is located at 913,911 N and 1,025,485 E. It was stopped at 519 feet and cut three zones of the

Combination vein at 475, 483, and 496 feet. This drilling was entirely in pink-tan quartzite. Drill hole TS-33 was collared at 6,391 feet and is located at 914,931 N and 1,024,618 E. This hole was stopped at 603 feet and intercepted the Combination vein at 473 feet. Pink to tan quartzite is the only rock type encountered in this hole also.

No distinct differences were noted between the hanging wall and the footwall on either a macroscopic or a microscopic level. The vein appeared to have more splits in TS-40 with two primary veins 10 feet apart and a smaller vein 10 feet below the lower primary one. However, these veins contained considerably more sulfides, including galena and sphalerite, and also appeared less oxidized than the single vein in TS-33.

Alteration around the vein is minor and generally seems to disappear within 6 to 8 inches from the vein. Original clay in the quartzite has been converted to sericite, but this is common in the unaltered quartzite, although not so strongly developed. Observed alteration consists of minor silicification, argillization of feldspars, and pyritization. Zones of the quartzite are apparently quite inhomogeneous with regard to mineral composition as pieces of wall rock contained within the vein range from slightly argillized to solid clay.

Pyritization occurs in fractures and as disseminated grains in the footwall and hanging wall. As a result of oxidation they have been partially replaced by hematite.

CHAPTER 3

ORE MINERALOGY AND PARAGENESIS

The Combination vein is a pinch-and-swell structure, which occupies a probable thrust fault in the Mount Shields Formation. The vein ranges in thickness from less than 1 to more than 10 feet but averages around 5 feet.

Commonly banded and vuggy, the vein contains both coarsely crystalline and fine-grained quartz with coarse-grained sulfides, sulfosalts, and huebnerite and is locally coated by yellow, blue, and green oxide minerals (Fig. 16). Because of its shallow dip and nearness to the surface, the vein is heavily oxidized almost everywhere it has been exposed by the workings.

On megascopic examination many individual pulses of hydrothermal fluid have precipitated within the Combination structure. The resulting bands are variable in thickness, from 4 to 16 inches, and are relatively unfractured throughout their thickness. They are, however, strongly discontinuous in length and seldom can be traced for as much as 75 feet. This feature has created problems with interpretation of quartz stages in polished sections as each of these veins is coherent and whole within itself. Examination of most of the sections indicates no movement or fracturing after the tetrahedrite crystallized. Early euhedral quartz does appear fragmented.

Figure 16. Block from the Combination vein showing oxide minerals (green) and tetrahedrite (dark gray)

Paragenesis

Table 2 lists all the ore minerals and their formulas as well as unknown minerals and their probable species.

The earliest minerals of the paragenetic sequence are quartz, pyrite, and huebnerite. Huebnerite forms flat, euhedral crystals from a third to 2 inches long. These are contained within the white, zoned, euhedral-to-subhedral quartz (Q_1). The crystals occasionally extend into cavities and at times are coated with small euhedral quartz crystals, which may be somewhat later than Q_1. Crystals are red brown and occur in a jackstraw pattern in distinct zones parallel to the sides of the vein. They are present in most of the mine and as a rule are contained in the white, coarsely crystalline quartz near the edge of the vein.

Huebnerite in contact with tetrahedrite shows very minor replacement by tetrahedrite (Fig. 17). Two pyrite crystals contained partially within a huebnerite crystal show euhedral faces with no corrosion (Fig. 18(). Billingsley (1983, personal commun.) reported replacement of huebnerite by sphalerite, but huebnerite was not seen in contact with sphalerite or any other sulfides in this study.

Megascopic examination of the vein implies multiple stages of quartz. Only two distinct varieties could be identified in the polished sections. The early quartz (Q_1) is white, coarsely crystalline, and euhedral to subhedral (Fig. 19). It contains euhedral to subhedral pyritohedrons of pyrite in a wide variety of sizes and also euhedral blades of huebnerite. Rarely, vugs and fractures in Q_1 are seen to be filled with a finer grained, clear quartz (Q_2), which varies from

Table 2. Ore and gangue minerals of the Black Pine mine, excluding secondary oxides, carbonate, sulfates, arsenates, and phosphates

Mineral	Formula	Ore Status[a]	Occurrence[b]
Tetrahedrite	$(Cu,Ag)_{10}(Fe,Zn)_2(As,Sb)_4S_{13}$	p	P
Quartz	SiO_2	G	P
Pyrite	FeS_2	G	P
Huebernite	$MnWO_2$	s	P
Sphalerite	ZnS	s/p	P
Galena	PbS	s/p	P
Luzonite	Cu_3AsS_4	s	P
Chalcopyrite	$CuFeS_2$	s	P/Ex
Silver	Ag	m	S
Copper	Cu	m	S
Chalcocite	Cu_2S	m	S
Covellite	CuS	m	S
Stromeyerite(?)	CuAgS	m	S
Aikinite(?)	$PbCuBiS_3$	m	P

a. p = principal
p = subordinate
m = minor
G = gangue

b. P = primary
S = secondary
Ex = exsolution

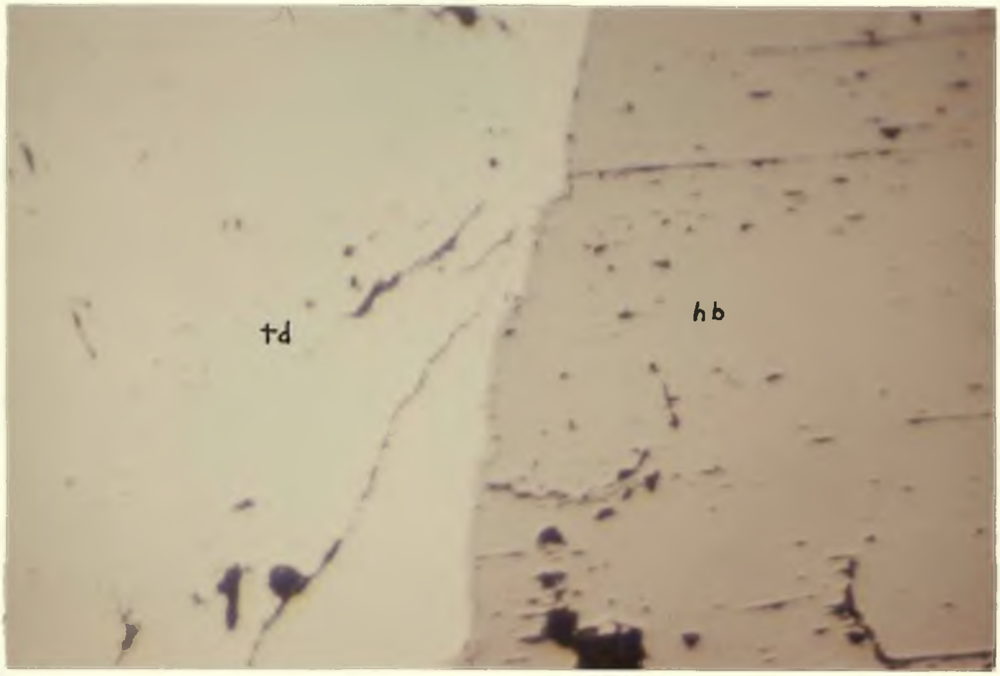


Figure 17. Tetrahedrite (td) showing slight reaction rim against huebnerite (hb). -- Width of field = 1.05 mm.

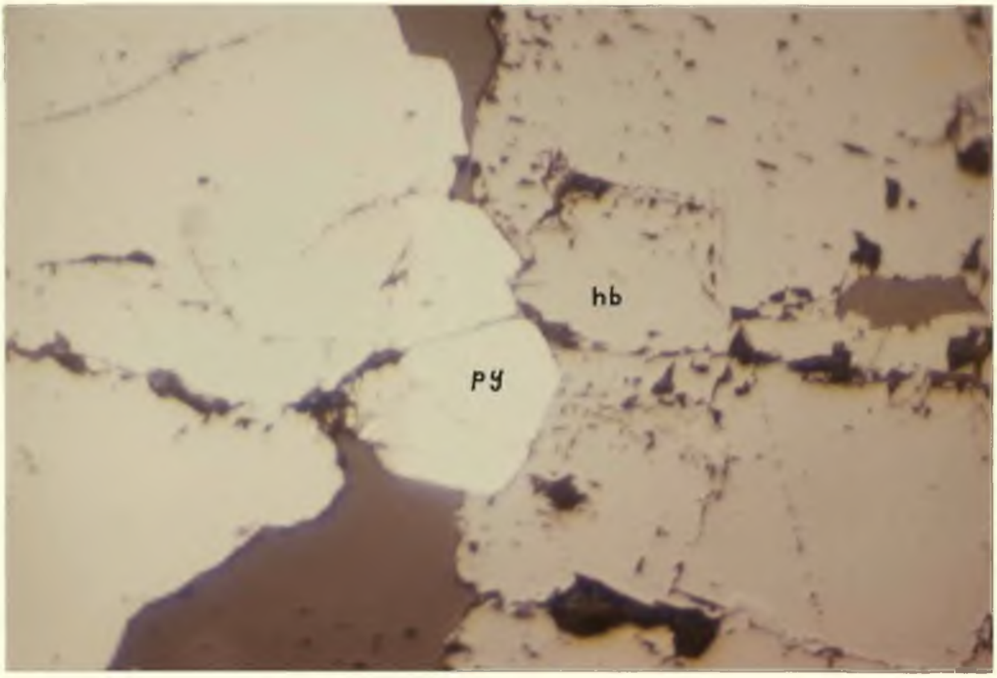


Figure 18. Euhedral pyrite faces (py) enclosed in a huebnerite crystal (hb). -- Width of field = 1.05 mm.

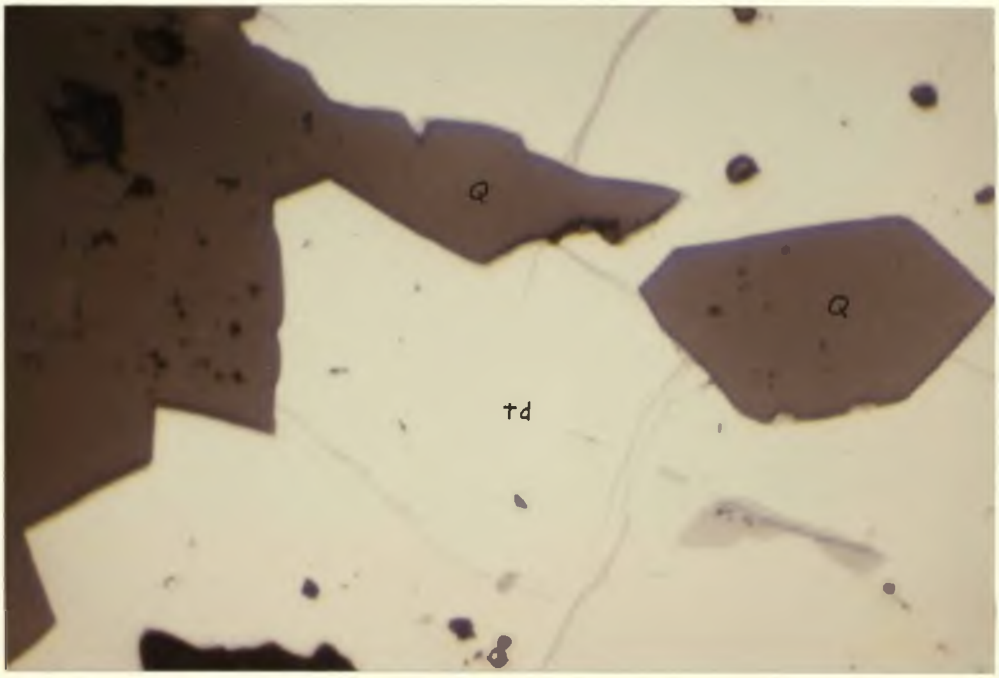


Figure 19. Euhedral quartz (Q) enclosed by tetrahedrite (td). -- Width of field = 1.05 mm.

euhedral to anhedral. The sugary gray appearance of Q_2 is due to the disseminated tetrahedrite and fine-grained pyritohedral pyrite it contains. Q_2 seems to be more abundant near the edge of the vein and may appear banded or laminated.

Pyrite occurs dominantly as euhedral to subhedral pyritohedrons but is also present as cubes and modified cubes. It is easily recognized from its shape, pale-yellow color, and relief after polishing. Almost all pyrite from the Black Pine mine has an unusually strong anomalous anisotropism, and this will be discussed in detail in Chapter 5. In Q_1, the grain size of the pyrite can be quite variable, from <1/16 to nearly 1½ inches, but in Q_2 the pyrite is fine grained, ranging from 177 to 350 microns. Pyrite crystals are seen in vugs in the quartz, as is the huebnerite.

Tetrahedrite, the principal ore mineral, appears to be exclusively open-space and fracture filling in Q_1 and Q_2. It takes a very good, although to somewhat pitted polish and appears pale tan with a very slight olive cast. Electron microprobe results show that both tetrahedrite and tennantite are present, but tetrahedrite is the most common. Irregular masses of tetrahedrite are seen in Q_1, and large euhedral crystals (roughly 1½ inches high) occur in vugs in some places. It is argentiferous and constitute between 4 and 7 percent of the vein.

Wherever it is in contact with pyrite, tetrahedrite replaces the pyrite to varying degrees (Fig 20). Tetrahedrite also replaces galena (Fig. 21). Luzonite occurs as an intergrowth with tetrahedrite and may even be exsolution in sample D', although Ramdohr (1969) testified that

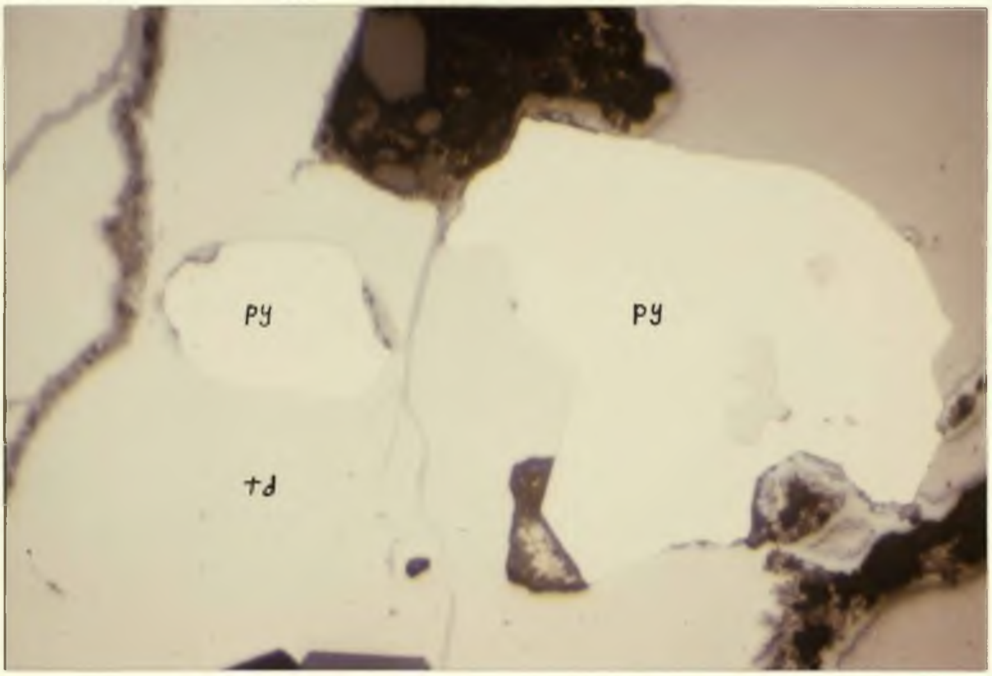


Figure 20. Tetrahedrite (td) replacing pyrite (py). -- Width of field = 1.05 mm.

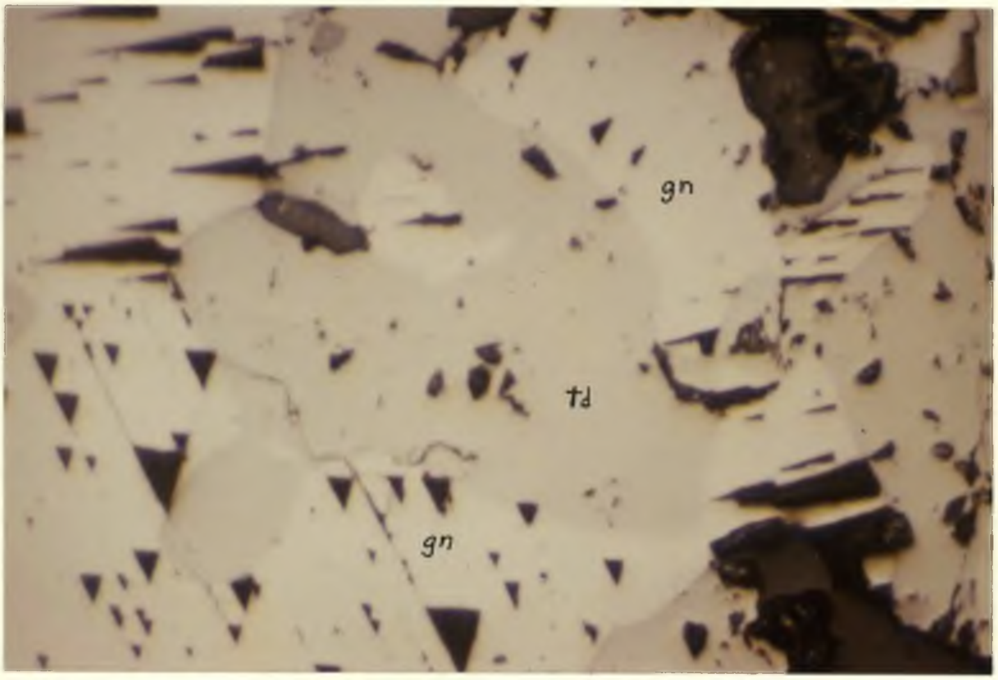


Figure 21. Tetrahedrite (td) replacing galena (gn). -- Width of field = 1.05 mm.

exsolution textures in tetrahedrite are exceedingly rare. Tetrahedrite is found throughout the mine but is less oxidized in deeper workings and away from the faults.

Sphalerite, far less common than tetrahedrite, also occurs as open-space filling in the vein. Although not a principal ore mineral, it is important in limited areas. Off the end of the 4270 drift and in the vicinity of samples 18 and 10, massive sphalerite makes up as much as 2 percent by volume of the vein. Sphalerite shows a pitted polish and is typically gray with a brownish cast and low reflectivity. It is located with tetrahedrite-rich bands and is most common where galena is also present. Sphalerite replaces tetrahedrite, galena, and pyrite (Fig. 22). It contains low iron, around 0.01 percent by weight, but random blebs of intergrown(?) pyrite and occasional chalcopyrite are seen in most samples.

Galena occurs in limited quantities throughout most of the mine workings but is especially important in the area near BP 8 and sample locations 2, 18, and 10 (Fig 13, in pocket). It is far more abundant at all three sample locations where it constitutes from 2 to 4 percent of the vein and, in addition, it is argentiferous. Galena is easily recognized under the microscope by triangular pits formed by polishing and by its white color and high reflectivity. Galena from the Black Pine mine has a slight pink tint, which may be due to trace elements as discussed in Chapter 5. Galena also occurs in the central to lower part of the vein and is more often present where sphalerite is most common. Galena probably replaces pyrite (Fig. 23) but is replaced by both tetrahedrite and sphalerite. Ore textures between tetrahedrite and galena are

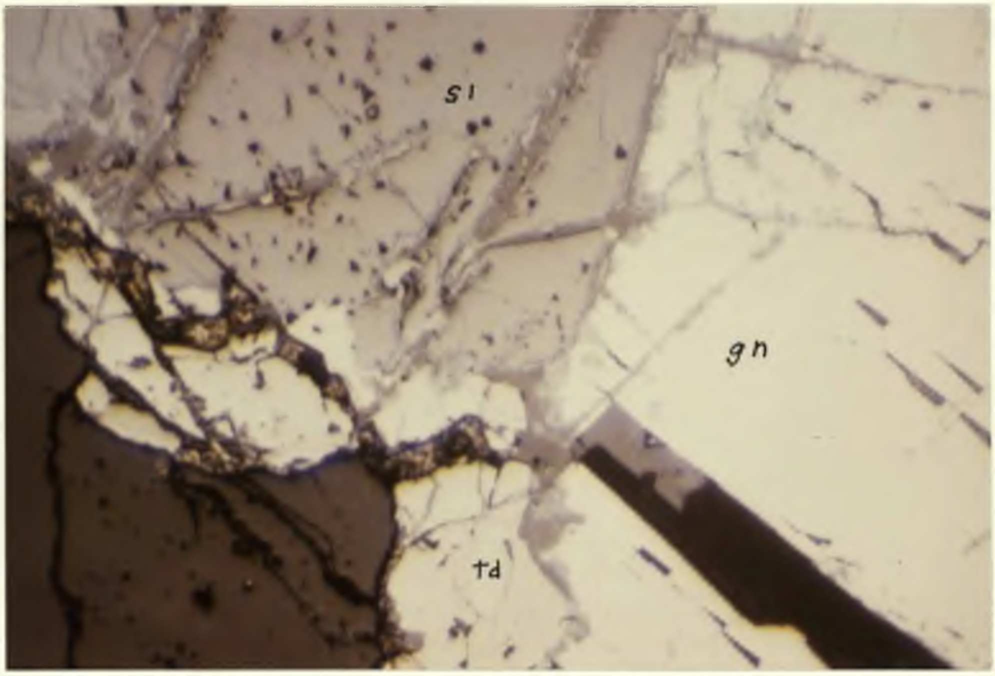


Figure 22. Sphalerite (sl) replacing tetrahedrite (td) and galena (gn). -- Width of field = 1.05 mm.

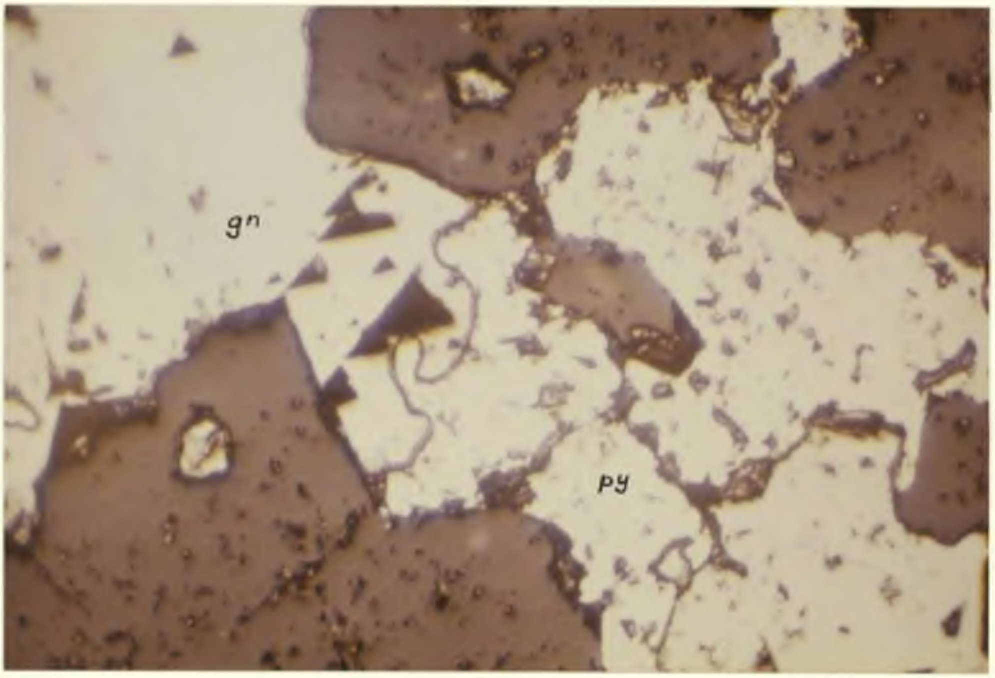


Figure 23. Galena (gn) replacing(?) pyrite (py). -- Width of field = 1.05 mm.

commonly somewhat more ambiguous. Criteria used to determine the paragenetic sequence are cuspate boundaries (convex side toward the galena), islands of replaced galena in tetrahedrite, and replacement boundaries that seem to utilize cleavage directions in the galena. Although I believe that tetrahedrite consistently replaces galena, it is possible that on some occasions the two minerals were deposited simultaneously and therefore exhibit intergrowth rather than replacement textures.

Luzonite occurs intimately intergrown with tetrahedrite and shows a pale-pink color in plane polarized light and strong anisotropism under crossed polars. Although it was seen in only four samples, it made up more than half of the sulfides in one polished section. It was recognized by a combination of optical properties and analysis by microprobe. The microprobe analyses gave an almost perfect stoichiometry of Cu_3AsS_4 with minor antimony and 0.74 percent by weight silver. Abundant lamellar twinning was observed, which according to Ramdohr (1969), allows distinction from enargite. Billingsley (1983, personal commun.) obtained an X-ray diffraction pattern matching famatinite (Cu_3SbS_4) during earlier thesis work, but no analyses during this study showed significant antimony. Luzonite was seen in only samples C, E, H, and A" and was not seen in contact with any other sulfides or quartz.

Chalcopyrite is very minor in the Combination vein. It occurs as irregular, free grains in quartz, as possible exsolution blebs in sphalerite, and as irregular islands in pyrite.

Both native silver and native copper are the result of supergene oxidation and are found near steep fault zones. Silver is found principally with chrysocolla but was also seen as flakes along oxidized fractures in tetrahedrite. Native copper was recognized and microprobed in sample location Z (Fig. 24). It occurs in oxidized vugs and appears very similar to native gold under the microscope. Both these minerals are discussed in Chapter 6.

With the help of the microprobe, it was possible to tentatively identify a mineral of the bismuthinite-aikinite "group." These minerals (including rezbanyite) are not related, but they have similar optical properties under crossed polars and are difficult to distinguish. Based on optical comparison with a reference sample (under polarized light), aikinite would appear to be the most likely identification and further reference will be treated as aikinite(?). This mineral was seen as irregular blebs in tetrahedrite and as one subhedral prism (Fig. 25). The mineral appeared pale yellow in plane polarized light and strongly anisotropic under crossed polars. Microprobe analysis of the sample yielded a rough stoichiometry in the range of Bi_2S_3 with trace copper and lead to $Cu_2PbBi_{19}S_{26}$. Difficulties in obtaining good microprobe data from the sample were caused by mutual interference of the sulfur, bismuth, and lead peaks and the small size of the sample of the mineral available. Although noted in several samples of tetrahedrite, only once was was it recognizable under the microprobe. This mineral appears to be rare, but its occurrence helps explain bismuth traces in the ore.

An attempt to identify a high-silver, unknown phase by use of the microprobe resulted in poor total analysis numbers. Out of nine

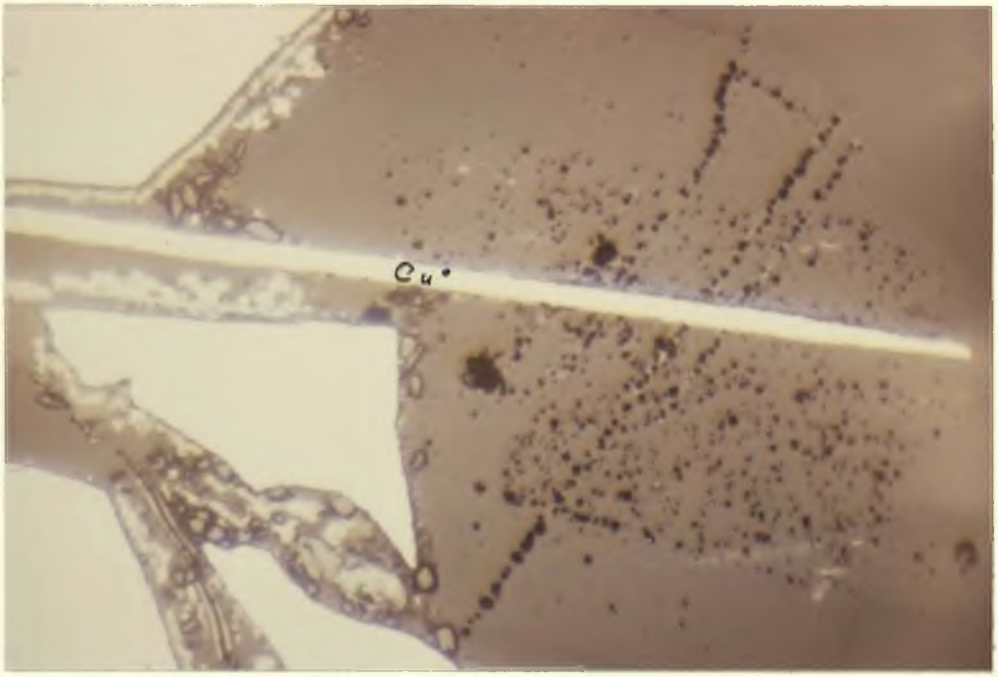


Figure 24. Native copper in polished section from sample location Z. -- Width of field = 1.05 mm.

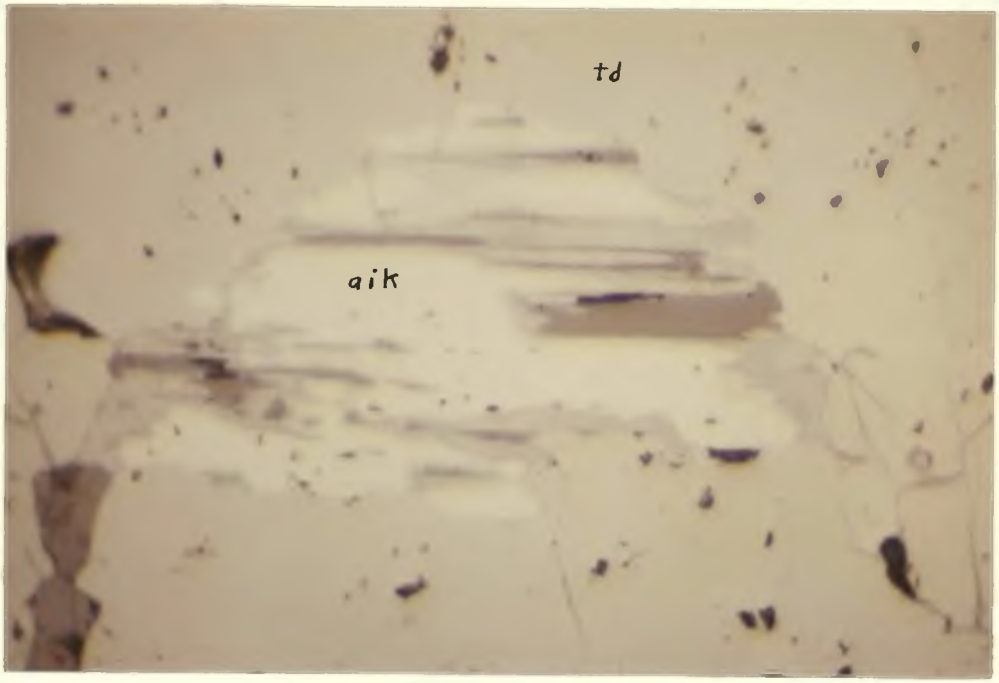


Figure 25. Subhedral prism of aikinite(?) in polished section from sample location Z. -- Width of field = 1.05 mm.

microprobe analyses, the mineral compositions appeared to indicate copper-silver sulfides of two different stoichiometries (Table 3). Because of poor optical resolution and inability to check optical properties on the microprobe, it was not determined whether these were optically distinct. The minerals have strong bireflectance and anisotropism with a grainy extinction pattern similar to stromeyerite (CuAgS). They occur as replacements along fractures exclusively in tetrahedrite and were occasionally seen in proximity to strongly oxidized pyrite. They are soft and take a poor polish, and, as seen in Figure 26, they sometimes contain a purplish high-iron phase that is probably goethite. These minerals were seen in samples C, E, L, and 2.

Due to the locally strongly oxidized nature of the Combination vein, the secondary copper sulfides covellite and chalcocite are very common in nearly all polished sections. Chalcocite is seen rimming tetrahedrite and in some places is rimmed by covellite (Fig. 27). Chalcocite is also seen replacing sphalerite and galena to varying degrees, usually as rims and along boundaries. It did not appear to directly replace pyrite, although covellite is commonly intimately mixed with the goethite surrounding oxidized pyrite. Covellite also replaces tetrahedrite commonly along fractures in a "wormy" pattern (Fig. 27) and replaces galena, sphalerite, aikinite(?), and luzonite preferentially to tetrahedrite (Fig. 28). In most samples, goethite appears to be the final (or most stable) oxidation product, excluding various exotic species mentioned in Chapter 6.

Table 3. Microprobe analysis of probable stromeyerite

Sample Number	Element, wt %								
	Cu	Fe	Zn	Pb	Sb	As	Ag	S	
2	19.46	0.05	0.12	0.06	0.16	0.05	69.91	8.95	96.76
	Stoichiometry	$CuAg_2S$ (approximate)							
	48.79	1.49	1.73	1.20	7.91	3.35	11.34	19.38	95.22
	Stoichiometry	Cu_9AgS_7 (approximate)							
	29.86	0.30	0.25	0.0	0.14	0.05	57.44	13.45	101.49
	Stoichiometry	CuAgS (approximate)							
	30.15	0.49	0.16	0.0	0.18	0.19	50.11	13.11	94.42
	Stoichiometry	CuAgS (approximate)							
C	25.20	0.03	0.04	0.01	0.09	0.0	44.92	11.62	81.91
	Stoichiometry	CuAgS (approximate)							
	55.86	0.03	0.0	0.0	0.35	0.04	23.68	18.47	98.46
	Stoichiometry	$Cu_9Ag_2S_6$ (approximate)							

a. Two values.

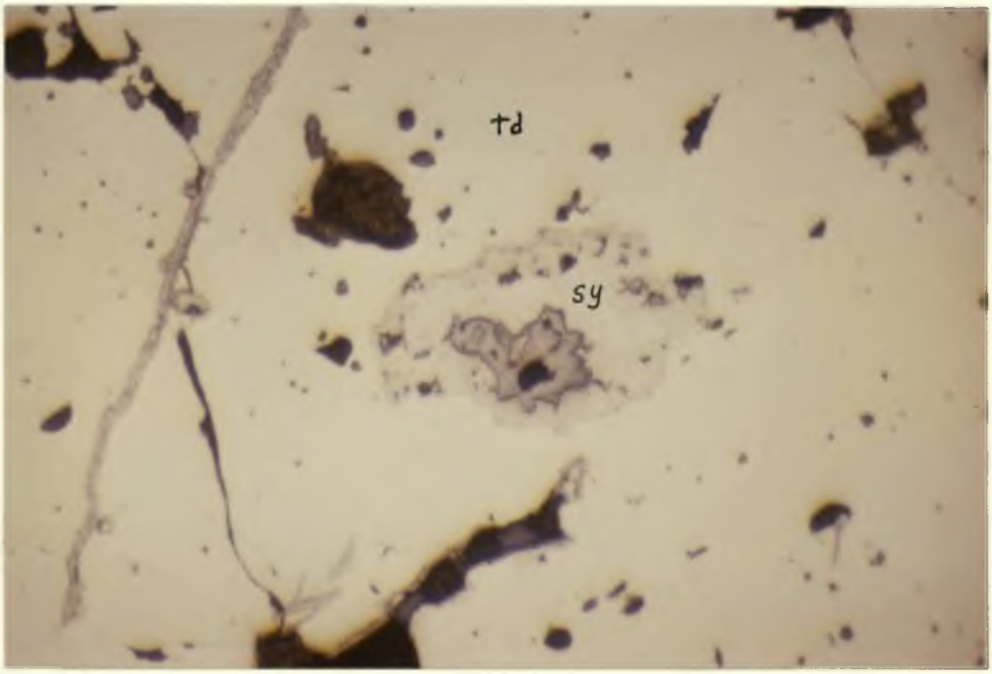


Figure 26. Stromeyerite(?) (sy) surrounded by tetrahedrite (td) and cored by goethite. -- Width of field = 1.05 mm.

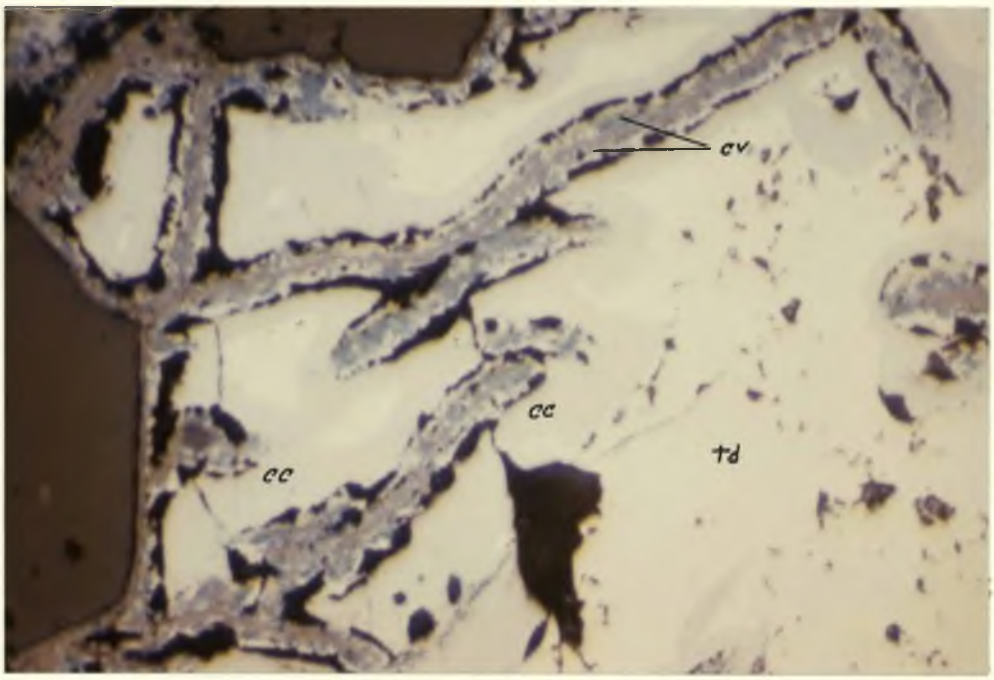


Figure 27. Tetrahedrite (td) being replaced in "wormy" pattern first by chalcocite (cc) and then by covellite (cv). -- Width of field = 1.05 mm.

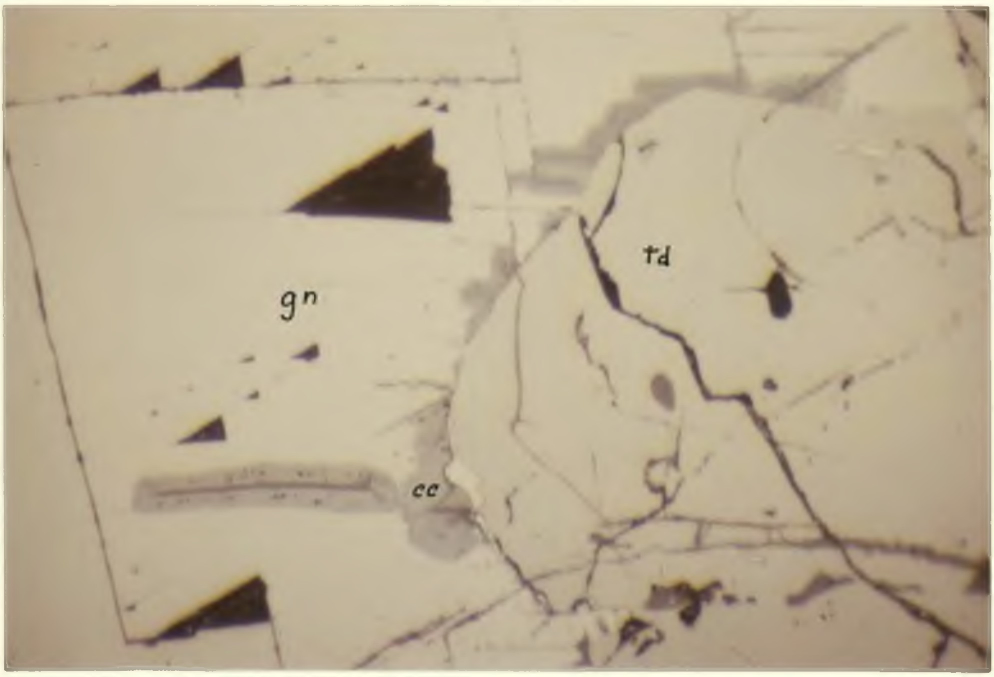


Figure 28. Preferential replacement of galena (gn) by chalcocite (cc) along boundary with tetrahedrite (td). -- Width of field = 1.05 mm.

Interpretation

Paragenetic relationships show that pyrite was the earliest mineral to crystallize, followed by huebnerite and quartz. Both pyrite and huebnerite show euhedral faces in vugs in the quartz. This finding indicates that they crystallized out of a solution that passed the same way as the solution that produced quartz (Q_1). The later quartz (Q_2) also contains euhedral pyrite, but although it is probably earlier than the ore sulfides, its exact timing is not certain.

Galena was probably the first of the principal ore sulfides and was followed by tetrahedrite, intergrown with luzonite and aikinite(?), and, finally, sphalerite. Supergene effects, spatially related to the faults and to the proximity to outcrop, produced stromeyerite(?), native silver, native copper, chalcocite, covellite, and, finally, goethite. There is a strong mineralogical change in the vicinity of drill hole BP-8, west of the 4270 drift. In that area, galena and sphalerite make up considerable proportions of the ore. This suggests the possibility of two ore fluids or fluid pulses; however, there is no microscopic evidence for this, as only one stage of tetrahedrite was observed. A paragenetic diagram is presented in Figure 29.

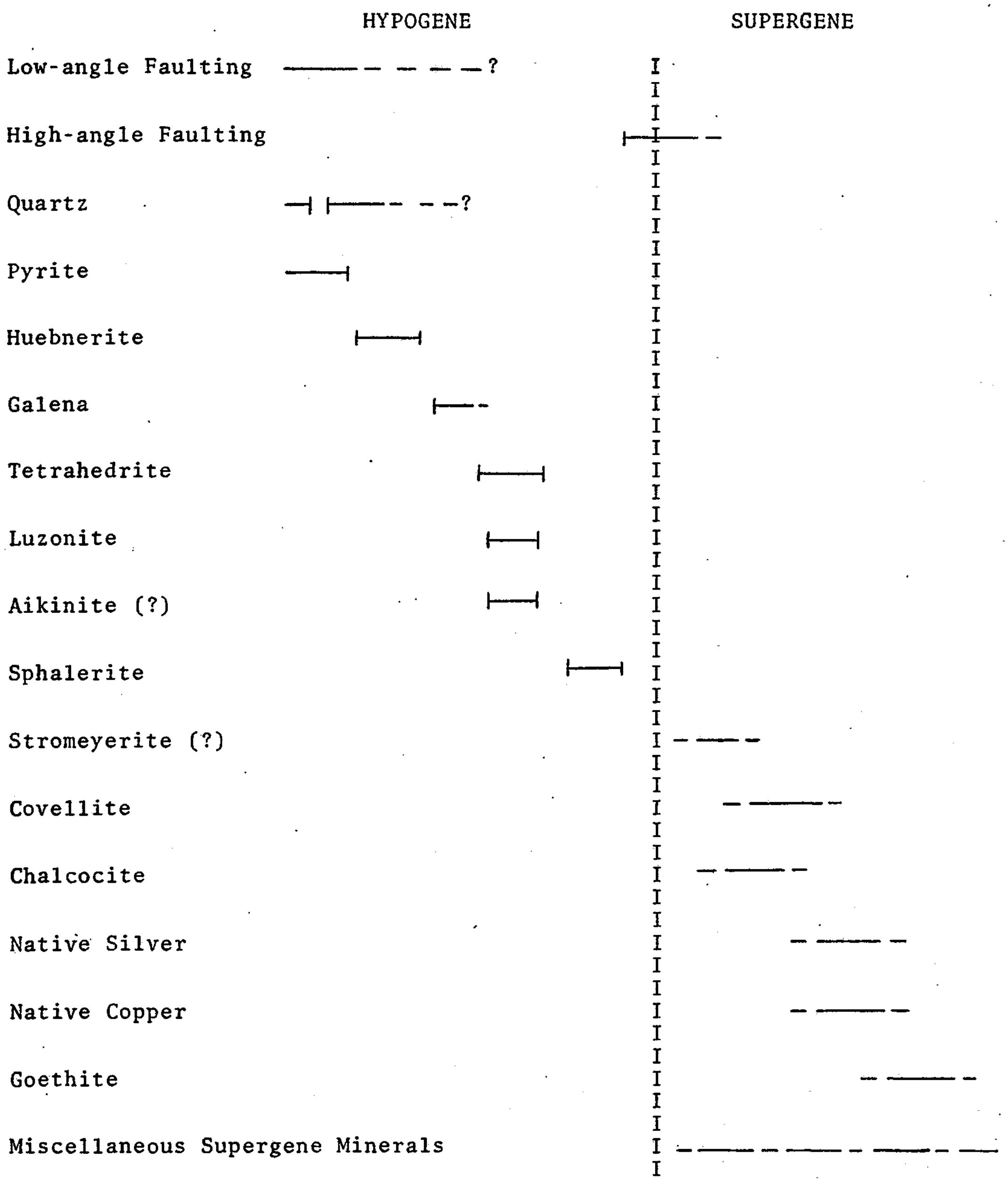


Figure 29. Paragenetic diagram of important ore and gangue minerals at the Black Pine mine

CHAPTER 4

ELEMENT ZONING

Major Elements in the Ore Minerals

Microprobe work done by Wu and Petersen (1977) on samples from Casapalca, Peru, indicated a strong positive correlation between antimony and silver in tetrahedrite. This was further explored by Hackbarth and Petersen (1984), and their findings also suggest that the amount of silver contained in the tetrahedrite lattice is positively correlated with the amount of antimony. Wu and Petersen examined this feature at a mine-level scale and compared it to the known mineralogic zoning. Their study showed that tennantite and high arsenic tetrahedrite contain less silver and tend to be nearer the center of the ore-bearing system. This central portion was rimmed by a silver-rich zone of tetrahedrite. The mineralogy (sphalerite, galena, pyrite, and tetrahedrite), and physical characteristics (open-space filling, banding, and cavities) of the major vein at Casapalca are similar to the Combination vein. It was suggested by Guilbert (1983, personal commun.) that microprobe analysis of the tetrahedrite at the Black Pine mine might reveal a zoning pattern similar to that at Casapalca. This pattern may indicate the location of high-grade silver mineralization and enable the mine operator to plan development work to exploit it more efficiently.

Tetrahedrite is the antimony-rich end member of the tetrahedrite-tennantite solid-solution series. The "ideal" formula would be

$Cu_{12}Sb_4S_{13}$, but Zn and Fe are almost invariably found in the mineral, and a more correct formula would be $Cu_{10}(Zn,Fe)_2Sb_4S_{13}$. Wuensch (1969) explained this formula choice on the basis of the coordination of copper atoms in two different geometries. Briefly, copper atoms in tetrahedrite are coordinated tetrahedrally and triangularly. Copper atoms can occupy both types of sites, but iron and zinc atoms substitute only in the tetrahedral sites (Billingsley, n.d.). This formula implies that iron and zinc atoms exclude copper atoms from the tetrahedral sites, but no where in the literature is this point specifically stated. Tennantite, the other end member, is $Cu_{10}(Zn,Fe)_2As_4S_{13}$, with the dividing line between the two species arbitrarily set at greater than 50 percent antimony (stoichiometrically) for tetrahedrite (Dana and Dana, 1944).

Partial replacement of copper by silver, mercury, and rarely, nickel, cobalt, and vanadium, is possible. Substitutions lead to species such as freibergite (>20 wt % Ag), schwatzite (Hg-rich tetrahedrite), and binnite (Ag-rich tennantite). Minor amounts of bismuth, tin, germanium, and tellurium substitute in the As-Sb sites, and tellurium may also substitute for sulfur (Ramdohr, 1969).

Work by Wu and Petersen (1977) indicates that the crystal structure of tetrahedrite could accommodate more silver with increasing antimony content. Their work seems substantiated by later work by Hackbarth and Petersen (1984). Riley's (1974) work also substantiates these results. The silver and antimony values did not always linearly correlate, but the antimony values were quite high in the Mt. Isa freibergite (25-28 wt % Sb). The important conclusion from Wu and

Petersen's work is that increasing arsenic and decreasing silver values are found near the center or source of the hydrothermal fluids, and they have cited several examples of this.

To test the relationship of antimony to silver at the Black Pine mine, two samples were initially analyzed by microprobe. In sample B, the antimony was 11.02 wt %, whereas the silver was 0.15 wt % (Table 4).

Sample B is located approximately 200 feet from the main haulage portal (Figs. 13 and 15, in pocket). In comparison, the sample taken from location AC contained 15.71 wt % Sb and 0.31 wt % Ag. The location of this sample is about 2,900 feet from the portal (Figs. 13 and 15, in pocket). This work indicated that a more extensive microprobe analysis might be able to resolve variation in the antimony and silver contents of the tetrahedrite.

Samples along cross section B-B' were also analyzed, and these results were somewhat less erratic than those along section A-A' (Table 5). Sample 3, taken from the high-grade zone near BP-8 and sample locations 2 and 13 (Fig. 13, in pocket; Fig. 30), was particularly interesting. This sample contained galena, tetrahedrite, and sphalerite in roughly equivalent amounts, but the tetrahedrite contained both silver and antimony in significantly greater proportions than most of the other samples (Table 6). Standards used on the microprobe are reported in Table A-1 (Appendix A). Appendix A explains microprobe analytical procedures.

Use of linear regression analysis on the plot of silver versus antimony for the 26 tetrahedrite samples tested showed a correlation

Table 4. Weight percentages of elements in tetrahedrite from samples on cross section A-A'

Sample	Cu	Ag	Zn	Fe	As	Sb	S	Total
B	41.54	0.15	6.89	0.28	13.98[a]	11.02	26.21	100.07
C	39.87	0.77	5.24	1.34	8.20	18.63	25.07	99.12
E	40.37	0.61	5.95	0.93	8.04	18.91	25.43	100.24
G	40.93	0.15	7.94	0.12	11.76[a]	13.46	26.00	100.36
H	40.89	0.50	6.69	0.56	8.54	17.96	25.69	100.83
I	40.19	0.27	6.53	1.23	7.49	18.33	25.16	99.20
K	39.05	1.81	7.57	0.14	7.69	18.68	25.20	100.14
M	39.99	0.42	8.13	0.27	11.00[a]	13.34	26.28	99.34
Q	42.09	0.31	7.92	0.12	9.16[a]	14.57	25.88	100.05
R	39.78	0.35	7.06	0.39	6.05	21.29	25.21	100.13
S	41.19	0.53	7.56	0.28	9.03	15.18	25.55	99.32
U	40.35	0.65	7.51	0.31	6.91	19.71	25.58	101.02
W	39.98	0.45	7.79	0.19	8.55	18.06	25.97	100.99
Y	41.08	0.36	7.38	0.34	10.58[a]	14.69	26.29	100.72
Z	40.14	0.71	6.03	1.12	5.06	22.06	25.19	100.31
AA	39.82	0.83	6.01	0.72	6.01	23.77	25.02	100.28
AC	41.35	0.31	6.65	0.07	10.31[a]	15.71	25.84	100.25

a. Denotes tennantite.

Table 5. Weight percentages of elements in tetrahedrite from samples on cross section B-B'

Sample	Cu	Ag	Zn	Fe	As	Sb	S	Total
A'	41.18	0.21	6.07	0.61	8.50	17.84	25.96	100.37
B'	41.16	0.28	7.66	0.25	11.41[a]	13.72	26.30	100.78
R	39.78	0.35	7.06	0.39	6.05	21.29	25.21	100.13
D'	41.12	0.47	6.09	0.76	7.08	19.99	25.86	101.37
E'	40.44	0.52	6.29	0.48	6.28	20.85	24.77	99.63
F'	41.26	0.56	5.42	0.78	5.69	21.85	25.45	101.01
G'	40.11	0.27	7.25	0.19	8.19	17.73	25.11	98.85
H'	40.85	0.21	6.23	0.74	7.43	19.31	24.99	99.76
I'	39.83	0.36	7.87	0.17	7.94	18.76	25.47	100.40

a. Denotes tennantite.

Figure 30. High-grade zone (outlined) and major high-angle faults encountered in workings. -- Reduction of figure 13 (in pocket).

Table 6. Weight percentages of elements in two tetrahedrite samples taken from the high-grade zone noted on Figure 32

Sample	Cu	Ag	Zn	Fe	As	Sb	S	Total
2	41.03	0.43	7.33	0.34	8.75	17.40	26.03	101.31
3	37.27	2.66	6.28	0.19	4.79	24.84	24.45	100.48

coefficient of 0.59 with a positive slope. This finding indicates that the silver and antimony have a fairly strong positive correlation. In calculating the correlation coefficients, the two high silver values from samples 3 and K were not included because their Ag-Sb ratio fell beyond one standard deviation from the mean (normal curve approximation). As was expected and as can be seen in Figures 31 and 32, there is a negative correlation of silver with arsenic ($\underline{r} = -0.56$). There is also a slight negative correlation ($\underline{r} = -0.42$) between copper and silver, but this is explained by the fact that the silver substitutes for the copper in the crystal lattice (Ramdohr, 1969). Iron and zinc showed no significant correlation with silver. Billingsley (n.d.) stated that silver substitutes for copper in the triangular sites and iron and zinc substitute in the tetrahedral sites. Thus, small increases in silver content will not affect iron and zinc. Graphs of silver versus antimony, arsenic, copper, iron, and zinc are contained in Appendix B.

Because galena and sphalerite are principal minerals with tetrahedrite in the high-grade zone, these minerals were also analyzed to determine compositions. They were seen and analyzed in samples 3, Y, and Q (Table 7). Low total microprobe analysis numbers on some of

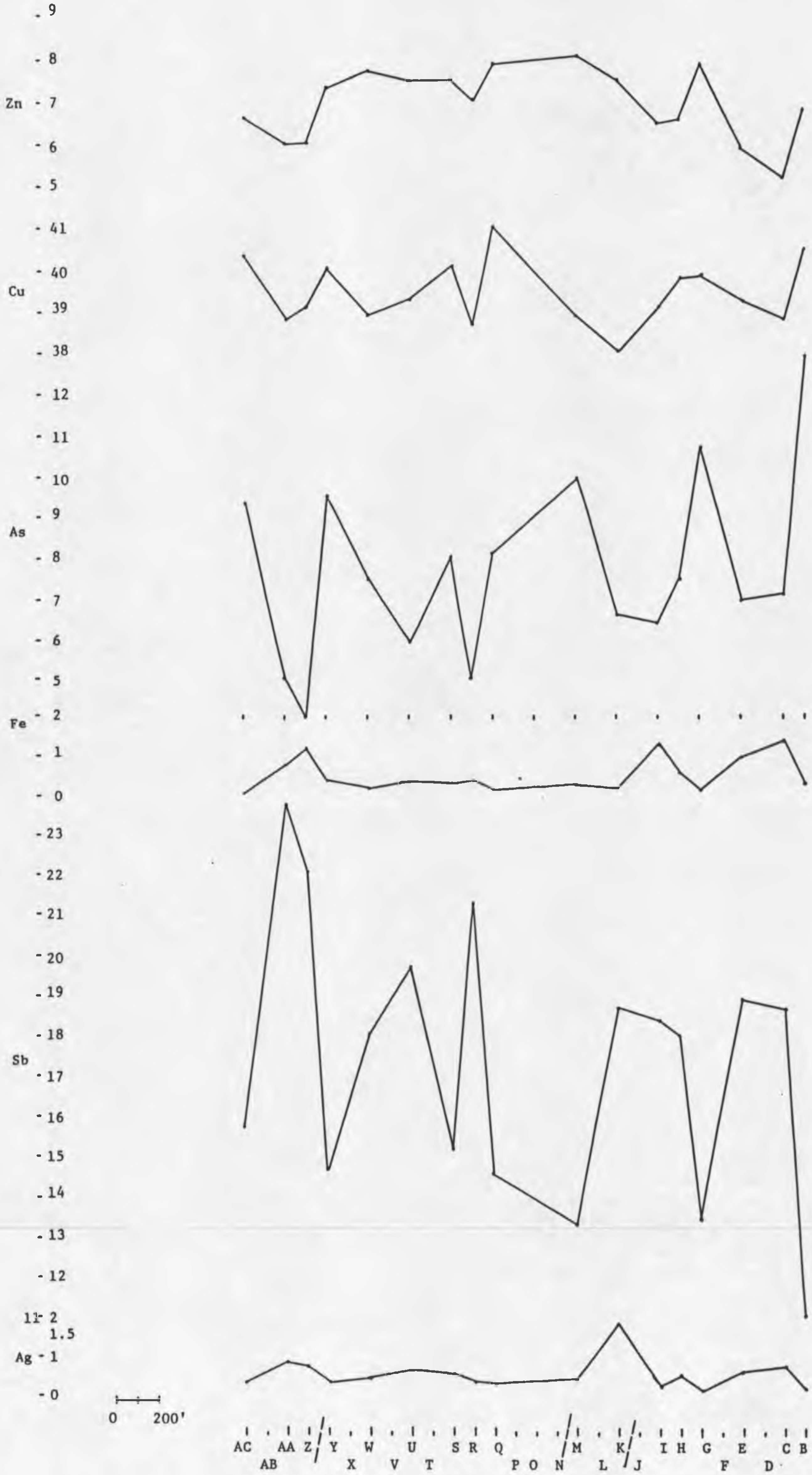


Figure 31. Graphs of weight percents of elements on tetrahedrite along cross section plane A-A' as determined by electron microprobe analysis. -- The samples from the locations on line two were not microprobe analyzed. Dashed lines indicate faults.

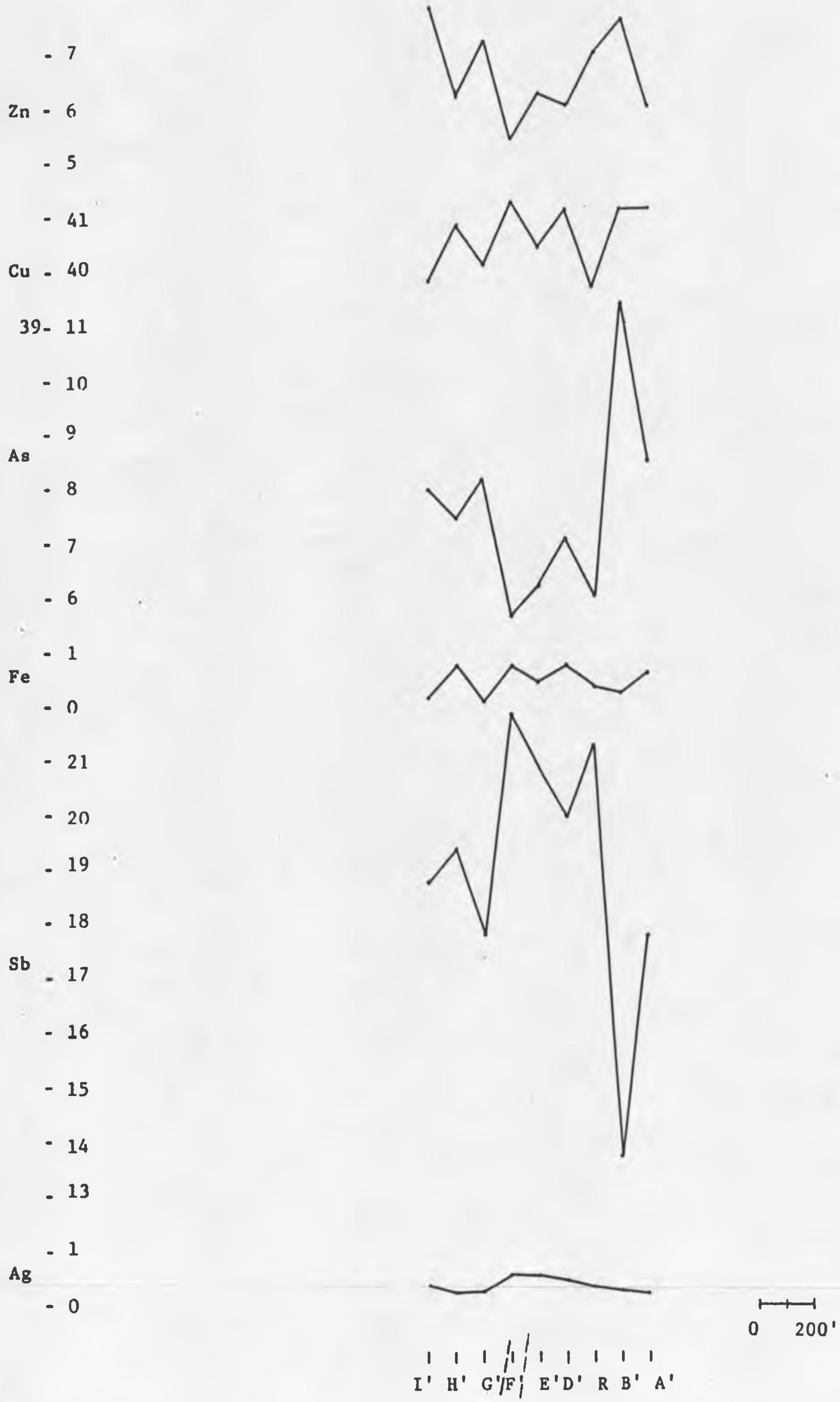


Figure 32. Graphs of weight percents of elements in tetrahedrite along cross section plane of B-B' as determined by electron microprobe analysis. -- Dashed lines indicate faults.

Table 7. Microprobe analysis of selected samples containing sphalerite and galena. -- Units in weight percent. (tr < 0.01).

Sample	Mineral	Elements								Total
3	Galena	Bi	Pb	Te	Se	Ag	S			
		0	85.2	tr	tr	0.15	10.85			96.20
	Galena	Cu	Fe	Zn	Pb	Sb	As	Ag	S	
		tr	0	83.59	0.18	tr	tr	10.81	94.72	
	Sphalerite	Zn	Cd	Fe	S					
		67.53	0.62	0.09	32.94					101.18
	Sphalerite	Cu	Fe	Zn	Pb	Sb	As	Ag	S	
		tr	0.14	59.84	0	0	0	tr	32.63	92.61
Y	Sphalerite	Zn	Cd	Fe	S					
		67.45	0.34	tr	32.88					100.67
Q	Galena	Bi	Pb	Te	Se	Ag	S			
		0	83.48	tr	tr	0.20	10.47			94.15
	Galena	Cu	Fe	Zn	Pb	Sb	As	Ag	S	
		0.24	tr	0.21	86.06	0.11	tr	0.12	10.80	97.63
	Sphalerite	Zn	Cd	Fe	S					
		64.97	0.45	0	32.70					98.13
	Sphalerite	Cu	Fe	Zn	Pb	Sb	As	Ag	S	
		0.19	tr	70.03	0	0	0	tr	33.15	103.42

the galena samples resulted from interference between the sulfur and lead peaks on the spectrometers. Low sphalerite values were attributed to early calibration problems with the zinc. Neither of these errors significantly affected detection of silver, which occurs in significant quantities in both galena samples.

Trace Elements

During microprobe analysis, both point probes and scans of areas were used to detect concentrations of trace elements in some of the minerals. Point probes of galena and sphalerite recorded in Table 7 show significant amounts of cadmium in the three samples of sphalerite. Iron is very low, and trace silver is present. Small amounts of copper were noted in both galena and sphalerite. Galena also contained significant antimony as well as trace tellurium and selenium, any one of which could be responsible for the slight pinkish tint seen in microscopic examination of the mineral.

Scans of mineral boundaries were done on sample 3 and showed a concentration of bismuth in the galena relative to the tetrahedrite. Selenium also showed a slightly higher concentration in the galena, but both elements were very minor in both species. Because both lead and sulfur interfere with the detection of bismuth in the galena, there may be more bismuth in the galena than indicated by microprobe analysis. Tellurium was evenly distributed and very minor in both the tetrahedrite and galena.

Because approximately 0.009 oz/ton Au is present in the Black Pine ore, an attempt was made to identify its mode of occurrence and the species carrying it. No native gold was positively identified in polished sections, but one suspect, highly reflective mineral with a yellowish tint proved to be native copper when analyzed (Fig. 24).

Microprobe analysis of pyrites from several scattered locations revealed gold in trace quantities (<0.01 wt %) in samples of small later pyrite from locations W and K. Gold values were noted in samples M, Z, and AA, and scans revealed preferential concentration of gold in the pyrite (Table 8). All pyrites analyzed by microprobe showed significant arsenic values, commonly from 0.27 to 0.33 wt %, and this may explain the strong anomalous anisotropism noted in the pyrite.

Interpretation

Four principal ore shoots are encountered along the main haulage drift (Figs. 31 and 32). These are indicated by silver-antimony peaks in the vicinities of samples C, K, U, and AA. Only one gentle peak, located at F', was noted on cross section B-B'.

Across section A-A', strikes of the Combination vein in the vicinity of shoots range between N. 10° W. and N. 20° W. On section B-B', however, near the peak at location F', the strike was N. 33° W. Dips ranged from 11° to 22° W. and seem to increase along the main haulage (Figs. 13 and 15, in pocket).

Relations of silver content to strike and dip of the vein are subtle. The work of Volin and others (1952) suggested that the best ore occurs where the strike of the vein changes to the north-northeast. Results of my study do not seem to support this as indicated by the strikes noted above. Literature also indicates that areas of flatter dip

Table 8. Microprobe analysis of several pyrite samples for retention of trace elements. -- Units in weight percentage (tr < 0.01); tr+ < 0.04).

Sample	Fe	As	Au	S	Total
K	46.44	0.29	tr	52.09	98.84
M	49.05	0.24	0	54.81	104.14
	45.96	0.22	tr+	53.81	99.22
	47.63	0.27	0	54.56	102.48
W					
Large pyrite	47.79	0.26	0	53.45	101.52
	47.97	0.30	0	53.59	101.87
Small pyrite	47.55	0.99	tr	52.77	101.33
	47.37	0.78	tr	53.20	101.38
Z	46.12	0.30	tr+	53.29	99.74
	46.34	0.30	0	51.91	98.97
AA	45.89	0.28	tr+	53.11	99.32
	46.20	0.30	0	52.56	99.07
	45.97	0.32	0	53.04	99.34

on the vein are of higher grade. A comparison of cross section A-A' on Figure 15 (in pocket) with Figure 31 shows no clear grade-dip relation; however, comparison of cross section B-B' (Fig. 15) with Figure 32 shows a distinct increase in grade associated with flattening of the vein.

A comparison of Figure 15 and Figure 31 shows abrupt changes in silver content of the tetrahedrite across faults between sample locations I and K and Y and Z. Figure 32 shows a sharp drop in silver content across the fault between locations F' and G'. The mine geologist Silva (1983, personal commun.) also stated that grades do not match up across many faults. This is a possible argument for some component of lateral slip on these faults, in addition to evidence presented in Chapter 3.

The correlation of silver and antimony at the Black Pine mine substantiates the use of high antimony-silver zones to define possibly zoning of the type described by Wu and Petersen (1977). Results of my study, however, do not appear to resolve the structurally controlled ore shoots from the overall element trend of the tetrahedrite. Graphs of the elements in the tetrahedrite indicate four shoots along the main haulage drift. A rounded shoot, which peaks between E' and F', is indicated on cross section B-B' (Fig. 15, in pocket). In a gross sense there is a definite mineralogical zoning in the mine, with a high-grade zone indicated by greater amounts of galena and sphalerite in the ore near sample locations 2 and 3 and drill hole BP-8 (Fig. 30). This combined with underground mapping leads to the definition of two kinds of ore:

1. Quartz-tetrahedrite-pyrite ore.

2. Quartz-tetrahedrite-galena-sphalerite-pyrite ore.

The first ore type is the lower grade, more abundant ore in the mine. It carries about 3 oz/t Ag and 0.4% Cu. The second ore type is much higher grade, running about 8 to 10 oz/t Ag and 0.8% Cu, The only megascopic difference between the two is the content of visible galena and sphalerite in the high-grade ore. Microscopically, there is more stromeyerite in the high-grade ore and 1 percent replacing tetrahedrite could increase the grade to about 9 oz/t Ag (assuming 3 oz/t in the tetrahedrite). Microprobe results (Tables 3 and 7) showed that both tetrahedrite and galena in the high-grade zone contain silver and that the tetrahedrite there holds more silver than most of the other samples analyzed by microprobe.

An important factor is the distance that the silver has traveled in solution. If it moved for tens or hundreds of feet, supergene silver could be of considerable importance in this zone. If the silver has traveled only a few feet or less, the stromeyerite(?) would have formed at the expense of nearby oxidized tetrahedrite and the grade would be unchanged.

The paragenetic sequence implies that early mineralization was lead rich, followed by a copper-silver assemblage made up principally of tetrahedrite. The final element in the suite was zinc in the form of sphalerite. This sequence agrees well with Barnes's (1979, p. 144) sequence for mineral zoning, but why this is not reflected in the overall mineralogic zonation is unclear. The localization of galena and sphalerite (and tetrahedrite) from tetrahedrite ore suggests two mineralizing events, but microscopic examination of the ore does not support this hypothesis.

In summary, my study has not adequately defined a high silver-antimony zone to the extent that it could be used to outline the source of the mineralizing fluids. However, shoots of high-grade mineralization were readily apparent, and subsequent work may indicate trends to these shoots that could aid in both mine planning and grade control.

CHAPTER 5

FLUID-INCLUSION DATA

Fluid-inclusions from the high-grade zone and the low-grade zone in the Black Pine mine were studied to attempt to determine possible differences in ore-fluid temperatures associated with the two ore types in the mine and the possible composition of the ore fluid. Fluid inclusions hosted by quartz were examined and tested on an SGE heating/cooling stage at the University of Arizona, Department of Geosciences. Initial petrographic descriptions were completed by transmitted light and a 50-power objective.

High-grade Zone (Sample Location 2)

Fluid-inclusions were noted in both quartz and huebnerite in the slide from Sample Location 2. In the huebnerite, three-phase inclusions were noted with two liquid phases and a vapor phase. These appear to be primary based on their lack of spatial association with other inclusions. They are elongate parallel to the C crystallographic axis of the huebnerite and show no evidence of necking down. The fluid inclusions are commonly 0.02 mm long but less than 0.001 mm wide. Much more common are planes of secondary inclusions cutting across the huebnerite crystals. These are normally smaller than 0.005 mm and phases cannot be resolved.

No temperature data were gathered on these inclusions during this study. Data from such inclusions could provide valuable information on the temperature and composition of the ore fluid that deposited the huebnerite and should be considered for future work.

Most inclusions in this sample are less than 0.005 mm and are in planar, netlike arrays or mark lineations that indicate straining of the quartz. A group of probably primary inclusions in unlineated quartz and surrounded by sulfide grains was located. These inclusions range in size from 0.005 to 0.01 mm.

The criteria used for primary designation of inclusions are found in detail in Barnes (1979). The inclusions studied were considered primary based on their random distribution throughout the host. They also seem to have similar liquid—vapor ratios. Most inclusions are three phase and contain liquid H_2O, liquid, CO_2, and vapor CO_2. Four-phase inclusions containing daughter salts were seen but were quite rare.

No distinct phase transition at temperatures below 0°C could be resolved, but the melting of a solid phase at 6.5°C suggests the presence of CO_2. The salinity based on this temperature would be about 6.5 mass % equivalent NaCl, as determined from data presented by Collins (1979). Homogenization temperatures for these inclusions averaged 247°C (n = 7, S.D. = 13.6).

Low-grade Zone (Sample Location C)

Most inclusions in this ample are small (<0.005 mm) and occur in planar zones. The inclusions are elongate and amoeboid within the zones, and phases could not be distinguished. There are also numerous secondary inclusions, about the same size, that occupy undulose, healed fractures. Commonly, minute inclusions mark lineations in strained quartz. Rare isotropic green solid inclusions were also seen, and opaque solid inclusions about 0.01 mm in size were common near sulfide masses.

A small field of probably primary inclusions was seen partly surrounded by sulfides. The size range of these inclusions was 0.005 to 0.01 mm, and evidence for primary origin was the random distribution and lack of relation to other inclusions present. Larger inclusions with resolvable vapor phases seemed to be more common in this slide than in the slide from the high-grade zone.

Most of the primary inclusions contain three phases: liquid H_2O, liquid CO_2, and vapor CO_2. One negative crystal was noted, and although several inclusions contained daughter salts, solid phases were rare overall. An average temperature of homogenization (vapor to liquid) for these inclusions was 248°C ($\underline{n}$ = 5, S.D. = 9.7).

Interpretation

Examination of fluid inclusions from the Black Pine mine indicates that the ore fluid was rich in carbon dioxide. Dissolved salts seem to constitute about 6.5 mass % in the inclusions (calculated from data presented by Collins, 1979). The similarity of homogenization temperatures from the two different locations implies that the thermal gradient in the mine was very small. This finding suggests that pressure and solution chemistry may have been more important in affecting the observed chemistry than temperature; however, this is not conclusively proven and would required a more detailed examination of fluid inclusions.

CHAPTER 6

SUPERGENE MINERALOGY

Due to a combination of shallow dip, cross-cutting joints and faults, and close proximity to the surface, the Combination vein has been extensively oxidized to varying degrees throughout the mine. Most of the orebody lies within 500 feet of the surface, and circulation of meteoric waters has resulted in oxidation of sulfides and reprecipitation of numerous secondary minerals in vugs and joints and near faults. To April 1984, 34 mineral species have been collected and identified from both underground workings and from the ore dump. The minerals were submitted to L. G. Zeihen, who carried out identification work as a part of research for the Montana Bureau of Mines and Geology. Identification techniques used microscopic examination, X-ray diffraction, and microchemical methods (Appendix A). What follows is a listing of all secondary mineral species identified at the time of writing.

1. Adamite (cuprian variety): $(Zn,Cu)_2(AsO_4)(OH)$; orthorhombic-monoclinic microcrystals. Cuprian adamite occurs in two crystal habits, emerald-green, diamond-shaped crystals and pale-green terminations. Few specimens have been found, but the crystals are typically perched on quartz crystals and associated with bayldonite. No specific mine locations were noted.

2. Anglesite: $PbSO_4$; orthorhombic microcrystals. Two crystal habits of anglesite were noted. One type consisted of long prismatic,

spear-shaped crystals. The other habit consists of tabular prisms similar to cerussite. Anglesite is of fairly rare occurrence in the mine, and no specific locations were noted.

3. Aurichalcite: $(Zn,Cu)_5(CO_3)_2(OH)_6$; orthorhombic microcrystals. Blue, radiating crystals are typical of aurichalcite. Not many specimens have been found, and mine locations are uncertain.

4. Azurite: $(Cu_3(CO_3)_2(OH)_2$; monoclinic microcrystals. Azurite occurs as stubby prisms or drusy coatings in cavities, closely associated with malachite, duftite, and chrysocolla. It is principally localized near faults, especially those that strike N. 40° W. on the west side of the main haulage.

5. Barite: $BaSO_4$; orthorhombic microcrystals. Flat transparent plates of barite have been noted from the mine. This minerals seems to be found toward the vein outcrop and possibly near faults. It is rare in the workings.

6. Bayldonite: $PbCu_3(AsO_4)_2(OH)_2$; monoclinic microcrystals. Drusy, pistachio yellow-green bayldonite crystals occur as coatings on quartz crystals and within vugs in tetrahedrite. It is quite common throughout the workings.

7. Beudantite: $PbFe_3(AsO_4)(SO_4)(OH)_6$; trigonal microcrystals. Crystals of beudantite occur as brown, drusy coatings on joints and as stubby, drusy vug fillings. Several specimens are known, but it is difficult to identify and may be more common than the number of specimens would indicate. No specific locations were noted.

8. Bindheimite: $Pb_2Sb_2O_6(O,OH)$; cubic noncrystalline. Powdery, yellow-orange bindheimite has a distinctive color and is fairly

common in the mine. It occurs on joints and vugs and can be difficult to tell from powdery iron oxides.

9. Brochantite: $Cu_4(SO_4)(OH)_6$; monoclinic microcrystals. Several habits of blue-green brochantite are seen, and most form radiating, drusy crystal groups coating cavities, especially in tetrahedrite. It also coats quartz and is sometimes associated with azurite near the north-striking faults west of the main haulage. It is fairly common in the mine.

10. Cerussite: $PbCO_3$; orthorhombic microcrystals to macrocrystals. Crystals up to 1 inch long have been found, and one habit is almost identical to crystalline quartz. Another habit is stubby, striated prisms, which have a blue tint due to inclusions of azurite and malachite. Cerussite is more common in the lower levels of the mine near the area around drill hole BP-8 where the massive tetrahedrite-galena-sphalerite ore is found.

11. Chalcocite: Cu_2S; monoclinal microcrystals. Chalcocite is seen replacing all sulfides in the mine except pyrite and is discussed in detail in the chapter on ore mineralogy.

12. Chrysocolla: $(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$; monoclinic. Chrysocolla is found in botryoidal form throughout most of the mine, but especially near fault zones. This mineral is often associated with azurite and malachite, and an intensely blue-colored variety is sometime found with native silver.

13. Clinoclase: $Cu_3(AsO_4)(OH)_3$; monoclinic microcrystals. A rare mineral at the mine, clinoclase forms diamond-shaped crystals with

curved faces. It is similar in color to azurite and occurs in vugs with azurite, brown, powdery limonite, or chrysocolla.

14. Copper: Cu°; cubic microcrystals to macrocrystals. Arborescent, dendritic native copper was found in stopes off the 4270 drift. It was seen in a polished section from location Z and seems to be localized near fault zones. It is not common in the workings.

15. Covellite: CuS; hexagonal microcrystals. Covellite was seen principally in polished sections and is described in more detail in Chapter 4. It appears to replace tetrahedrite and other ore sulfides in the supergene environment.

16. Cuprite: Cu_2O; cubic microcrystals. "Girder structure" best describes one habit of cuprite. It is closely associated with chrysocolla and malachite, and the slender needles it forms grow at right angles to each other and resemble the girders of an unfinished building. The mineral is not common, and mine locations are of doubtful accuracy.

17. Duftite: $PbCu(AsO_4)(OH)$; orthorhombic microcrystals. Duftite is a rare mineral species and is uncommon at the Black Pine mine. It forms olive-green botryoids closely associated with azurite. One specimen was found near the eastward turn of the N. 40° W.-striking fault, and several other specimens exist from unverified locations.

18. Goethite: alpha FeO(OH); orthorhombic noncrystalline. Goethite was observed under reflected light in several polished sections as a fracture core in sulfide minerals. It appears as irregular replacements of a secondary copper-silver sulfide mineral, which may be

stromeyerite, at sample location 2. Goethite also replaces other secondary sulfides and pyrite.

19. Hemimorphite: $Zn_4Si_2O_7(OH)_2 \cdot H_2O$; orthorhombic microcrystals. Hemimorphite appears in two varieties in the Black Pine mine. It was first identified as a white earthy coating (calamine) on quartz. More recent specimens show the classic tabular crystals in clusters. Not many specimens have been found, but the calamine variety is not very conspicuous and may be more common that it would appear from this study.

20. Libethenite: $Cu_2(PO_4)(OH)$; orthorhombic microcrystals. Blue-green botryoids and spherulites of libethenite are difficult to distinguish from pseudomalachite. Because of this, it may be more common in the mine than previously thought. No specific mine locations were noted.

21. Malachite: $Cu_2(CO_3)(OH)_2$; monoclinic microcrystals. Principally showing spherulitic or botryoidal forms, malachite is common in the workings. It is rarely associated with azurite, and this implies curious Eh-pH conditions during oxidation. Malachite is found in many places in the mine, but no specific locations are given.

22. Olivenite: $Cu_2AsO_4(OH)$; orthorhombic microcrystals. Only one specimen of olivenite is known from the mine. The crystals occur as minute olive-green plates in an unusual cockscomb form similar in habit to marcasite. The mine location is not known.

23. Pharmacosiderite: $KFe_4(AsO_4)_3(OH)_4 \cdot 6\text{-}7H_2O$; cubic microcrystals. The only specimen of this mineral came from a boulder on the ore dump. It occurs as minute yellowish-green cubes on heavily

oxidized vein material (principally limonite). It has not been found in place underground.

24. Pseudomalachite: $Cu_3(PO_4)_2(OH)_4 \cdot H_2O$; monoclinic microcrystals, botryoids. Pseudomalachite occurs as smooth blue-green botryoids. Commonly found throughout the mine, it is seen in cavities coating quartz and occasionally replacing other minerals.

25. Pyrolusite: MnO_2; tetragonal, noncrystalline. Commonly coating joints above and below the vein, pyrolusite is common in at least several hundred feet of the section. Pyrolusite occurs as black, dusty coatings on other secondary minerals and is one of the last mineral precipitated in most places. This mineral is found throughout the mine.

26. Pyromorphite: $Pb_5(PO_4)_3Cl$; hexagonal microcrystals to thumbnails. Pyromorphite is found almost everywhere in the mine and in a wide variety of colors. Small, clear-to-brown prisms occur, and needlelike prisms from clear to yellow have been found. Crystals as large as three-quarters of an inch have been observed but are not common.

27. Quartz: SiO_2; trigonal microcrystals to macrocrystals. Zoned, banded quartz is the principal gangue mineral in the Combination vein. Large crystals in vugs are found throughout the mine and numerous Japan-law twins have been collected.

28. Scorodite: $FeAsO_4 \cdot 2H_2O$; orthorhombic microcrystalline. Scorodite was seen as a greenish coating on quartz in one specimen. No specific mine locations are known.

29. Silver: Ag°; cubic microcrystals to thumbnails. Native silver is found localized along almost all of the faults in the mine, especially

where the N. 40° W.-striking fault horsetails off through the main haulage drift (Fig. 13, in pocket). It occurs as tiny crystals in vugs and as tinfoil-like masses along oxidized shears near the faults. An unusually intensely blue chrysocolla is closely associated with some of the silver.

30. Stibiconite: $Sb_2O_6(OH)$; noncrystalline. Stibiconite forms pseudomorphs after crystals of tetrahedrite leaving smooth, euhedral tetrahedrite forms made up of tan-brown spongy material. It has been identified in numerous specimens and is found with strongly oxidized tetrahedrite.

31. Stolzite: $PbWO_4$; tetragonal microcrystals. Two crystal forms of stolzite are found. The most common is in crystals of blocky or pseudocubic habit perched on huebnerite that is being oxidized. A much more platy habit, identical to wulfenite, has been found, but it is far rarer. Stolzite fluoresces under short-wave ultraviolet light and is found throughout the mine but is somewhat rare.

32. Stromeyerite(?): CuAgS; orthorhombic crystals. This mineral was only tentatively identified based on optical properties and microprobe results. It occurs as irregular replacements in tetrahedrite along fractures and near strongly oxidized pyrite. It is discussed in greater detail in the chapter on ore mineralogy.

33. Tsumebite: $Pb_2Cu(PO_4)(SO_3)(OH)$; monoclinic microcrystals. Tsumebite is a rare mineral worldwide, and only two specimens are known from the Black Pine mine. It occurs as very small, pale-green, platy crystals growing in rosettes. One specimen shows close association with brochantite. No specific mine locations are known.

34. Veszelyite: $(Cu,Zn)_3(PO_4)(OH)_3 \cdot 2H_2O$; monoclinic microcrystals to macrocrystals. Another very rare mineral species, veszelyite has been found at only four or five mines in the world, and the premier location for large crystals is the Black Pine mine. The color of large crystals appears black but is actually a deep bluish green, and when in the platy habit, they are superficially similar to a doubly terminated azurite crystal. Crystals in a somewhat blocky habit have also been observed. The deep blue-green color is more apparent in the drusy crystals coating quartz. Veszelyite has been found in many locations in the mine, two being off the main haulage drift about 1,550 feet from the adit entry. A very large crystal about 1 inch long and 3/4 inches wide at the base was found in the 4840 drift. The mineral occurs in steeply dipping, north-striking joints, and large crystals have formed where these joints cut cavities. It is commonly associated with bayldonite and chrysocolla.

Identification of these minerals was carried out primarily for the advancement of scientific knowledge; however, many of these minerals are fairly stable in the surface environment. As explained in the following chapter, this suggests that some of them (cerussite, hemimorphite, pseudomalachite) may be incorporated by mass wasting and erosion into stream sediments and provide an indicator for these veins in a regional geochemical survey.

CHAPTER 7

SUMMARY

This thesis describes in brief the lithology and geology of the Black Pine mine, southwestern Montana The ore-mineral paragenesis, the element and mineral zoning, and the mineralogy of the deposit were studied in depth, while attempting to map the element zoning and mine-level structural geology.

The regional geology, as interpreted by Hughes (1970), consists of a logical interplay of compressional structures. They are related to translation of the allochthonous Sapphire block on a décollement surface, probably the Philipsburg thrust fault. The eastward movement of this block resulted from a gravity slide initiated by doming of the sediments over the Idaho batholith (Hughes, 1970). The Combination vein itself has characteristics of both a thrust fault and a filled fissure and could have resulted from concentric folding, although steep faults that cut the vein probably represent a conjugate fault set and are post-ore and postthrusting.

Two drill holes logged showed no lithological differences above and below the vein. Studies of the core and thin sections showed minor alteration, principally silicification, argillization, and pyritization, restricted to areas within 15 cm (6 inches) of the vein. Additional examination of the core showed only one possible marker bed, and based on that result, along with the shallow dip of both the vein and bedding, the best markers for estimating movement on faults would be contacts between distinctly different lithologies such as the contact of the Mount Shields 2 and Mount Shields 3.

The principal ore mineral is argentiferous tetrahedrite, in some places accompanied by sphalerite and galena. Huebnerite is common throughout the mine but is not currently recovered. Gangue and minor hypogene minerals consist of quartz, pyrite, chalcopyrite, luzonite, and aikinite(?). Important secondary minerals include native silver, native copper, stromeyerite(?), chalcocite, and covellite.

Banding on a megascopic scale implies several pulses of quartz, but this could not be verified under the microscope. Only two distinct phases were noted, one being massive to coarsely crystalline and white, the other being transparent and more finely crystalline and containing fine-grained, euhedral pyrite. The earliest minerals in the paragenetic sequence are pyrite, huebnerite, and quartz. Galena was deposited next, followed by tetrahedrite with intergrown luzonite and aikinite(?). Sphalerite was the last hypogene ore mineral deposited, and these minerals, from galena on, are open-space filling.

A definite mineralogy change is encountered west of the 4270 drift, where higher grade ore contains considerably more sphalerite and galena. Increased grade there is a result of both hypogene and supergene processes. Microprobe analyses of the primary tetrahedrite and galena showed higher than normal silver content, but significant secondary stromeyerite(?) was deposited along minute fractures in the tetrahedrite as well.

Trace elements at the Black Pine mine are mostly of scientific interest. With the possibility of market changes, however, and the interference of some elements in smelting and processing, these can be important. Gold is the most important trace element at the mine and is found in small quantities in some of the pyrite. All pyrite that was microprobed contained arsenic, averaging 0.27 wt % As, but no correlation with gold content was seen. Sphalerite contains low iron but also contains cadmium (average = 0.5 wt % Cd). Galena contains trace silver and antimony and very minor bismuth, tellurium, and selenium.

Tetrahedrite along two cross-sectional planes was microprobed for the elements Cu, Ag, Fe, Zn, Sb, As, and S. This was done in an attempt to identify large-scale element zoning in the deposit in the form of a high-silver-antimony outer zone around a low-silver, high-arsenic inner zone. This study delineated ore shoots, with both distinct and indistinct controls but did not pick out an overall zonation pattern.

Two distinctive ore types are present in the mines. High-grade ore contains significant amounts of sphalerite and galena, which is absent from low-grade material. The presence of two ore types suggests two mineralizing events, and this idea was tested by conducting heating and cooling studies of fluid inclusions from the two ore types. This study showed that the ore fluid was high in CO_2 but also indicated a very small thermal gradient as temperatures from locations 2 and C (Fig. 13, in pocket) were 247°C and 248°C, respectively. These fluid-inclusion homogenization temperatures imply that pressure and solution chemistry were important in localzing high-grade zones.

Due to the flat dip of the vein, the proximity to the surface, the open, vuggy nature of the vein, and the cross-cutting faults, the Combination vein is highly oxidized in most places in the mine. Because of this, a large number of supergene minerals have been formed. Thirty-four supergene mineral have been identified, with the probability of many more being noted in the near future. Several exceedingly rare species have been found, the largest crystals being veszelyite, a rare copper phosphate. Most of the supergene minerals are arsenates, but phosphates, carbonates, and sulfates have been identified.

CHAPTER 8

CONCLUSIONS AND APPLICATIONS

This work was oriented principally toward mine-level exploration to aid in locating high-grade zones; however, some of the features examined have applications for regional exploration.

Regional Exploration

Geology

Based on this study, the principal vein localizing structures seem to be the flanks of anticlines where concentric folding has caused a combination of bedding-plane openings and thrusting. In addition, a heat source or metal source suggests target areas for similar deposits where anticlinal flanks have been intruded by igneous rocks.

Geophysics

Geophysical exploration methods could be used in the detection of shallowly dipping veins in several ways. Regional structure implies north-striking directions, and this coupled with disseminated pyrite around the vein suggests that east-west induced-polarization traverses could detect subcrops of veins at shallow depth. The drawback to this method lies in the induced-polarization response of a vein like the Combination. From this study, the pyritic alteration is very localized around the vein and seldom extends for more than 6 inches into the host rock. Orientation surveys would be required to ensure that a meaningful response would be generated by a vein.

Refraction seismics might also provide a method for detection of a shallowly dipping vein, but again, an orientation survey would be required to determine the usefulness of the technique.

The anomaly generated by the dike north of the mine indicates that aeromagnetic surveys would be useful in detecting shallow intrusions not exposed at the surface. Again, high-priority targets generated would be in areas where anomalies coincide with the flanks of anticlines.

Geochemistry

Geochemical surveys might provide a method regional exploration for veins similar to the combination. Based on the mineralogy of the deposit, indicator elements would consist of Ag, Cu, As, Sb, Pb, and Zn. Soil surveys on traverses perpendicular to the general strike of anticlines would be likely to detect subcropping veins based on coincident anomalies of these elements.

Due to the restricted nature of the alteration, rock-chip samples would probably not provide useful information; however, the rock geochemistry around veins like the Combination remains to be tested.

Supergene mineralogy has important potential in regional exploration. Several of the more common oxide minerals at the Black Pine mine are phosphates, and microchemical tests on many of these have shown them to be soluble in acid only with great difficulty (Zeihen, 1983, personal commun.). They are also among the last minerals formed and are therefore the closest to equilibrium with the atmosphere. These minerals such as pseudomalachite and pyromorphite, in addition to cerussite, hemimorphite, and bindheimite, could conceivably be concentrated in the heavy and intermediate fractions of stream sediments. The possibility of such concentrations suggests stream sediment sampling as a technique for regional exploration.

Mine-level Exploration

Exploration on a mine level can be one of the most expensive parts of development work. It is critical that new ore be located and proven as far ahead of development work as is feasibly possible.

Surface Exploration

Current surface exploration is conducted by grid drilling on 100- to 200-foot centers. The element zoning resolved in this study might be applied effectively to such data. If a vein cut in a drill hole contained subeconomic silver grades, assays for antimony and/or arsenic compared with results from nearby holes might indicate a direction in which silver and antimony increase. Zinc and lead assays might also be considered, as increases in these suggest higher grade silver ore compared to ore containing tetrahedrite alone.

Most geophysical methods would be difficult to apply to mine-level exploration. The important factor at this stage is grade and tonnage, not vein location; and with a shallowly-dipping target containing spotty silver grades, the resolution of most geophysical techniques would not be adequate.

Subsurface Exploration

Face assays and drifting, in coordination with surface drilling, are the current methods of underground exploration at the Black Pine mine. Both high-grade and low-grade ore exists at the mine, and this study attempted to identify high-grade ore controls to provide additional tools for exploration.

Mineralogic controls on high-grade ore are strongly evident on a megascopic scale when comparing the quartz–pyrite–tetrahedrite ore to the quartz–pyrite–tetrahedrite–sphalerite–galena ore. Assays indicate that ore containing galena and sphalerite contains between 8 and 10 oz/t Ag, whereas the ore containing tetrahedrite alone assays about 3 oz/t Ag. Microprobe analysis gives 2.79 wt % Ag (combined galena–tetrahedrite, sample 3) in one sample of the Q–py–td–sl–gn ore. This compares with 0.35 to 0.60 wt % Ag (average) in the Q–py–td ore. It would seem that ore containing galena and sphalerite is more likely to carry high silver grades. The high-grade ore is found principally in the southwest portion of the workings near the 4270 level (Fig. 30).

Paragenetic relationships do not reflect the overall zonation in the mine. Ore mineralogy indicates that an outer zone of galena-rich ore should give way to a zone of tetrahedrite, which, in turn, should grade into a zone dominated by sphalerite. In the workings. the galena and sphalerite tend to occur together with tetrahedrite and distinctly separate from tetrahedrite-dominated areas. This is strongly suggestive of two mineralizing events, but no evidence for more than one pulse of tetrahedrite was indicated by microscopic examination, and fluid inclusion temperatures of homogenization suggested similar temperatures at locations 2 and C (Fig. 13, in pocket). Thus, practical aspects of the paragenetic relationships are limited.

On a microscopic scale, a potentially important factor in silver grade was the presence of small amounts of stromeyerite(?) replacing the tetrahedrite (sample 2, Fig. 26). If the grade is converted to oz/t from wt % and sy(?) is assumed to be about 1% by volume of the tetrahedrite (or 0.07% of the vein), silver grade could increase from 3 to 9 oz/t based only on 1% sy(?) replacing tetrahedrite. The most important factors are the conditions for replacement of the tetrahedrite. If the silver remained in solution for distances on the order of hundreds of feet, this could be very important, as distances of inches or feet would simply mean enrichment at the expense of nearby oxidized tetrahedrite. The stromeyerite(?) was identified in the high-grade zone noted above. This study indicates that hypogene and possibly supergene processes were responsible for the high-grade ore. Thus, the grade will not drop off dramatically with depth because the base of the supergene zone is reached.

Another controlling factor of high-grade ore was thought to be element zoning of arsenic and antimony in the tetrahedrite. Based on a study of the arsenic–antimony–silver zoning in tetrahedrite at Casapalca, Peru (Wu and Petersen, 1977), it was hoped that my study would indicate a high-silver, high-antimony zone peripheral to a low-silver, high-arsenic conduit. Microprobe analysis of selected tetrahedrite samples from the Combination vein indicated no clear-cut solution conduit or peripheral high-grade zone; instead, four silver peaks were noted on a graph of wt% versus distance (Fig. 31) along a N. 40° W.

trend, and one rounded peak on a similar graph in a N. 50° E. direction (Fig. 32). This suggests that high-grade zones occur in shoots at fairly regular intervals and at some angle to the main haulage direction.

The primary value of this information is to indicate that ore should not change in grade dramatically with depth. It also suggests that the optimum direction for cutting ore shoots is in the current N. 40° W. development direction.

The structural geology of the mine was mapped in some detail to determine the effect of structure on the high-grade ore zones. The structure occupied by the vein is the principal ore control with sulfide minerals as open-space filling in the vein. The structure cuts across bedding and has occasional rotated wall-rock fragments in it, but the sulfides are not fragmental and the amount of movement on the structure was not determined. Previous work on the mine (Volin and others, 1952) suggested that high-grade ore shoots had a northerly trend parallel to folding. Microprobe data suggest high-grade shoots that cross the N. 40° W. main haulage at some angle, but determination of the exact trends of these shoots would require a parallel traverse. From this study, conflicting structural data were obtained from the two cross-sectional directions (Fig. 30). Along section A-A' no relation of grade to strike and dip of the vein or to strike and dip of the wall rock was noted. Data from section B-B', however, suggested increasing content of silver in the tetrahedrite associated with flattening of the vein. This suggests that compressional forces were directed such that more space was opened on flatter portions of the vein. Additionally, dipping, lean portions of the vein should not be considered final ore boundaries, as the cross-cutting nature of the vein structure indicates the possibility of ore shoots beyond thin low-grade areas.

Other structures that appear to influence grade in the mine are four high-angle postore faults (Fig. 30). Silva(1983, personal commun,), the mine geologist stated that grades do not match well across these structures. Some component of lateral motion is suggested by the trend of slickensides in the southeasternmost fault, whereas microprobe analysis of the tetrahedrite indicated rather sudden changes in the silver content across faults between locations Z and Y (Figs. 30 and 31) and locations F' and G' (Figs. 30 and 32). Vein-fault geometry indicates right-lateral motion on the faults. Exploration for high-grade zones truncated by northeast-striking faults should use detailed fault problem solutions and drilling information from the right of the location where the fault was encountered.

If mineralization was closely tied to the intrusion to the north, it is possible that thermal effects may have influenced the zoning in the mine. Classic zonation as discussed by Barnes (1979) and seen at Butte, Montana, has high-iron and high-copper minerals toward the (presumably hotter) center of the mineralizing system and a peripheral area of lead-zinc-silver mineralization. Applied to the geology at the Black Pine mine, low-silver tetrahedrite (and possibly more pyrite?) and minor lead and zinc would be found father to the north nearer the dike. More abundant lead, zinc, and high-silver tetrahedrite would occur subparallel to the dike but at some greater distance. The above zonation suggests that high-grade silver zones may trend N. 60° E. and be localized by the intersection of mineral zonation with flatter portions of the vein (Fig. 33).

Sources of Metals

One possible source for the metals of the Combination vein is a stratabound massive sulfide deposit. Evidence for this is entirely circumstantial, but based on recent thinking in ore-deposit genesis (Ramalingaswamy and Cheney, 1977), this possibility should not be overlooked. The similarity of the mineralogy of the Combination vein ore to that of many of the ores of the Coeur d'Alene district, Idaho, along with the similarity of the host lithologies, suggests that a comparison is not unreasonable.

Although the stratigraphic horizon (Middle Missoula Group) is higher than the horizons that host deposits such as the Sullivan, British Columbia, and those in the Coeur d'Alene district (all lower Belt), it seems reasonable that host-rock lithology, with implications for depositional environments and controlling structures, might be more important than time—stratigraphic correlations. In addition, upward remobilization from depth would not require that any of the Missoula Group was necessarily the host.

A more likely source of the metals is a nearby intrusion that crops out as a dike about a mile north of the adit entry. Based on aeromagnetic survey data, this may be connected at depth with the Henderson Creek stock and a southwestern intrusive outcrop (Fig. 5, in pocket). A possible tie between the intrusion and the Combination vein is suggested by the presence of disseminated scheelite in the

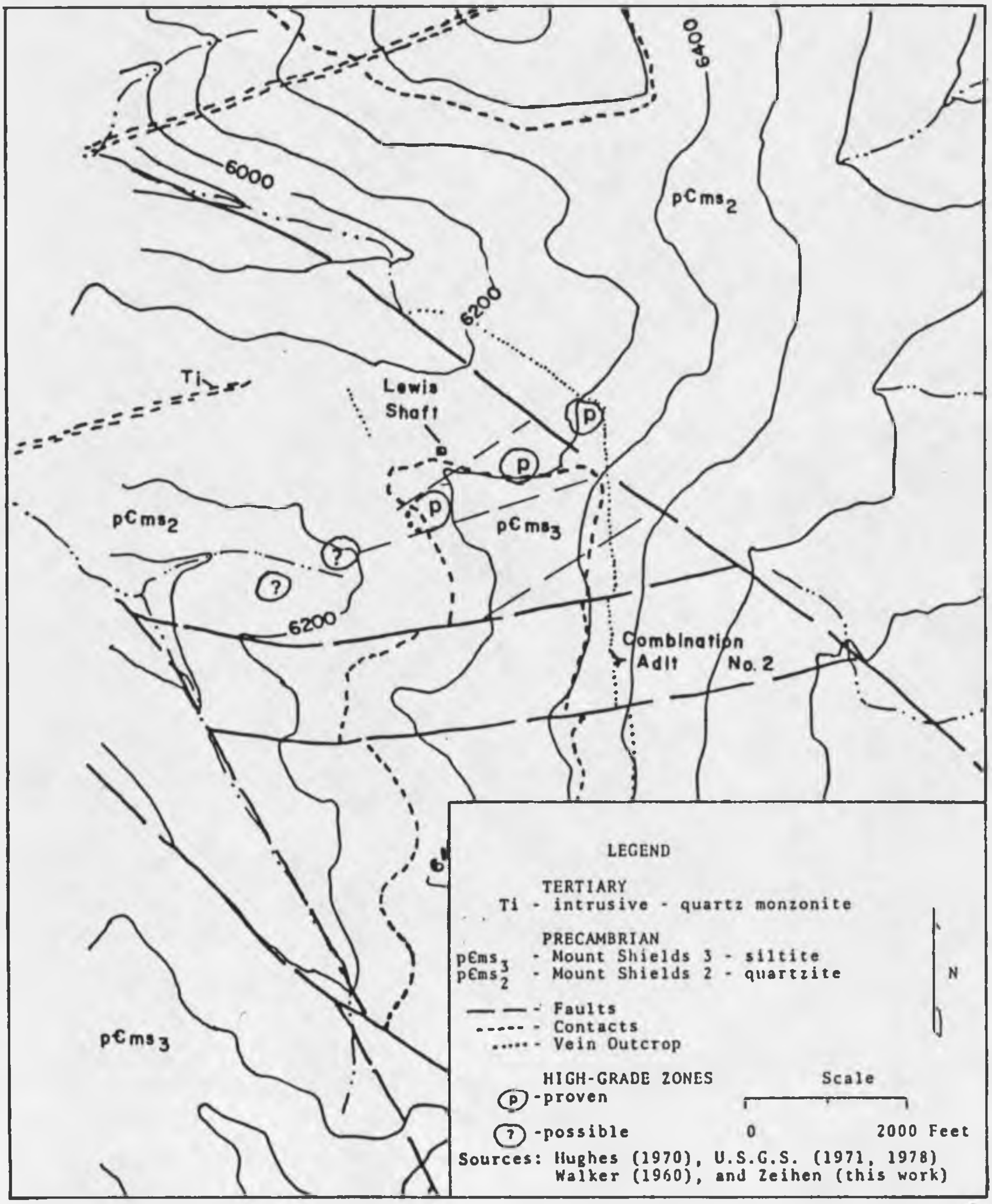


Figure 33. Regional map showing possible trends and locations at high-grade zones

Henderson Creek stock and the huebnerite found throughout the mine workings.

APPENDIX A

FIELD AND LABORATORY TECHNIQUES

The surface topographic profile above the main haulage (section A-A') at the Black Pine mine was completed using a brunton compass and a cloth tape. Mapping was done on a scale of 1" = 100', and 100-foot stations were marked with flags. Surface geology was noted, as were roads and power lines. Topography for section B-B' was obtained from a 1" = 200'-scale topographic map in Inspiration Development Company's files at the mine. The contour interval was 20 feet. Underground workings were located on these cross sections by using surveyed elevations for the floor and back obtained from mine maps. Underground mapping was done on a scale of 1" = 40'. Mapping sheets were traced from mine maps, and geology was mapped onto these sheets by using a brunton and tape. At most random sample locations, vertical sections of the vein roughly 4 feet along the rib were sketched in field notes, and differences in mineralogy were noted. Polished sections were made from selected sample locations and along the cross-section directions.

Diamond drill holes TS-33 and TS-40 were logged on a scale of 1" = 10 feet, and a number of samples were taken for both megascopic and microscopic examination.

Minor field checking of the geology presented on Figure 9 (in pocket) was also completed.

Some specimens for reflected-light examination were ground and polished by me. The first step was to cut the specimen. This was followed by grinding on a rotating lap with 400-micron and 500-micron grit. Prepolishing was done with 1000-micron grit, and the procedure was completed with 6-micron and 0.3-micron steps. Thin sections and polished sections of samples collected at intervals across and along the main haulage were prepared commercially by Robert Jones of Butte, Montana. Due to the friable nature of much of the vein material, it was treated by vacuum impregnation with epoxy to prevent plucking during the polishing process.

Polished sections were examined under reflected light, and identifications made on the basis of reflectivity, optical properties, Vickers hardness testing, and microchemical techniques and by electron microprobe. Microchemical techniques used can by found in Short (1948). Most commonly used were the potassic mercuric thiocyanate tests for zinc and copper. For silver and lead, the chloride and ammonium hydroxide tests were used.

Supergene oxide minerals that could not be readily identified were submitted to Lester G. Zeihen of the Montana College of Mineral Science and Technology for identification by X-ray diffraction techniques. X-ray needles of minerals were prepared by crushing small, relatively pure amounts of them and embedding that in an acetone-based glue (Duco Cement). Needles so prepared were mounted in a Debye-Scherrar, 114.6-mm (diameter) diffraction camera. Kodak direct-exposure film, SO-445, fine focus, was mounted in the Straumanis method and exposed to copper K-alpha radiation with a nickel filter.

Samples were run for 4-5 hours at 35 kV and 30 mA. Film was developed with Kodak D-19 developer, and X-ray lines were measured to obtain d-spacings. Values were then compared with a card file using the Hanawalt method as well as a card file of reference films. Additional verification occasionally required microchemical techniques to determine between isostructural minerals such as duftite and mottramite.

Electron microprobe work on the specimens was done by me in conjunction with T. M. Teska of the Department of Lunar and Planetary Sciences at The University of Arizona. The microprobe was an Applied Research Laboratories Model SEMQ, coordinated with the Tracer-Northern Computer hardware Model 880/1310. The system was used at 35 μA beam current, 50 μA sample current, and 15 mV. The software is a standard commercial program called TASKII that calculates weight percent of an element based on counts received from any of four spectrometers compared to a standard. The standards used are listed in Table A-1. Samples were mounted with clay epoxy, leveled on glass slides, and coated with carbon prior to analysis.

Values presented in this thesis were obtained by averaging three point analyses from different places on the tetrahedrite sample. Other minerals such as pyrite, galena, and sphalerite were analyzed less often depending on data required and total weight percent calculated.

Table A-1. Standards for elements used in electron microprobe study

Element	Standard	Wt %
Ag	silver	100
As	arsenopyrite	46.01
Au	gold	100
Bi	bismuth	100
Cd	cadmium	100
Cu	copper	100
Fe	troilite	63.5
Pb	galena	86.6
S	troilite	36.5
Sb	antimony	100
Zn	zinc	100

APPENDIX B

GRAPHS OF SILVER VERSUS OTHER ELEMENTS IN TETRAHEDRITE

Results of microprobe analyses of tetrahedrite samples were used to calculate correlation coefficients between silver and each of the other major elements in the tetrahedrite. Calculations were done by using a linear regression analysis program provided in the Applications Manual for the Texas Instruments SR-56 programmable calculator. Graphs of silver versus the various elements are presented.

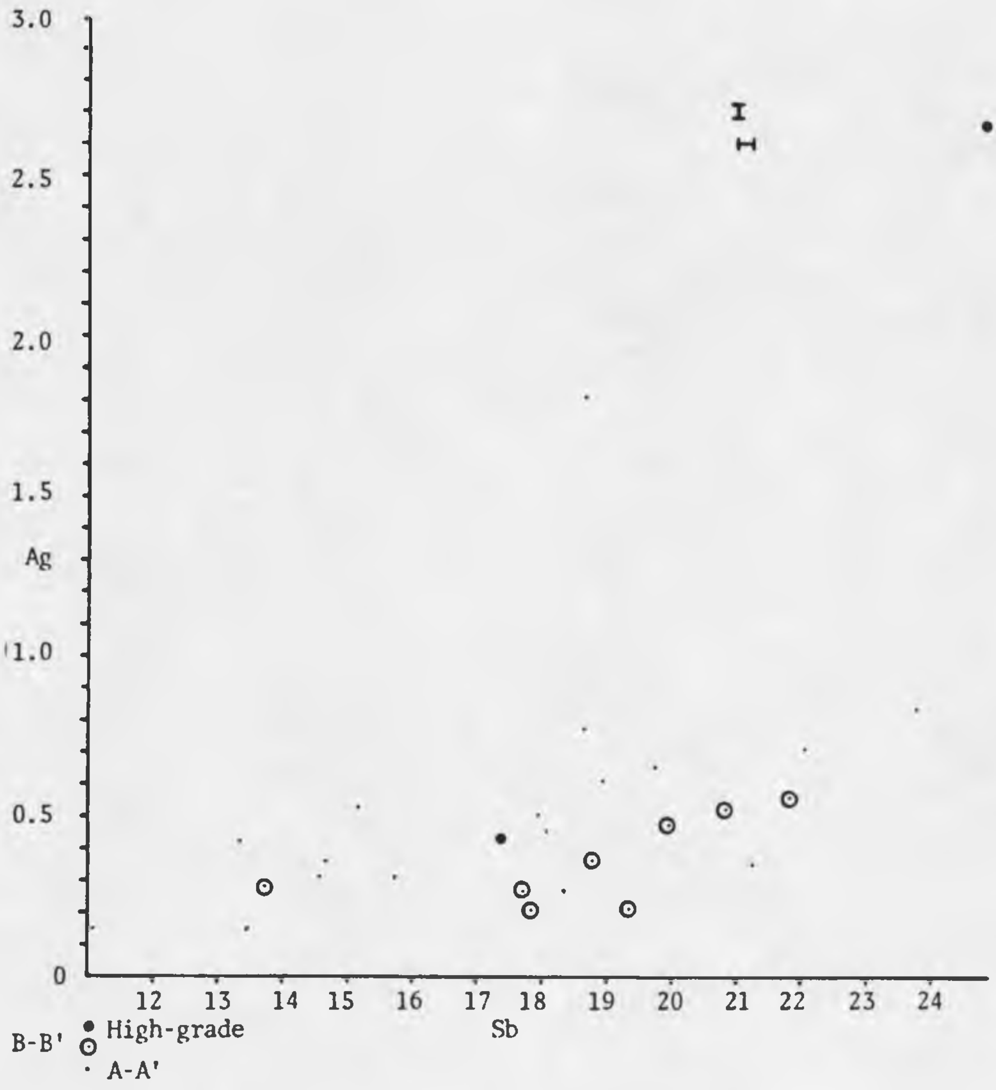


Figure B-1. Silver versus antimony. -- Values are in weight %; bars indicate analytical uncertainty for each element.

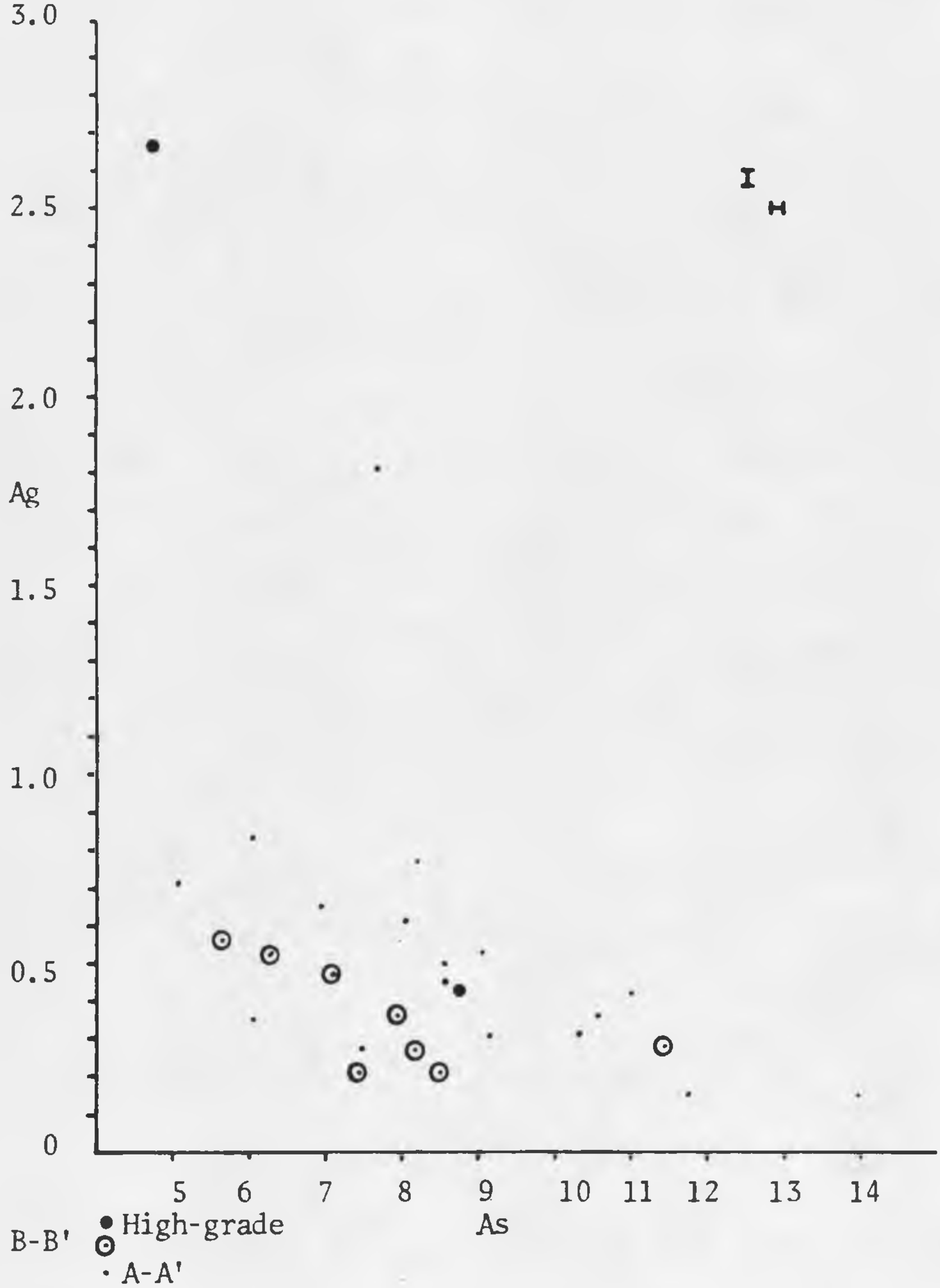


Figure B-2. Silver versus arsenic. -- Values are in weight %; bars indicate analytical uncertainty for each element.

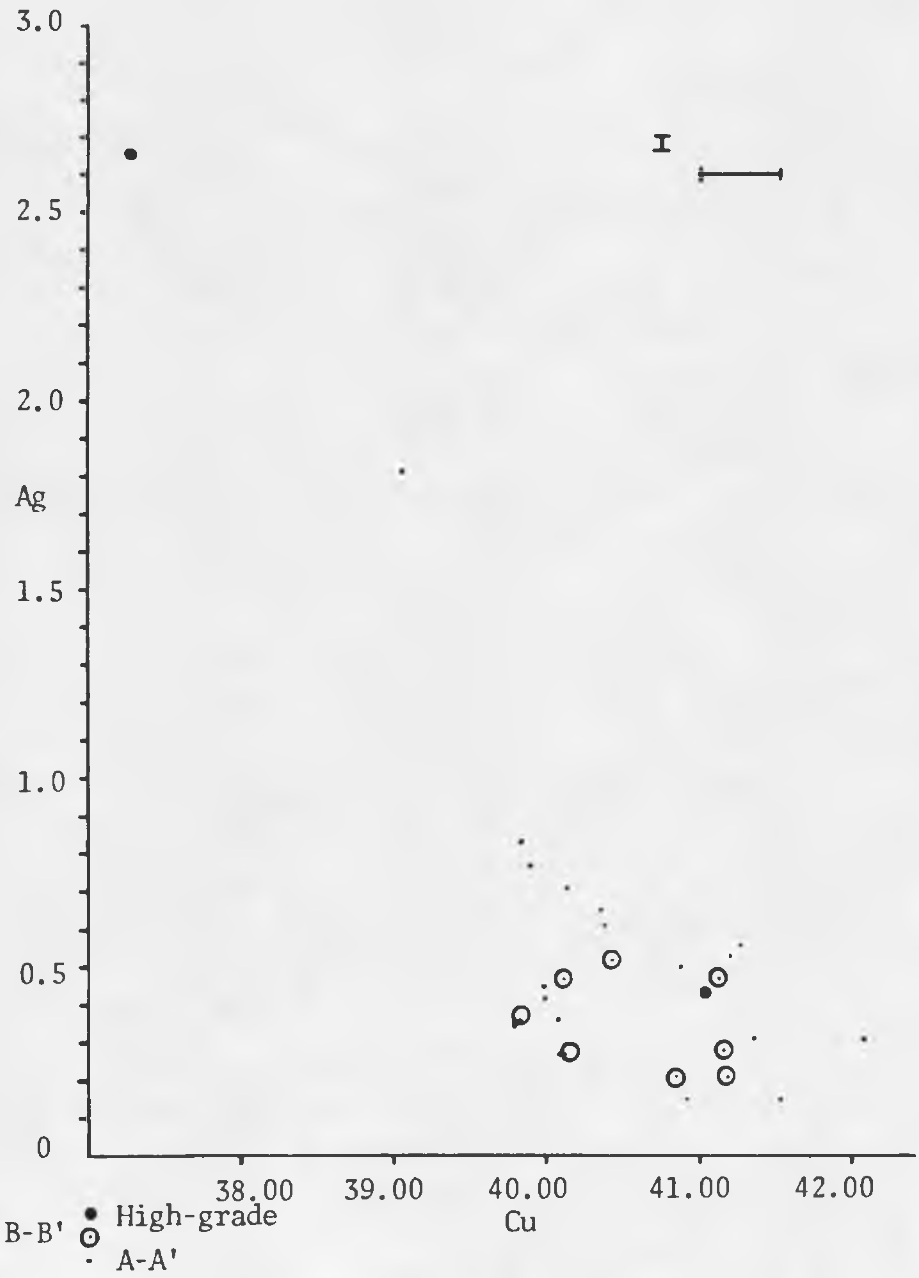


Figure B-3. Silver versus copper. -- Values are in weight %; bars indicate analytical uncertainty for each element.

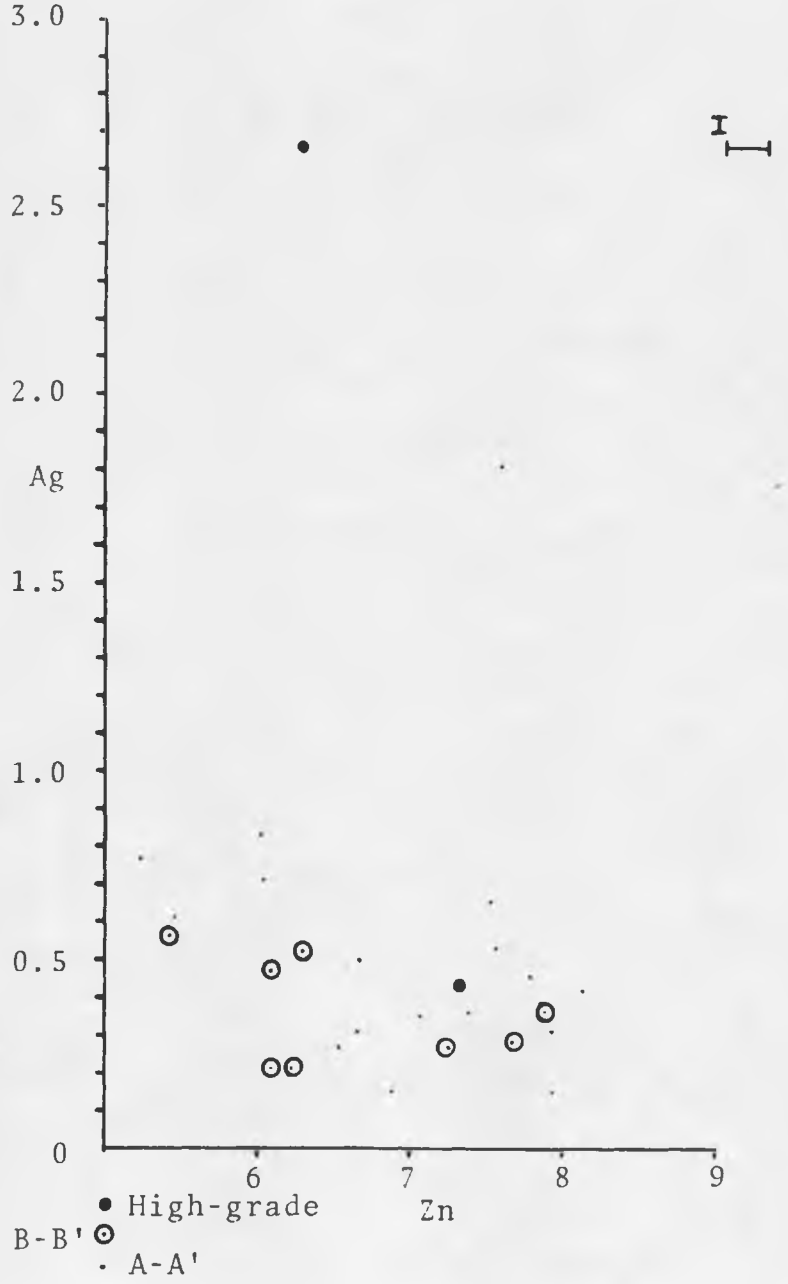


Figure B-4. Silver versus zinc. -- Values are in weight %; bars indicate analytical uncertainty for each element.

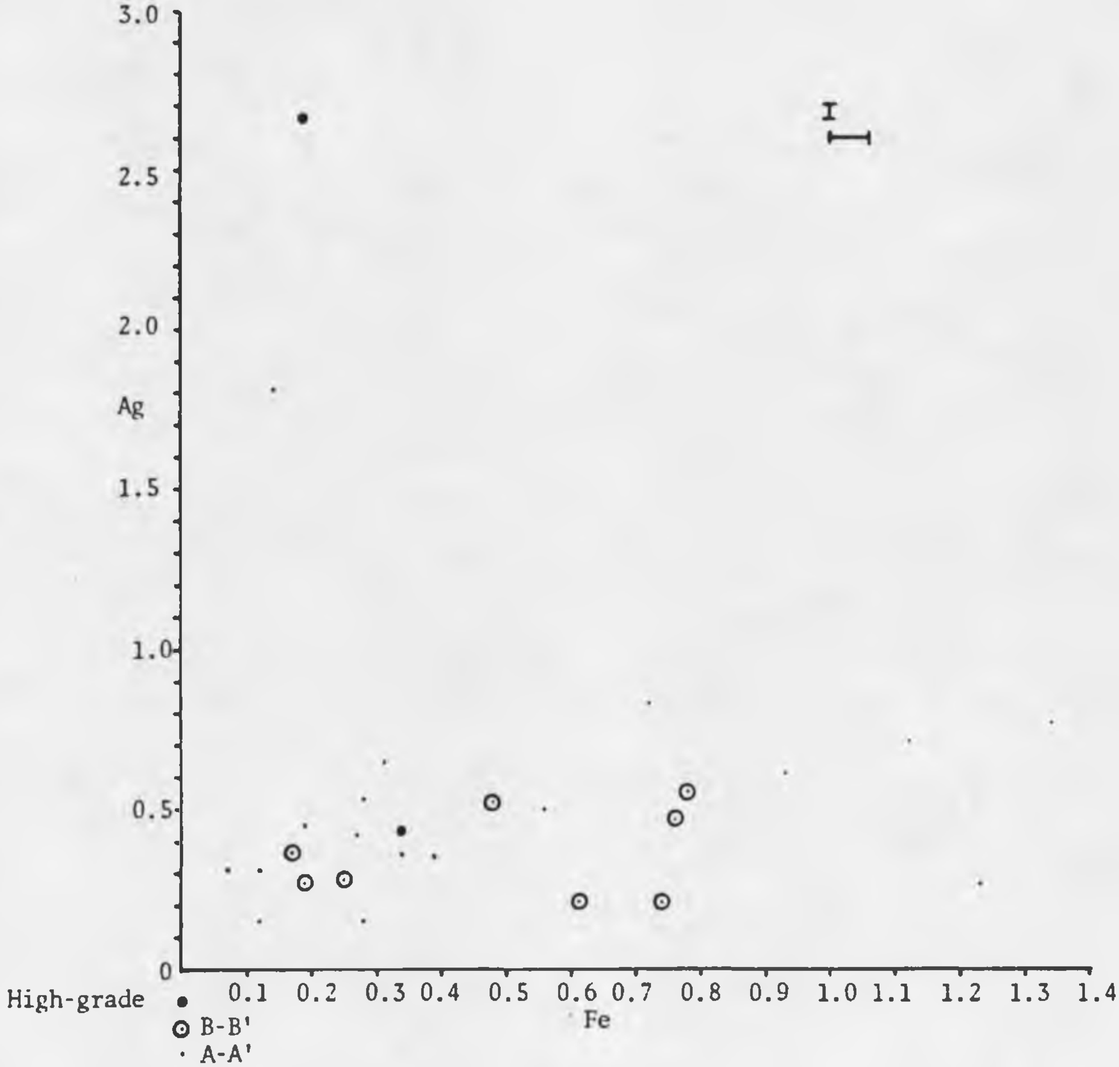


Figure B-5. Silver versus iron. -- Values are in weight %; bars indicate analytical uncertainty for each element.

REFERENCES

Barnes, H. L., 1979, Geochemistry of hydrothermal ore deposits: New York, John Wiley, 798 pp.

Billingsley, O., 1983, Oral communication: Graduate student, University of Montana, Missoula.

Billingsley, O., n.d., Mineralogy and elemental trends of the Black Pine mine, Granite County, Montana: M.S. thesis draft, University of Montana, Missoula.

Chapman, R. W., Gottfried, D., and Waring, C. L., 1955, Age determinations on some rocks from the Boulder batholith and other batholiths of western Montana: Geol. Soc. America Bull., v. 66, p. 607-610.

Cole, J. W., 1950, Investigation of the Sunrise copper-gold mine, Granite County, Montana: U.S. Bureau of Mines, Report of Investigations 4689, 13 p.

Collins, L. F., 1979, Gas hydrates in CO_2-bearing fluid inclusions and the use of freezing data for estimation of salinity: Econ. Geology, v. 74, no. 6, 1435-1444.

Dana, J. D., and Dana, L. S., 1944, The system of mineralogy, 7th ed., Vol. I: New York, Wiley, 155-488.

Daniel, F., and Berg, R. B., 1981, Radiometric dates of rocks in Montana: Butte, Montana Bureau of Mines and Geology Bulletin 114, 136 p.

Davis, J. C., 1973, Statistics and data analysis for geology: New York, Wiley, 550 p.

De Sitter, L. U., 1956, Structural geology: New York, McGraw-Hill, 452 p.

De Williams, P., and Reed, J. C., 1972, Status report; Black Pine Mine Project: Inspiration Development Co., Black Pine Mine, Boulder County, Montana, unpublished report.

Emmons, W. H., and Calkins, F. C., 1913, Geology and ore deposits of the Philipsburg quadrangle, Montana: U.S. Geological Survey Prof. Paper 78.

Giletti, B. J., 1968, Isotope geochronology of Montana and Wyoming, in Hamilton, E. I., and Ferguson, R. M., eds., Radiometric dating for geologists: New York, Interscience, p. 111-146.

Guilbert, J. M., 1983, Personal communication: Professor of Geosciences, University of Arizona, Tucson.

Hackbarth, C. J., and Peterson, U., 1984, A fractional crystallization model for the deposition of argentian tetrahedrite: Econ. Geology, v. 79, no. 3., p. 448-460.

Harrison, J. E., 1972, Precambrian Belt Basin of northwestern United States--its geometry, sedimentation, and copper occurrences: Geol. Soc. American Bull., v. 83, p. 1215-1240.

Hughes, G. J., 1970, Precambrian stratigraphy and structure in the Henderson-Wallace Creek igneous belt, Granite County, Montana: unpublished M.S. thesis, Michigan Technological University, Houghton, 93 p.

Hundhausen, R. J., 1949, Investigation of Henderson Gulch tungsten deposit, Granite County, Montana: U.S. Bureau of Mines Report of Investigation, Vol. 4613, 8 p.

Krohn, D. H., and Weist, M. M., 1977, Principal information on Montana mines: Butte, Montana Bureau of Mines and Geology Special Publication 75, 57 p.

McMannis, W. J., 1965, Résumé of depositional and structural history of western Montana: American Association of Professional Geologists Bull., v. 49, no. 11, p. 1801-1823.

Ramalingaswamy, V. M., and Cheney, E. S., 1977, Stratiform mineralization and origin of some of the vein deposits, Bunker Hill Mine, Coeur d'Alene district, Idaho: Society of Economic Geologists, Coeur d'Alene Field Conference, Idaho, 1977: Moscow, Idaho Bureau of Mines and Geology Bulletin 24, p. 35-43.

Ramdohr, P., 1969, The ore minerals and their intergrowths: New York, Pergamon Press. 1174 p.

Riley, J. F., 1974, The tetrahedrite-freibergite series, with reference to the Mount Isa Pb-Zn-Ag orebody: Mineralium Deposita, v. 9, p. 117-124.

Short, M. L., 1940, Microscopic determination of the ore minerals, 2nd ed.: U.S. Geological Survey Bulletin 914, 313 p.

Silva, A., 1983. Personal communication: Mine geologist, Inspiration Development Co., Black Pine Mine, Granite County, Montana.

Volin, M. E., Roby, R. N., and Cole, J. W., 1952, Investigations of the combination silver-tungsten mine, Granite County, Montana: U.S. Bureau of Mines Report of Investigations 4914, 26 p.

Waisman, D., 1984, Geology and structural implications at the Black Pine Mine, Granite County, Montana: Unpublished M.S. thesis, University of Montana, Missoula.

Walker, D. D., 1960, Tungsten resources of Montana: Deposits of the Philipsburg batholith, Granite and Deer Lodge Counties: U.S. Bureau of Mines Report of Investigations 5612, 55 p.

Wallace, C. A., Schmidt, R. G., Waters, M. R., Lidke, D. J., and French, A. B., 1981, Preliminary geologic map of the Butte 1° x 2° quadrangle, central Montana: U.S. Geological Survey Open-File Report 81-1030.

White, L., 1976, Trackless mining on a small scale: Inspiration's Black Pine silver mine: Engineering and Mining Journal, v. 177, no. 9, p. 98-100.

Winston, D., 1973, Stratigraphy and sedimentary features of the Missoula Group, western Montana, Field Trip #2, Belt Symposium 1973, Vol. I: Moscow, University of Idaho, Idaho Bureau of Mines and Geology, p. 235-252.

Winston, D., 1984, Sedimentology and stratigraphy of the Missoula Group, in Hobbs, S. W., ed., The Belt: Butte, Montana Bureau of Mines and Geology Special Publication 90, p. 30-32.

Wu, I, and Petersen, U., 1977, Geochemistry of tetrahedrite and mineral zoning at Casapalca, Peru: Economic Geology, v. 72, p. 993-1016.

Wuensch, B. J., 1964, The crystal structure of tetrahedrite, $Cu_{12}Sb_4S_{13}$: Z. Krist., v. 119, p. 437-453.

Zeihen, L. G., 1983, Personal communication: Mineralogist, Montana Bureau of mines and Geology, Butte.

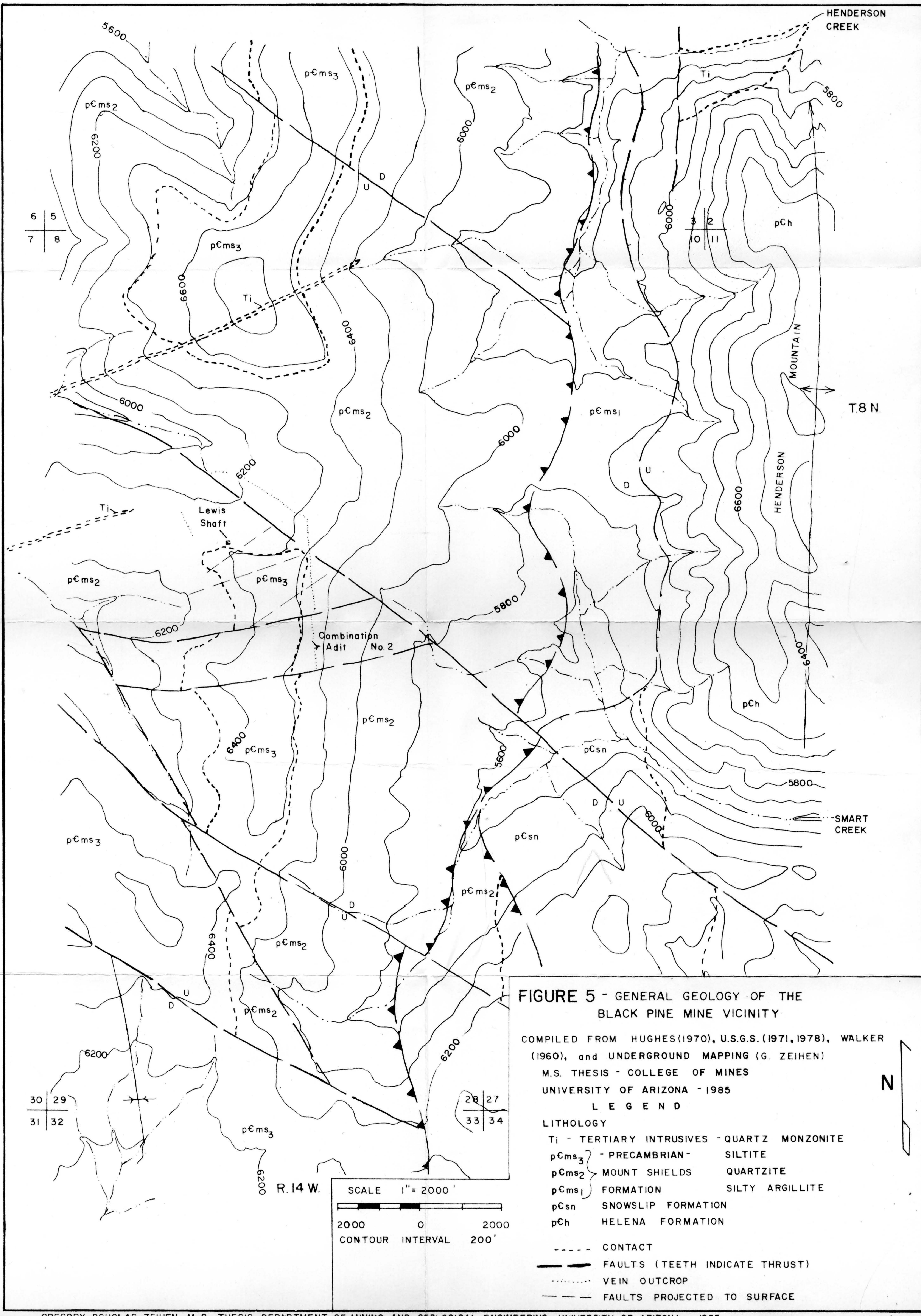
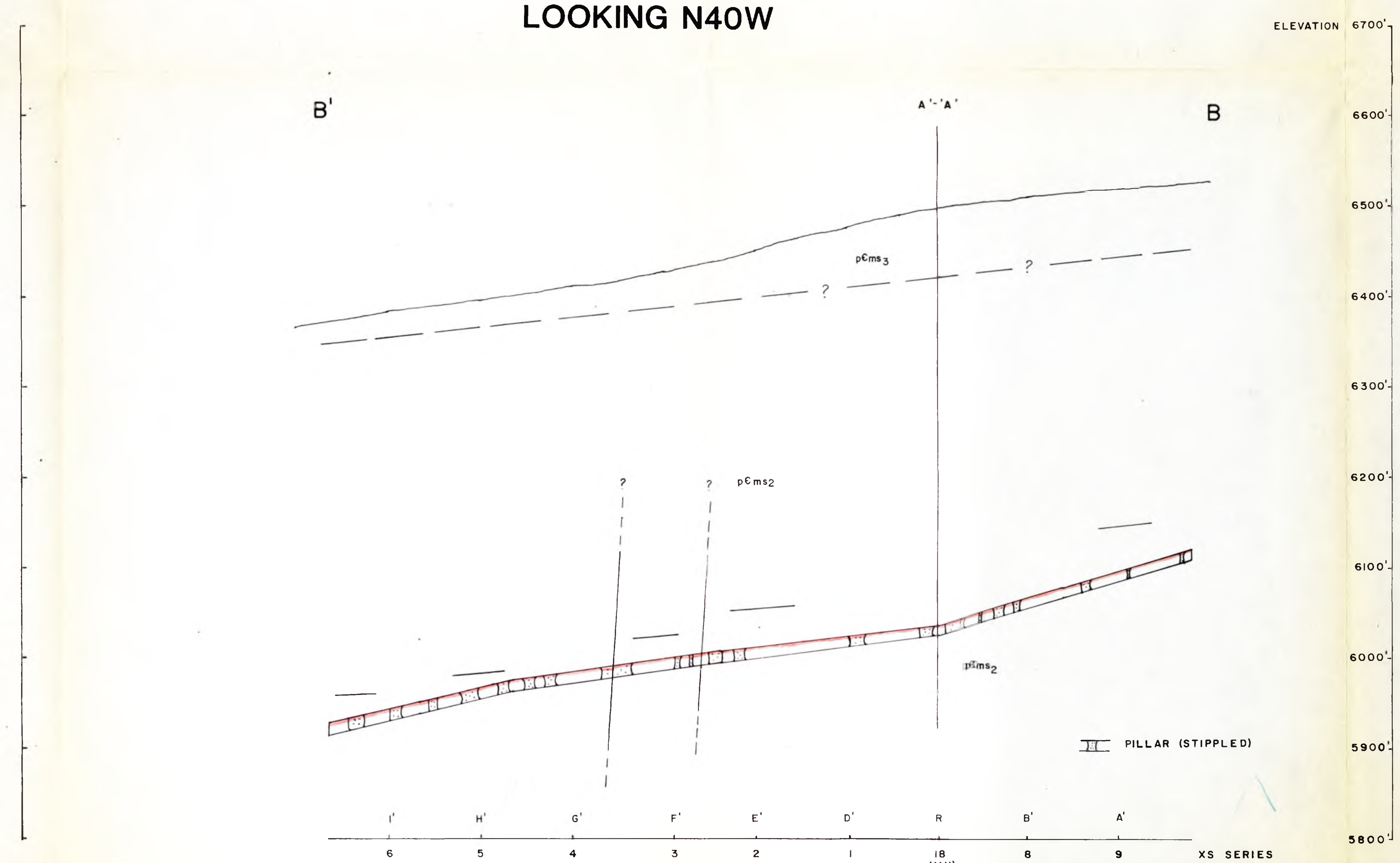


FIGURE 5 - GENERAL GEOLOGY OF THE BLACK PINE MINE VICINITY

CROSS SECTION A–A′
LOOKING N50E

CROSS SECTION B–B′
LOOKING N40W



BLACK PINE MINE
COMBINATION VEIN

GRANITE COUNTY, MONTANA
WORKINGS BY INSPIRATION DEVELOPMENT CO.
GEOLOGY BY GREG ZEIHEN

AUGUST 9, 1983

L E G E N D

- WORKINGS - DASHED WHERE PROJECTED TO SECTION
- FAULTS SHOWING RELATIVE MOTION
- VEIN
- BEDDING
- A, B' SAMPLE LOCATION
- pЄms3 MOUNT SHIELDS 3
- pЄms2 MOUNT SHIELDS 2

SCALE 1" = 100' NO VERTICAL EXAGGERATION

100 0 100 200

FIGURE 15 – CROSS SECTIONAL VEIWS, COMBINATION VEIN

GREGORY DOUGLAS ZEIHEN, M. S. THESIS
DEPARTMENT OF MINING AND GEOLOGICAL ENGINEERING, UNIVERSITY OF ARIZONA
1985

FIGURE 13 - PLAN MAP
GREGORY D. ZEIHEN - M.S. THESIS
COLLEGE OF MINES
UNIVERSITY OF ARIZONA - 1984
BLACK PINE MINE
COMBINATION VEIN
GRANITE COUNTY, MONTANA
WORKINGS BY INSPIRATION DEVELOPMENT CO.
GEOLOGY BY GREG ZEIHEN
AUGUST 9, 1983
LEGEND
TIMBERS
STRIKE AND DIP OF VEIN (RED)
STRIKE AND DIP OF FAULTS (BLUE)
STRIKE AND DIP OF BEDDING
RAISES AND SHAFTS
WORKINGS - DASHES INDICATE BENCHES
DIAMOND DRILL HOLES
SAMPLE LOCATIONS
N
SCALE 1" = 100'
100
0
100
200
LEWIS SHAFT
A'
A
B
B'
OLD WORKINGS - POOR SURVEY CONTROL
THIS SIDE OF DASHED LINE
1' CLAY GOUGE
6" GOUGE
2' GOUGE
MAIN HAULAGE
BP-2
BP-8
BP-45
TS-33
TS-40
N 915,800
N 915,400
N 915,000
N 914,600
N 914,200
N 913,800
N 913,400
E 1,024,000
E 1,024,400
E 1,024,800
E 1,025,200
E 1,025,600
E 1,026,000
E 1,026,400
GREGORY DOUGLAS ZEIHEN, M. S. THESIS
DEPARTMENT OF MINING AND GEOLOGICAL ENGINEERING,
UNIVERSITY OF ARIZONA 1985