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THE MINERALOGY AND PARAGENESIS OF THE TUNGSTEN-BEARING QUARTZ VEINS, ELKHORN MINING DISTRICT, BEAVERHEAD COUNTY, MONTANA

by

Andrew Leo Hardiman

A Thesis
Presented to the Graduate Committee of Lehigh University in Candidacy for the Degree of Master of Science in The Department of Geological Sciences

Lehigh University
1975
This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

May 9, 1975
(date)

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THE MINERALOGY AND PARAGENESIS OF THE TUNGSTEN-BEARING QUARTZ VEINS, ELKHORN MINING DISTRICT, BEAVERHEAD COUNTY, MONTANA

ABSTRACT

The Elkhorn mining district is in the batholithic rocks of the Pioneer Mountains in southwestern Montana. Small quantities of base metals have been mined in the district prior to 1940. Mineralization in the district occurs in two sets of quartz fissure veins in granodiorite. The vein material is brecciated and sheared white quartz in which ore minerals occur as disseminated grains and cement.

The ore minerals are members of the wolframite series, sphalerite, ruby silver, chalcopyrite, tennantite, enargite, and galena. Secondary ore minerals are argentite, digenite, cuprite, native copper, and native silver. Pyrite and rhodocrosite are common gangue minerals. Wolframite crystallized first followed by sphalerite, ruby silver, chalcopyrite, tennantite, enargite, and galena. There were several episodes of brecciation during mineralization. Tungsten mineralization is associated with the principal vein set. This vein set is parallel to a regional fault trend.
INTRODUCTION

The Elkhorn mining district is in the batholithic rocks of the Pioneer Range of southwestern Montana. Some base metals were recovered from the district as early as 1872; however total production during the past 70 years is only 53,000 tons. In recent years the potential of tungsten mineralization in the district was recognized and this led to renewed exploration in the district. The purpose of this study is to describe the geology of the district with special emphasis on the mineralogy and petrology as related to tungsten mineralization. The area of study is located generally in sections 10-15, 21-23, 26-28, 33 and 34, T.4S., R.12W., the Polaris 15 Minute Quadrangle, Beaverhead County, Montana. (Figure 1)

The Pioneer Range trends approximately northeast-southwest covering approximately 2600 square kilometers. The range is bounded on the north, east, and west by the Big Hole River, and on the southeast and south by the Beaverhead River and Grasshopper Creek. Barren glaciated peaks form the backbone of the range of which Mt. Tweedy is the highest peak. Intermediate slopes are heavily forested with pine, fir and spruce. There are broad grass-covered upland meadows. Below the intermediate slopes are sparsely-forested, sagebrush-covered foothills. Relief is about 1600 meters.

Most of the Pioneer Range has a semiarid climate with
Figure 1. Index map showing location of the Pioneer batholith and the Elkhorn mining district.
an annual precipitation of about 50 cm. Summer temperatures rarely reach 38°C. Heavy snows and low temperatures commonly make the higher elevations inaccessible during the winter and early spring.

The Elkhorn mining district is located on the east and west flank of Comet Mountain. The mountain has an elevation of 3100 meters and is the main topographic feature in the Elkhorn mining district. The east face of Comet Mountain is a cirque above a north-south trending U-shaped valley forming the headwaters of the Wise River. The west side of Comet Mountain is a steep slope heavily forested below 2700 meters.

According to Geach (1972), the first discovery of ore in the district was in 1872, and a small quantity of ore assaying 9 kg. of silver per ton was shipped. By 1921, the Boston Montana Company, under which the district's mining claims were consolidated in 1913, had spent 5 million dollars on various projects. These included the following: 1) 7300 meters of underground development, 2) 55 km. of railway connecting the mining district and the town of Divide, Montana, 3) 68 km. of high tension electric lines, and 4) a 750 ton ore treatment plant. Development continued until early in the decade 1930 when all major development stopped due to financial difficulties. There was no activity in the district during the period 1946 to 1968. Silgold Mines Inc., a subsidiary of Coin Canyon Mines Ltd., controlled the mineral rights of the area from
1968 to 1972. Activity during this time included the following: surface mapping, underground rehabilitation and sampling, and limited diamond drilling. During 1973 and 1974 Bethlehem Steel in joint venture with General Electric conducted an exploration program in the district.

REGIONAL GEOLOGY

Southwestern Montana is located within the Northern Rocky Mountain Physiographic Province. The oldest sedimentary rocks in western Montana are rocks of the Belt "Super Group" of Precambrian Y age (1600 to 800 my). These Belt rocks are interbedded quartzites, argillites, and limestones, ranging in thickness from 1500 meters in southwestern Montana to about 12,000 meters in northwestern Montana. The nature of the contact between Belt rocks and overlying Paleozoic and Mesozoic sedimentary rocks is uncertain, but no major unconformities are apparent. Intermittent sedimentation occurred throughout the Paleozoic and early Mesozoic. According to Harrison (1974), there was nearly continuous tectonic activity from the period of Belt deposition to Jurassic time; however there was little or no igneous activity. He further suggests that tectonic features of the pre-Belt basement and the Belt basin influenced post-Belt structures and location, of intrusives in southwestern Montana.

A period of overlapping tectonic, volcanic, and plutonic activity began in Jurassic time and lasted until
Eocene time (Robinson et al., 1968; Hamilton and Myers, 1974). Most of the igneous rocks of southwestern Montana were formed during this period. They include: the composite Boulder batholith and associated Elkhorn volcanics (78 to 68 my., Tilling and others, 1968), the Idaho batholith (168 to 38 my., McDowell and Kulp, 1969), the Pioneer batholith (70 to 76.5 my., Zen, 1975), the Philipsburg batholith (72 to 76.7 my., Hyndman and others, 1972), and the Tobacco Root batholith (52 to 75 my., Giletti, 1966). Regional folding and faulting accompanied the igneous activity. Thrust sheets containing Belt and younger rocks have been tectonically translated to the east and overlie Cretaceous sedimentary rocks. The Belt rocks described by Myers (1952) on the eastern edge of the Pioneer batholith are interpreted by Harrison (1974) to indicate a tectonic transport of about 160 km. Smaller scale thrust sheets of Belt rocks over Cretaceous sedimentary rocks have been reported north and south of the Pioneer batholith (Fraser and Waldrop, 1972; Pattee, 1960).

High-angle Basin and Range-type faulting began in the mid-Tertiary and possibly continued into the Pleistocene.

The Pioneer Batholith

The Pioneer batholith forms the core of the Pioneer Range in southwestern Montana. (Figure 2) It intrudes sedimentary and metamorphic rocks ranging in age from Precambrian to Upper Cretaceous. On the west, the batholith
Figure 2. Geology of the Pioneer batholith.
is in contact with Precambrian Belt Series rocks and Paleozoic rocks. Karlstrom (1948) reported that contact metamorphic rocks have formed from Paleozoic calcareous sedimentary rocks on the north. On the east the intrusive rock is in contact with folded and faulted Paleozoic and Mesozoic sedimentary rocks. On the southern margin, the intrusive rock is in contact with complexly folded and faulted Precambrian and Paleozoic sediments. Pattee (1960) reported a 2 km. wide thrust zone. This zone, called the Kelley Thrust, consists of fault blocks of Paleozoic and Mesozoic sedimentary rocks which are overthrust by Beltian strata (Geach, 1972).

According to Zen (1975), the Pioneer batholith is a composite intrusive containing no fewer than eight rock types ranging from quartz diorite to granite. The dominant rock type is a coarse-grained, biotite-hornblende "granite" which in hand specimen resembles the Butte Quartz Monzonite. However, he points out that chemical analyses of all but the quartz diorite suggests the rocks of the Pioneer batholith belong to Tilling's (1973) "sodic series" of the Boulder batholith.

Other rock types within the batholith include coarse-grained pyroxenite and gabbro (Zen, 1975). Abundant aplite, lamprophyre, and pegmatitic dikes are associated with a quartz monzonite along the northern border of the intrusive
are reported by Karlstrom (1948).

The Elkhorn Mining District

The Elkhorn mining district is centrally located within the Pioneer batholith. (Figure 3) The detailed structural geology of the district has not been established because of lack of outcrop. The Comet fault is the principal structural feature in the area. This fault transects the area as a north-south trending shear zone near the eastern margin of the district and the eastern base of Comet Mountain. It is approximately 90 meters wide and dips 45° to the west. Comet Mountain has been interpreted as a fault block, and this would require the fault to have a vertical component of movement of at least 350 meters (Geach, 1972). The Mono fault parallels the Comet fault 360 meters to the west and dips 45° to the east. The strike length of these faults is not known, but both extend beyond the Elkhorn district. They may be related to north-south trending faults mapped on the northern and southern margin of the batholith. Fifteen faults of less magnitude have been mapped on the basis of truncations or divergences of well defined veins and on the basis of topographic expression. There are many more faults than previously mapped, and these faults are a factor in the control of ore deposition (Melrose and others, 1974).

IGNEOUS ROCK DESCRIPTION

The country rock in the Elkhorn mining district was described by Winchell (1914) as a "porphyritic biotite-
Figure 3. Geology of the Elkhorn mining district (after Melrose et al., 1974).
hornblende quartz monzonite. In the present study the petrography was aided by the availability of diamond drill core. Hand specimen examination of this core suggests that the country rock is fairly uniform throughout the district. It is a medium-grained, grey-green rock with abundant mafic minerals. Several specimens were stained for potassium feldspar and plagioclase. These stained plagioclase are generally anhedral to subhedral and show some zoning. Plagioclase is about twice as abundant as potassium feldspar. Large anhedral potassium feldspar crystals poikilitically enclose all other minerals in the rock. Potassium feldspar occurs also as smaller crystals interstitial to larger plagioclase or large anhedral quartz. Quartz is moderately fractured and appears grey and vitreous. Quartz is more abundant than potassium feldspar.

Seventy-two thin sections of fresh and altered country rock were examined. Modal analysis of seven sections with approximately 650 points per slide showed plagioclase to average 47.3% and to range from 40% to 50.7%. Alkali feldspar averaged 16.6% with a range of 6.7% to 32.8%, and quartz averaged 27.7% with a range of 23.8% to 30.4%. Accessory and minor minerals including biotite, hornblende, sphene, apatite, and opaques made up 3.3% to 11.8% of the rock slides (with an average of 8.4%). The dominant rock type is granodiorite although some specimens approach a quartz monzonite in composition.
MINERALOGY

Plagioclase

The plagioclase is anhedral to subhedral, ranging in size from less than 1 mm. to greater than 4 mm. It occurs as small crystals poikilitically enclosed in large anhedral potassium feldspar. (Plate 1) It occurs also as large discreet crystals. Plagioclase in and near aplite dikes is graphically intergrown with quartz and potassium feldspar. The plagioclase is commonly zoned and is twinned according to the Albite, Pericline, and Carlsbad laws.

The composition of the plagioclase was established by optical properties including indices, 2V, and sign. The beta indices of the plagioclase were consistently less than the omega index of quartz. This indicates that the composition is less calcic than An_{17}. Centered optic axis figures show the 2V to be close to 90. The optic sign was determined to be negative from centered figures established to be acute biseotropic figures by Kamb's method. All of the optic data show the plagioclase to be within the range of An_{10} to An_{17}. Although the exact difference in composition within zoned plagioclase was not determined, the optical data for the cores of zoned plagioclase did not differ significantly from that of the rims.

The plagioclase in most sections have several interesting characteristics in common. Although almost all the plagioclase show some evidence of zoning, in many zoning
Plate 1. Photomicrograph of plagioclase poikilitically enclosed in alkali feldspar.
Plate 2a. Photomicrograph of partially "annealed" plagioclase.
Plate 2b. Photomicrograph of resorbed plagioclase.
appears partially to almost completely "annealed".

(Plate 2) The zoning appears to be homogenized yielding a
simply-twinned homogeneous pseudomorph, apparently of the
same composition. Generally, all stages of this trans-
formation are represented in one section.

Most of the minerals in thin section appear to be
fractured. However, the plagioclase is the most extensive-
ly fractured mineral and in some crystals sheared segments
are clearly offset. (Plates 3 and 4) Deformed twin planes
are common. Interestingly, deformed, fractured and sheared
plagioclase crystals commonly are surrounded by minerals
lacking fracture or shear. The deformation of the plagio-
clase is not accompanied by alteration.

Besides being generally anhedral and zoned, the outer-
most zones of plagioclase are wide irregularly-shaped
margins. Plagioclase poikilitically included in large
potassium feldspar generally have similar margins but also
commonly show some evidence of resorption and replacement by
potassium feldspar. (Plate 5) Occasionally where plagio-
clase is in contact with potassium feldspar, a thin layer
of myrmekite-like intergrowth occurs between the layers.

Alkali Feldspar

The alkali feldspar is anhedral and ranges in size
from less than 1 mm. to greater than 9 mm. Alkali feldspar
grains poikilitically enolose all of the other minerals in
the rock, and it occurs also as small crystals interstitial
Plate 3. Photomicrograph of fractured plagioclase.
Plate 4. Photomicrograph of deformed plagioclase.
Plate 5. Photomicrograph of resorbed plagioclase in orthoclase.
to other major minerals. Optical data show that the alkali feldspar has a range in composition and structural state. For example, interference figures and acute bisectrix figures yield $2V$ values from less than $50^\circ$ to greater than $80^\circ$. The alkali feldspar is faintly to strongly perthitic. Generally the perthitic lamellae within individual crystals are unevenly distributed and occasionally two directions of perthitic lamellae are developed. The alkali feldspar is generally untwinned; however, many crystals have domains where microcline grid-twinning is developed. (Plate 6) Rarely, crystals are completely triclinically twinned. Within a single specimen a limited range in the extent of twinning is commonly found.

Four determinations of the composition and structural state of the alkali feldspar were made using the method of Wright and Steward (1968). All samples had structural states intermediate between maximum microcline and high sanidine. The compositions of two of the samples based on the X-ray diffraction analysis is roughly $0r_{50}$ and $0r_{90}$. The other two samples have anomalous properties and their compositions could not be determined. Thus, both optical and X-ray properties establish that the alkali feldspar has a large range in composition and structural state.

Quartz

The quartz is anhedral, moderately fractured, and grains range in size from less than 1 mm. to greater than
Generally quartz is interstitial to alkali feldspar and plagioclase, but rarely it poikilitically encloses plagioclase, biotite, and hornblende. Quartz in and near aplite dikes is graphically intergrown with plagioclase and alkali feldspar. Quartz commonly shows strong undulatory extinction.

Accessories

The principal accessories are biotite, hornblende, sphene, magnetite, and apatite. Zircon is rare. Subhedral biotite occurring as grains ranging in size from less than 1 mm. to greater than 4 mm. is the most abundant accessory. Microfolds are common in biotite. Plagioclase is rarely poikilitically enclosed in biotite. Subhedral to euhedral green hornblende ranges in size from less than 1 mm. to greater than 3 mm. This hornblende is commonly poikilitically enclosed in quartz and alkali feldspar. Subhedral to euhedral sphene and magnetite are common in most thin sections. Apatite occurs as euhedral crystallites in other minerals.

Wallrock alteration associated with four veins in the Elkhorn mining district was studied. Thin section examination of drill core was supplemented with X-ray diffraction methods as described by Roy (1968). It was found that the nature and extent of alteration of the host rock adjacent to quartz veins is highly variable; however, three distinct
zones generally can be recognized.

In the outermost alteration zone plagioclase, biotite, hornblende, magnetite, and sphene are altered. Alkali feldspar is not altered. The granodiorite in general is slightly to moderately fractured. The intensity of the alteration appears to be directly proportional to the degree of the fracturing of the rock. Some plagioclase is completely altered to kaolinite but most show alteration of a particular composition zone or, rarely, of the core. (Plate 7) Plagioclase poikilitically enclosed in alkali feldspar is altered along fractures common to both minerals, but the alkali feldspar is unaltered. There is incipient alteration of hornblende and primary biotite. Hornblende alters to chlorite and, rarely, to secondary biotite. Primary biotite is altered marginally and along cleavages to chlorite. Magnetite commonly is rimmed and replaced by pyrite. Leucoxene occurs along fractures in sphene, and it also occurs with pyrite along cleavage traces of altered biotite. Where plagioclase is completely altered to kaolinite, medium grained muscovite accompanies chlorite as an alteration of biotite and hornblende.

The extent of the outermost alteration zone is highly variable. It depends on the degree of fracture of the country rock and the size and proximity of the veins. Kaolinization is observed in thin section of rocks as much as 25 meters above the veins. The average distance of the outermost zone from the veins is about 12 to 16 meters.
Plate 7. Photomicrograph of the selective alteration of zones in plagioclase.
Alteration in the intermediate zone is more uniform and pervasive. Plagioclase is altered to fine-grained muscovite. Pseudomorphs of muscovite after plagioclase are common in thin section. Biotite and hornblende are altered to coarse muscovite with pyrite and leucoxene along cleavage traces. These alteration minerals occur as pseudomorphs after the primary minerals. Magnetite and sphene are completely altered to pyrite and leucoxene along cleavage traces. These alteration minerals occur as pseudomorphs after the primary minerals. Magnetite and sphene are completely altered to pyrite and leucoxene, respectively. Although poikilitic plagioclase, biotite, sphene, and hornblende in alkali feldspar are completely altered, the alkali feldspar is unaltered. (Plate 8) In some perthitic alkali feldspar the albitic lamellae have been selectively altered to muscovite.

Within the innermost alteration zone the wallrock has two distinct textures. The altered rock in the outermost area of the inner zone retains the texture of the original country rock. Quartz replaces the fine-grained muscovite pseudomorphs after plagioclase and partially replaces alkali feldspar. Coarse-grained muscovite pseudomorphs after biotite and hornblende also are partially replaced by quartz. Both "silicified" pseudomorphs are in a matrix consisting of primary quartz and alkali feldspar, which also is partially replaced by secondary quartz.
Plate 8. Photomicrograph of pseudomorphs of kaolinite after plagioclase in unaltered orthoclase.
The altered rock adjacent to the vein lacks the texture of the original granodiorite. Mineralogically, the rocks consist primarily of quartz and fine-grained muscovite. Veinlets of quartz are abundant, and quartz commonly cements and replaces brecciated and sheared wallrock. In some rocks secondary quartz is graphically intergrown with massive fine-grained muscovite. Rarely, finely brecciated quartz is found in a matrix of fine-grained muscovite.

Other minerals present in the innermost alteration zone include: adularia, epidote, and a pink carbonate. Euhedral adularia with the optic properties of sanidine is present in some of the rocks. Some margins of the adularia appear resorbed and replaced by quartz. The carbonate was identified by X-ray to belong to the dolomite-rhodocrosite series. It occurs in veinlets and is disseminated in the rock. Epidote is a rare alteration product.

In one core a different type of altered rock was found. This rock is olive-green as a result of plagioclase being completely altered to chlorite. In contrast, the alkali feldspar is relatively fresh. This rock was found over about 20 meters between the outermost zone and the intermediate zone. In cores it appears sheared, and as a result was erroneously listed as fault gouge in some of the core logs. Thin sections showing the fresh alkali feldspar establish that either this chloritized rock is not gouge or that there has been a period of mineralization after faulting.
VEINS

General Statement

Thirty-six quartz veins, forming two sets, are within an area 1.2 km by 2.4 km (Melrose et al., 1974). (figure 3) The principal veins are all in one set which strikes approximately N.50°E. and dips steeply to the southeast. These veins are the Storm, Park, Arora, Blue Eye Anni, Montreal, Blue Jay, Idanna, Ram, St. Louis, and Homestake. The less developed veins strike approximately east-west and dip steeply to the north or south. These veins include the Simpson, Old Elkhorn, Lynx, Copper Queen, Central, Lost Cloud, and Aspen. The average length of the veins in the district is about 210 meters; however individual veins have been mapped for 500 meters. The veins range in width from 1 to 7.5 meters. Diamond drilling shows that the vein widths and dips vary with depth.

Generally, good outcrops of veins are available as a result of development and because they are more resistant to weathering than the country rock. The veins consist primarily of coarse crystalline, massive quartz. Vugs and cavities are rare. On the surface the veins are heavily iron-stained with well developed leached-sulphide boxworks. Drill cores show that oxidation and leaching have taken place to a considerable depth. White quartz is commonly brecciated and cemented by fine-grained, grey quartz and sulphides. The ore minerals are disseminated, or they
occur in clots or veinlets. This distribution commonly
gives the veins a spotted and banded appearance.

Four types of vein samples were collected. These are
samples from ore bins and dumps presumably from the under-
ground workings on the 300- and 1000-foot levels, dump
samples from numerous prospect pits and other surface work-

Park Vein

The Park vein strikes approximately N.43°E., dipping
66° to the southeast. It is about 5 meters wide and 195
meters long. The vein is heavily Fe-stained with well
developed boxwork quartz and massive pyrite. Samples from
the Park vein include samples from ore bins and chip samples
from the vein. The primary ore minerals include huebnerite,
tennantite, galena, sphalerite, and chalcopyrite. Common
secondary ore minerals are covellite, chalcocite, and
copper carbonates. Quartz, pyrite, and rhodocrosite are
common gangue minerals.

Huebnerite is common in specimens from the dumps and
in chip samples from the vein. It occurs as finely dis-
seminated crystals and also as brecciated crystals. The
breccia fragments are most common. Polished sections show huebnerite to be heterogeneous; but, based on the X-ray and optics, most is the manganese-rich end member. Domains of individual crystals have the optical properties of the more Fe-rich wolframite, particularly along grain boundaries and fractures. Tests by Bethlehem Steel Corporation using the electron microprobe have previously shown Fe-rich domains in huebnerite from the Storm vein. In polished section huebnerite is always brecciated and commonly occurs with medium to finely brecciated quartz. It is commonly associated with coarse sphalerite, but it is rarely included in the sphalerite. (Plate 9) Brecciated huebnerite is commonly cemented by and in some regions replaced by sphalerite. Huebnerite is also veined by quartz, galena, and tennantite. Pyrite also occurs adjacent to huebnerite, generally with mutually interfering boundaries.

Sphalerite is very common in hand specimens from the veins. X-ray diffraction, according to the method described by Skinner (1959), indicates that sphalerite contains less than 5 mole % FeS. It occurs as disseminated grains or clots. It is intimately related with other sulphides, particularly galena. In polished section, sphalerite is generally free of inclusions; however, some sphalerite is choked with inclusions of pyrite and chalcopyrite. (Plate 10) Sphalerite appears to be veined and replaced by both galena and tennantite. (Plates 11 and 12) Rarely, sphalerite included in tennantite is veined by chalcopyrite.
Plate 11. Photomicrograph of sphalerite veined and replaced by tennantite.
Plate 12. Photomicrograph of sphalerite replaced by galena and tennantite.
Tennantite is probably the most abundant ore mineral in the Park vein. X-ray diffraction and optical properties indicated that it is very close to the arsenic-rich end member of the tetrahedrite-tennantite series. The tennantite occurs as fine disseminated crystals or as clots or veinlets. Tennantite clearly crosscuts and replaces sphalerite and pyrite. (Plate 13) Although it cements brecciated quartz fragments, it is also veined and replaced by quartz. Covellite and chalocite are associated with that tennantite which is being replaced by quartz. Although galena generally appears to be replaced by tennantite, definitive relations are rare. Rhodocrosite is commonly associated with tennantite.

Galena is ordinarily associated with massive sulphides, and it rarely occurs as discreet veinlets or clots. Some galena appears to be deformed. In polished sections; galena is intimately associated with sphalerite and tennantite. Definitive textural relations show that galena replaces tennantite and pyrite. Chalcopyrite occurs as blebs in galena, including in the galena blebs in pyrite.

Storm Vein

The Storm vein is the principal vein of the district, striking N.40°E. and dipping steeply to the southeast. It is approximately 500 meters long and 5 meters wide. It consists primarily of massive, white quartz; however, the
Plate 13. Photomicrograph of sphalerite and pyrite replaced by tennantite.
white quartz is commonly brecciated and cemented by fine-grained grey quartz and sulphides. Due to development work, the vein is well exposed along its entire length. Outcrops are heavily Fe-stained with abundant leached-sulphide boxworks. Diamond drilling shows that the vein is leached to a considerable depth.

Samples of vein material studied include dump samples, chip samples, and core samples. The primary ore minerals include members of the wolframite series, sphalerite, galena, tennantite, chalcopyrite, and a ruby silver. Covellite, chalcocite, azurite, and malachite are common secondary minerals. Beudantite, a lead-iron-arsenic sulfate, and stetfeldite, a silver-antimonate, were identified by X-ray diffraction. These minerals are oxidation products on vein outcrops, occurring along fractures and as crusts on leached sulphide boxworks. Quartz, pyrite, fine-grained muscovite, and clay are common gangue minerals. In addition, Bethlehem Steel Corporation identified the following minerals from the same vein: scheelite, raspite or stolzite, argentite, and cuprite. Silver was also observed by microprobe in coatings on pyrite; however the mineral form is undetermined. Fluorite and goethite were identified as gangue minerals.

Minerals of the wolframite series are the most common ore minerals in dump and chip samples from the vein. They occur as discreet bladed, anhedral crystals in white quartz.
There are also clots of coarse brecciated wolframite associated with sphalerite and brecciated quartz. Wolframite is altered marginally along fractures to ferberite. X-ray diffraction and optics show that wolframite from the surface samples of the Storm vein is more Fe-rich than the wolframite from the Park vein. Wolframite in core samples is more Mn-rich than the surface samples from the same vein.

In general, wolframite from the Storm vein is highly brecciated and associated with coarse sphalerite. It is rarely included in sphalerite. Coarse wolframite and sphalerite occur sporadically as breccia fragments in a matrix of fine-grained grey quartz and brecciated pyrite. Rarely, wolframite shows deformed cleavage traces. Galena, tennantite, chalcopyrite, and pyrite occur along cleavage traces of wolframite. Some wolframite is replaced by quartz.

Sphalerite is abundant and usually associated with brecciated wolframite. It also is disseminated in white quartz. X-ray methods show the sphalerite to contain less than 5 mole % FeS. Although sphalerite with wolframite occurs as breccia fragments in a matrix of quartz and brecciated pyrite; rarely, sphalerite cements brecciated pyrite. Sphalerite encloses tennantite, galena chalcopyrite, and pyrite. Some galena and tennantite replace
sphalerite, and rarely sphalerite replaces pyrite. Covellite and chalococite are common secondary minerals encrusting fractures in sphalerite. Sphalerite is rarely replaced by chalococite along cleavages. A ruby silver is included in sphalerite. (Plate 14) Optical properties suggest it is either pyrargyrite or proustite; however, since a silver-antimonate is a common oxidation mineral, it is probably pyrargyrite.

Galena occurs as disseminated grains and clots associated with brecciated white quartz. It commonly forms the matrix of finely brecciated quartz and pyrite. Blebs of galena are common in wolframite, sphalerite, and pyrite. Galena replaces tennantite. Chalcopyrite commonly occurs as blebs in galena.

Blue Eye Anni

The Blue Eye Anni vein and associated veinlets lie west of the other principal veins in the district. (Figure 3) It is approximately 300 meters long and 2 meters wide. Because of poor exposures, chip samples were not taken; however, dump samples and core samples were studied. Core samples show the vein to be white quartz that is highly sheared and cemented by fine fragments of grey quartz and sulphides. The primary ore minerals are wolframite, sphalerite, tennantite, galena, chalcopyrite, enargite, and a ruby silver. Pyrite and rhodocrosite are common gangue minerals.
The mineralogy and textural relationships of the minerals in polished section are similar to those described in the Park and Storm veins; however, there are some differences. Wolframite was not found in the main vein but was present in the veinlets. It also is sparsely disseminated in the altered wallrock immediately adjacent to the veinlets. The sphalerite of the Blue Eye Anni contains about 12 mole % of FeS, roughly twice that of the sphalerite from other veins. Sphalerite and pyrite formed early and were later brecciated and replaced by galena, tennantite, and chalcopyrite. Chalcopyrite is much more abundant in the Blue Eye Anni, and sphalerite commonly is choked with chalcopyrite inclusions. These inclusions are interpreted as a replacement rather than an exsolution feature because of heterogeneous distribution of the inclusions and cross-cutting relations.

The age relations between chalcopyrite, galena, and tennantite are not well defined. Galena veins rhodocrosite and replaces tennantite, and rarely tennantite veins and replaces galena. Tennantite veins chalcopyrite in cavity fillings, but brecciated tennantite is replaced along cleavages by chalcopyrite. Chalcopyrite generally veins sphalerite separating it from galena and tennantite that appears to be replacing the sphalerite. Chalcopyrite occurs as blebs in galena and pyrite, and enargite occurs as blebs and veinlets in chalcopyrite.
Montreal Vein

The Montreal vein lies at the eastern edge of the district. (Figure 3) It strikes approximately N*45°E. and dips steeply to the southeast. The vein is about 325 meters long. However, if the Montreal Extension vein, or Arora vein, is included, the total length would be 600 meters. Samples studied from the vein include chip, dump, and core samples. The principal ore minerals are huebnerite, sphalerite, tennantite, and ruby silver. Minor ore minerals are galena and chalcopyrite. Copper carbonates are common secondary minerals. Pyrite and fine-grained muscovite are common gangue minerals.

Samples from the surface and at depth all show the white quartz to be highly brecciated and cemented by a dark fine-grained material. Polished sections show very finely brecciated quartz, huebnerite, sphalerite, tennantite and ruby silver cementing larger fragments of white quartz. In some areas fine-grained muscovite and clay are abundant in the matrix.

The ore minerals are highly brecciated, and as a result optical properties and textural relations are difficult to determine. Huebnerite is heterogeneous as shown by differences in color as viewed in polished sections. Breccia fragments are darker and therefore more Fe-rich along the margins. Optically, sphalerite contains few inclusions and it appears to be Fe-poor. A ruby silver
occurs as finely brecciated grains and rarely replaces sphalerite. Brecciated pyrite is cemented and replaced by tennantite. Galena is sparsely distributed as breccia fragments. Following the cessation of mineralization, there was a final period of brecciation.

Other Veins

Samples from the Blue Jay, Lost Cloud, Old Elkhorn, and Simpson veins include dump and chip samples. These were studied by using polished sections and mineral identification was confirmed by use of X-ray diffraction.

Dump samples from the Blue Jay vein show highly brecciated white quartz cemented by dark, fine-grained quartz and ore minerals. The principal ore minerals are sphalerite, tennantite, and galena. They occur as cavity fillings and disseminated in quartz filling around the clasts of quartz. No wolframite was found. Sphalerite is replaced by both galena and tennantite. Tennantite is replaced by galena.

There are many secondary ore minerals associated with the dark, fine-grained material cementing the brecciated white quartz. Native copper occurs with cuprite as dendrites and cavity fillings. Native silver encrusts and replaces digenite. Minor argentite occurs with digenite and is replaced by native silver.

Samples studied from the Lost Cloud, Simpson, and Old Elkhorn included dump and chip samples. White brecciated
quartz is cemented by dark, fine-grained brecciated quartz and ore minerals. The Lost Cloud, Simpson, and Old Elkhorn all have disseminated grains of tennantite and sphalerite. These ore minerals also occur as cavity fillings. Many Lost Cloud samples are leached with well developed boxworks. Beudantite from the Lost Cloud vein previously identified by the Bethlehem Steel Corporation was confirmed by X-ray diffraction. This mineral is a lead-iron-arsenic sulfate. Samples from the Old Elkhorn vein have cavity fillings and veinlets of huebnerite in white quartz. There are no sulphides associated with the huebnerite.

PARAGENESIS

Minerals of the wolframite series crystallized in white massive quartz. These tungsten minerals occur as veinlets, disseminated grains, and cavity fillings; and they formed earlier than all other ore minerals. The wolframite was brecciated before sphalerite crystallized. Sphalerite veins and encloses brecciated wolframite, and it forms cavity fillings in brecciated white quartz. Massive pyrite accompanied the sphalerite, and some pyrite crystallized with wolframite. Chalcopyrite, tennantite, and galena are intimately related. Most galena postdates tennantite and rhodocrosite, and most tennantite and enargite crystallized after chalcopyrite. The ruby silver appears to be hypogene. It is included in sphalerite and rarely replaces sphalerite. It occurs along with the other common ore minerals in brecciated veins and is absent in
rocks containing typical secondary minerals. The common secondary minerals are: argentite, digenite, chalcocite, covellite, cuprite, native copper, and native silver. Beudantite and stetfeldite occur in leached-sulphide boxworks. Paragenetic relations are summarized in figure 4.

Based on their mineral assemblage, the Elkhorn veins would belong to Lindgren's hypothermal class of ore deposits; however, the assemblage tennantite-enargite-ruby silver may indicate a transition to the mesothermal class. Although the sphalerite in the Elkhorn veins has a low Fe-content, the absence of pyrrhotite in the veins makes the sphalerite geobarometer-geothermometer unapplicable. The veins differ from the typical quartz fissure veins with well developed crustification and comb structures. The veins are characterized by shearing parallel to the vein and most of the gangue and ore is shattered. The origin of the tungsten mineralization is considered in an overview of tungsten mineralization in southwest Montana in the **Discussion**.

**DISCUSSION**

**Pioneer Batholith**

Several aspects of the nature of the Pioneer batholith must be discussed before considering the origin for the mineralization. These include the contact relations within and around the batholith, the areal extent of the host rock in the Elkhorn district, and the age of the Elkhorn veins.
Figure 4. Paragenesis of the ore and gangue minerals of the Elkhorn mining district.
The manner of emplacement of the Pioneer batholith is important in evaluating the origin of known tungsten-bearing quartz veins within the batholith and tectite occurrences along the eastern margin. Harrison (1974) proposes that the tectonic setting of the Belt basin influenced the emplacement of Late Cretaceous intrusives in southwestern Montana. The Pioneer batholith lies immediately west of his "Dillion Block" (Figure 5). This block of pre-Belt metamorphic rocks was a stable buttress while the area west and north of the block underwent intermittent subsidence. Although overlapping periods of tectonism, plutonism, and volcanism occurred in southwestern Montana during Late Cretaceous (Robinson et al., 1968) thrusting of Belt and younger rocks may have preceded the intrusion of the Pioneer batholith. Fraser (1972) reports that Tertiary intrusives in the Wise River area (Figure 2) were emplaced along and beneath thrust plates of Belt rocks. The thrusts at Wise River override Cretaceous sediments. To the south, Harrison (1974) interpreted characteristics of the Belt rocks described by Myers (1952) on the eastern margin of the batholith. He concluded that these Belt rocks were tectonically transported 160 km. from the west.

Little has been published concerning the nature of the contact of the batholithic rocks with the Belt rocks on the western margin. These Belt rocks are undifferentiated,
Figure 5. Tectonic setting of the Belt basin (after Harrison, et al., 1974).
carbonate-bearing, metasediments of the Missoula Group (Ross, 1963). Geach (1927) considers the intrusive in the Wisdom area (Figure 2) to be separate from the Pioneer batholith. Although no large scale thrust sheets have been mapped, the possibility of intrusive activity beneath thrust sheets along the western margin of the batholith should be considered.

Intrusive relations of the batholithic rocks within the Pioneer batholith have not been established. Zen (1975) reports that the batholith is composite with at least eight rock types. The areal extent of the granodiorite in the Elkhorn district is not known. This rock has some distinctive characteristics. For example, thin sections of the rock show highly resorbed, sheared and fractured plagioclase. Some zoned plagioclase appear partially "annealed". Large poikilitic potassium feldspars have a range of structural states, composition, and degrees of unmixing. These characteristics may be the result of several events, for example: 1) mineralization of the veins or 2) emplacement of a later intrusive. Tilling (1968) described variations in the structural state and degree of unmixing of alkali feldspars in the Radar Creek pluton. He proposed that this was the result of disequilibrium cooling and a secondary adjustment of the structural state by reheating the pluton by the intrusion of the Butte quartz monzonite.
Age dates of rocks from the Pioneer batholith (Zen, 1975) show that there was intrusive activity from 76.5 to 70 my. ago. This activity was associated with the formation of the batholith. There was also a Tertiary thermal event responsible for the intrusive and volcanic rocks near the batholith. The mineralization of the Elkhorn veins could be related to activity in either of these periods. Potassium-argon age dating of both the host rock and secondary biotite from close to the veins would establish whether a Tertiary or older event was responsible for mineralization.

Tungsten Mineralization

In evaluating the Pioneer batholith as an exploration area for tungsten mineralization, the distribution and nature of the known tungsten occurrences must be considered. Pattee (1960) described the tungsten deposits of the batholith (Figure 6); however, no conclusions were presented concerning the origin or emplacement of mineralization. Most of the occurrences are small tactite bodies associated with Paleozoic and Mesozoic carbonates. Scheelite and powellite are the principal tungsten minerals. Besides the veins at Elkhorn, only one other quartz fissure-vein with tungsten minerals occurs. This vein is north of the Elkhorn district. It strikes to the northeast and dips steeply to the southeast, as do the major Elkhorn veins. Wolframite and scheelite occur in the vein. Descriptions of the tungsten
Figure 6. Tungsten occurrences of the Pioneer batholith.
occurrences in the batholith by Pattee (1960) and Geach (1972) suggest that the deposits are associated with granodiorite; although quartz monzonite is present.

Most of the tungsten deposits in and around the Pioneer batholith occur along drainages. This may be fortuitous or simply result from better exposures in these areas. There may be some structural control of the drainages. The faults shown in figure 6 are compiled from the maps of Myers (1952), Ross (1963), and Scholten (1968). The occurrence of tungsten mineralization appears to be related to faults. One set of faults has a north-south trend, as the Comet fault at Elkhorn. The other set of faults trend northeast to southwest. In the Elkhorn district the veins lie west of the north-south trending Comet fault. No significant mineralization occurs within the batholith to the east of Elkhorn. However, there are tantalite bodies along the eastern margin of the batholith. The faults postdate the veins. Therefore, both the faults and the veins are products of some unknown structural control. However, this does not negate the potential usefulness of faults as a guide to mineralized areas.

CONCLUSIONS

The intrusive rock in the Elkhorn district is a biotite hornblende granodiorite. It has undergone a complex history. This involved fractional crystallization of plagioclase as shown by the cores being strongly
zoned and the rims being weakly zoned. Then there was formation of large poikilitic potassium feldspar. The rock has been fractured and sheared. A later thermal event altered the structural state of the alkali feldspar and partly annealed the zoned plagioclase. This thermal event may be related to another intrusive or possibly with the tungsten mineralization. This resulted in the secondary adjustment.

Of the two sets of quartz fissure veins present in the district, the principal northeast trending veins are parallel to the northeast-southwest faults. The east-west veins cannot be related to other structural features in the batholith. The Comet fault postdates the formation of the veins, and it is also related to the north-south structural trend.

The tungsten bearing minerals, huebnerite and wolframite, crystallized early in the history of the veins. Sphalerite, ruby silver, chalcopyrite, tennantite, and galena were later. Secondary enrichment resulted in crystallization of argentite, digenite, cuprite, native copper, and native silver. Several episodes of brecciation and shearing during mineralization imparting a banded appearance to the vein material. The brecciated vein material is cemented by finely brecciated and sheared quartz, pyrite, and ore minerals. These ore minerals are those that were present in the vein prior to shearing and
minerals associated with the shearing. High tungsten veins cannot be related to other structural features in the batholith. The Comet fault postdates the formation of the veins, and it is also related to the north-south structural trend.

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Wallrock alteration in the Elkhorn district is variable in composition and extent. It consists of kaolinite, muscovite, quartz, and rare secondary potassium feldspar. Selective alteration of plagioclase in the wallrock suggests that the ore-forming solution was saturated with respect to potassium feldspar but deficient relative to the plagioclase.
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VITA

Andrew Leo Hardiman was born on January 20, 1950. He received his primary and secondary education in the Philadelphia area and graduated from Bishop McDevitt High School in 1967. In June of 1967 he entered LaSalle College in Philadelphia. He married Terry Ann Taylor of Jenkintown, Pennsylvania, in 1970. In 1973 he received a B.A. in Earth Science from LaSalle College. He entered the Graduate School at Lehigh University in September, 1973. He was a teaching assistant at Lehigh from 1973 to 1975. In the summer of 1974 he was an assistant field geologist in Southwest Montana for Bethlehem Steel Corporation. He received his M.S. in Geology in 1975. In June of 1975 he began work as a geologist for the California Division of Chevron Oil Company in New Orleans, Louisiana.