



Controls on ore deposition, Polaris mining district, Pioneer Mountains, Beaverhead County, Montana  
by Thomas Edward Davis

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE  
in Earth Sciences

Montana State University

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Abstract:

The Polaris silver mining district is located along the southern margin of the Cretaceous Pioneer batholith. The silver ore replaces Mississippian age Madison Group limestone though in other districts of the Pioneer region Cambrian carbonates may also be mineralized. Other stratigraphic units present in the Pioneer district are the Precambrian Missoula Group and the Cambrian Meagher, Park, and Pilgrim Formations.

These strata underwent six stages of faulting, probably during the Laramide orogeny. In chronological order, the fault systems strike: N 33° W; N-S; E-W; N 60° E; N 40° E; and N-S. A N-S fold set formed after the first stage of faulting, and an E-W fold set developed after all faulting. A third folding episode, evident only underground, has folded the Polaris (N 60° E) fault.

The batholith intruded passively after the fifth and perhaps after the sixth episode of faulting. Ore mineralization is presumed to have followed intrusion of the batholith, at least of its deeper levels, by analogy with other ore districts in the Pioneer region. Ore replaces Madison Group limestone along N 60° E faults; only these faults were open at the time of mineralization since they were parallel to the direction of maximum stress.

In the Polaris Mine, the principal mine of the district, the paragenetic sequence of mineralization is: pyrite, sphalerite; galena; pyrargyrite(?); and native silver.

Quartz is the principal gangue mineral; limestone in ore-bearing areas is stained dark brown. Zoning of metals within the Polaris Mine from surface downward is: (1) Cu-Ag; (2) Ag; (3) Pb-Zn-Ag. Ore is deposited for several feet into the Madison limestone from the Polaris fault. High grade orebodies (averaging 40 oz/ton Ag) are disc-shaped and appear controlled by breccia zones formed at the intersections of the Polaris fault with E-W and N 45° W faults.

Future exploration in the district should emphasize | (1) Madison limestone where adjacent to a N 60° E fault, and (2) skarn zones in the Madison formed by metasomatism from the batholith. Included in Category (1) are the lower workings of the Polaris Mine, the Silver King Mine, and two newly discovered N 60° E faults. Metals to be prospected for are Ag and Pb in Category (1) settings and Ag-W-Mo in the Category (2) environment.

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PIONEER MOUNTAINS, BEAVERHEAD COUNTY, MONTANA

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A thesis submitted in partial fulfillment  
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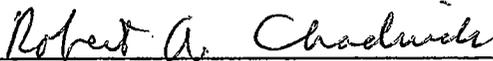
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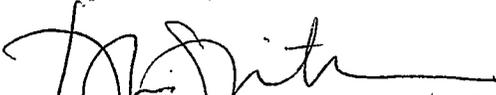
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## ABSTRACT

The Polaris silver mining district is located along the southern margin of the Cretaceous Pioneer batholith. The silver ore replaces Mississippian age Madison Group limestone, though in other districts of the Pioneer region Cambrian carbonates may also be mineralized. Other stratigraphic units present in the Pioneer district are the Precambrian Missoula Group and the Cambrian Meagher, Park, and Pilgrim Formations.

These strata underwent six stages of faulting, probably during the Laramide orogeny. In chronological order, the fault systems strike: N 33° W; N-S; E-W; N 60° E; N 40° E; and N-S. A N-S fold set formed after the first stage of faulting, and an E-W fold set developed after all faulting. A third folding episode, evident only underground, has folded the Polaris (N 60° E) fault.

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In the Polaris Mine, the principal mine of the district, the paragenetic sequence of mineralization is: pyrite, sphalerite; galena; pyrargyrite(?); and native silver. Quartz is the principal gangue mineral; limestone in ore-bearing areas is stained dark brown. Zoning of metals within the Polaris Mine from surface downward is: (1) Cu-Ag; (2) Ag; (3) Pb-Zn-Ag. Ore is deposited for several feet into the Madison limestone from the Polaris fault. High grade orebodies (averaging 40 oz/ton Ag) are disc-shaped and appear controlled by breccia zones formed at the intersections of the Polaris fault with E-W and N 45° W faults.

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## INTRODUCTION

### Purpose

The Pioneer Mountains are a major region of ore production, but few mining districts within it have been studied in detail. The purpose of this study is to determine the structural and chemical controls on ore deposition within one of these mining districts, the Polaris mining district. Favorable areas for future exploration are recommended based upon the results of this study.

### Access and Location

The Polaris mining district is located 42 miles west of Dillon, Montana on the western flank of the Pioneer Mountains, Beaverhead County, Montana (Figure 1). This district is an area of  $2\frac{1}{4}$  square miles comprising a portion of the Billings Creek drainage and part of the Farlin Creek drainage.

The major access is via a 2 mile long dirt road which follows Billings Creek north from the town of Polaris. The road is kept open year round by the present mining operation at the Polaris mine.

### Climate and Topography

In the area of the Polaris mine, access is governed by the elevation and the climate. The climate in the vicinity of Polaris, Montana is semiarid with temperatures ranging

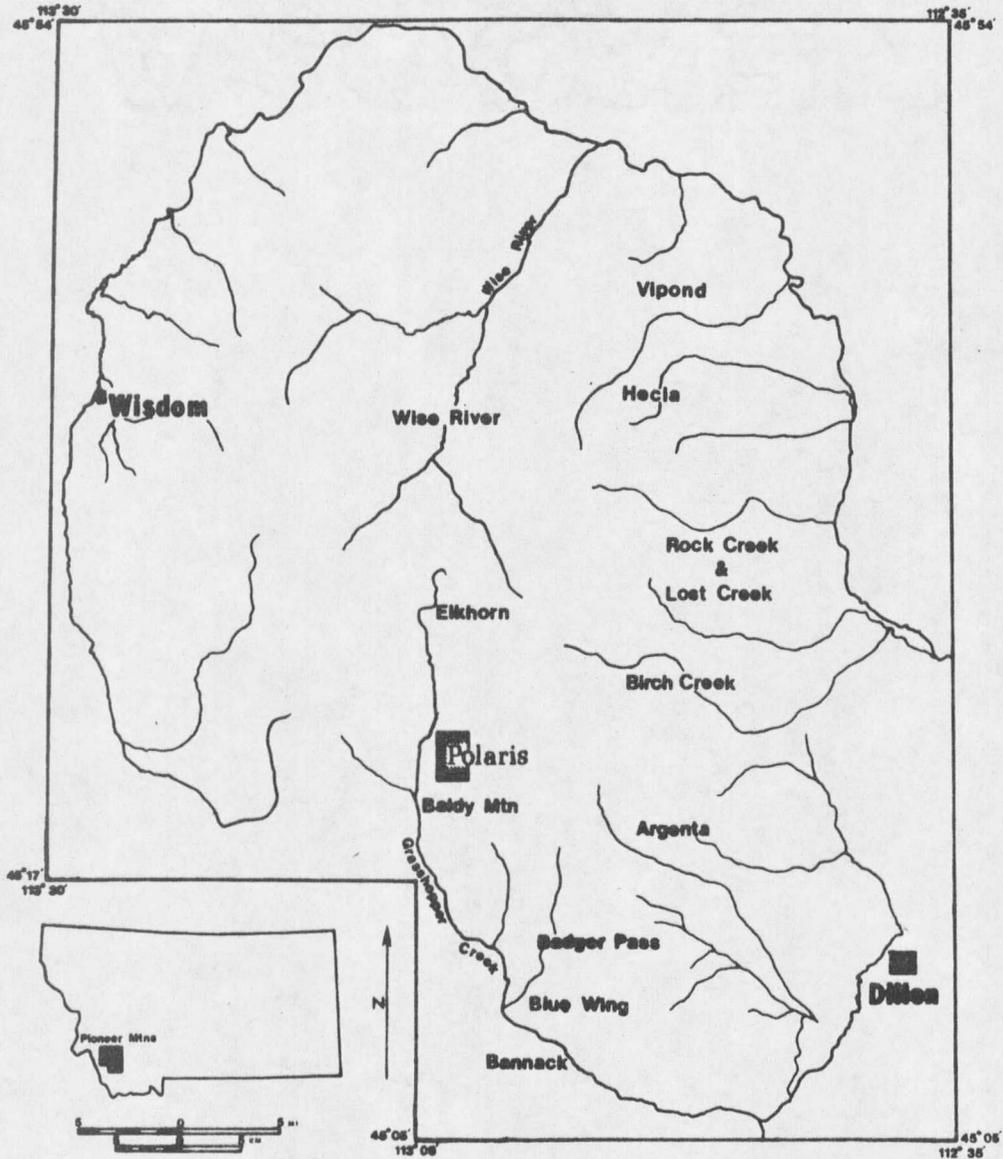


Figure 1. Index map showing the location of mining districts in the Pioneer Mountains. Study area is shaded as are the towns of Dillon and Wisdom.

from 100°F in the summer to -40°F in the winter (Geach, 1972). Snow can be a problem as early as September, but it does not usually remain on the ground until late October or early November. Snow frequently remains on forest-covered, northern slopes until May, at which time the snow rapidly melts. Southern slopes, which are covered with sagebrush, can be snowfree year-round during mild winters. Precipitation is highest from April to July and is lowest from November to February (Geach, 1972).

The elevation of the region around the Polaris mine rises from 6,400 feet at Grasshopper Creek to 10,568 feet on the top of Baldy Mountain. The Polaris mining district is from 6,500 feet to 7,900 feet elevation.

The region around Polaris is composed of east-west and northeast-southwest trending valleys and ridges. The major stream valleys are linear, but the tributaries are randomly oriented so that the overall drainage pattern is dendritic. The slopes rising eastward from Grasshopper Creek have the appearance of a dissected pediment.

#### History and Production

The Polaris mine deposit was discovered in 1883 and by 1885 the principal quartz claims were located (Corry, 1918). Ore was first hauled by ox team to Fort Benton and then

shipped by boat to the east; some ore went to Swansea, Wales (Pardee, 1933).

In 1886 the Polaris mine was reported to have produced \$60,000 worth of silver (Corry, 1918). However, Winchell (1914) believed that the \$60,000 was produced from the Silver Fissure mine and not the Polaris mine. Twenty men operated the Polaris mine at this time, and they sunk a shaft that was 200 feet long (Geach, 1972).

In 1891, the Polaris Mining and Milling Company purchased the mine and drove the lower Polaris adit to a length of 2,300 feet, which was about 600 feet in elevation below the vein outcrop. Drifts were driven on the adit level and an inclined raise connected the older upper workings with the adit. By the time the company ceased operations in 1901(?), \$250,000 worth of ore had been mined (Geach, 1972).

The property was later acquired by J. E. Morse at a sheriff's sale and sold in 1905 to the Silver Fissure Mining Company (Geach, 1972). This company built a 100-ton smelter, quarters for miners, an assay office, a business office, storage houses, and other facilities (Corry, 1918). Due to an insufficient supply of ore the smelter was in operation for less than one year.

Lease holders worked the property until 1918, when it

was leased to the similarly-named Silver Fissure Silver Mining Company (Geach, 1972). Reserves were reported by a mining consultant, Arthur Corry, to be 69,000 tons of ore containing 1,500,000 ounces of silver and 1,300 ounces of gold. The company erected a 50-ton mill employing chloridizing roasting and hyposulfite leaching of the ore. Small shipments were made in 1919 and in 1922, but operations by the company ceased soon thereafter.

Production for the property was small and sporadic until 1959. Lee James of Polaris maintained production from a surface cut (Geach, 1972) until 1968 when the Midnight Mines Corporation leased the property. Since 1968 this corporation has opened up old workings on the 130-foot level and on the 260-foot level. Present operations are attempting to open up the 570-foot level to permit access to the lower workings. Table 1 shows production from the Polaris mining district between 1902 and 1965.

#### Previous Investigations

Very little geologic work has been done in this region until recently. In the last couple of years, a flurry of activity in the Pioneer Mountains has resulted from the rise in the price of silver, gold, and petroleum, as well as from proposals to classify the region as a wilderness.

Table 1

Production of Ore, Polaris District, 1902-65  
(After Geach, 1972)

Year	Ore (tons)	Gold (oz.)	Silver (oz.)	Copper (lb.)	Lead (lb.)	Zinc (lb.)
1902-07	none					
1908	11	65	2,811	2,204	----	----
1909	none					
1910	2	----	196	----	----	----
1911	none					
1912	51	8	4,309	628	----	----
1913	none					
1914	19	3	2,363	198	----	----
1915	10	1	1,223	125	----	----
1916	none					
1917	446	14	13,768	----	----	----
1918	193	15	12,035	3,680	----	----
1919	56	4	3,400	1,236	----	----
1920	87	6	5,239	1,299	----	----
1921	none					
1922	275	8	10,955	493	126	----
1923	none					
1924	3	<1	247	33	----	----
1925	1	1	11	----	----	----
1926-33	none					
1934	151	83	266	675	379	----
1935	85	19	1,056	747	4,450	----
1936	366	39	626	----	----	----
1937-38	none					
1939	8	----	436	----	----	----
1940	5	----	180	44	80	----
1941-51	none					
1952	32	4	157	75	1,105	----
1953-54	none					
1955	1	----	161	----	100	----
1956	26	1	2,274	200	1,700	900
1957	none					
1958	7	----	107	----	----	200
1959	29	----	165	----	----	----
1960	none					
1961	920	17	17,230	700	2,200	10,000

Table 1. (continued)

Year	Ore (tons)	Gold (oz.)	Silver (oz.)	Copper (lbs.)	Lead (lb.)	Zinc (lb.)
1962	481	9	4,673	1,600	----	----
1963	450	6	12,324	2,400	----	----
1964	588	5	11,673	2,300	----	----
1965	581	4	12,138	2,300	1,000	1,000
Total	4,884	312	120,023	20,937	11,140	12,100

In 1914, Winchell conducted a reconnaissance of the mining districts in the Dillon, Montana region. This general study provided only limited information for many of the mining districts.

In 1918, Arthur Corry visited the Polaris mine as a consultant. He estimated the ore reserves at the mine, but spent little time looking at the geology.

Pardee and Schrader (1933) reported on the Greater Helena mining region. They put together a history of structural geology, described the formations, and discussed the zoning within this region.

The physiography and the ground-water supply in the Big Hole Basin was studied by Perry in 1934. He summarized the order of landform development within this region.

Klepper (1950) conducted a structural and stratigraphic reconnaissance of parts of Beaverhead and Madison Counties, Montana, and reported upon the nonmetallic resources of these counties.

In 1953, Alden published his work on the physiography and glacial geology of western Montana. This paper contains sections dealing specifically with the Polaris region.

Breit (oral and written communications) prepared a geologic map during a geochemical study of the Polaris mining

district, which formed part of the East Pioneer Wilderness study of the U.S. Geological Survey (Berger and others, 1979).

Cox (oral communication) of the Montana Bureau of Mines and Geology is currently mapping the Polaris quadrangle.

### Methods

Field work was conducted in the spring and fall of 1979 and in the summer of 1980. Surface mapping utilized a base map with a scale of 1:8,000. The base map was enlarged from a U.S. Geological Survey T-type map of the Polaris quadrangle which had a scale of 1:24,000.<sup>1</sup> Underground mapping could only be done on the 260-foot level. The workings were mapped on a scale of 1:500 with a Brunton compass and a 30 meter cloth tape. Backsightings were taken with the Brunton compass in order to correct for the magnetic deviations occurring within the mine.

Rock samples were taken where available on the surface and in the mine. Nine polished sections and twenty thin sections were prepared in order to identify mineralogy and determine the paragenetic sequence. A scanning electron microprobe (Montana State University Physics Department) was

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<sup>1</sup>T-type map is an unpublished U.S. Geological Survey topography map.

used to determine the identity and distribution of the elements within the ore.

## REGIONAL GEOLOGY

### Regional Stratigraphy

The stratigraphy of the region in and around the Pioneer Mountains differs lithologically from that of most of Montana. The stratigraphy is described for the Pioneer region. Formations not found in the Polaris mining district are included, as a knowledge of the complete stratigraphic column is necessary for proper interpretation of field data (Figure 2).

The regional stratigraphy was compiled from many sources. References are stated at the start of the discussion of each formation, or included in the text where deemed appropriate.

Precambrian Belt. The Precambrian Belt Supergroup has not been studied in Beaverhead County in any detail. However, the Missoula Group is known to be present within the Pioneer Mountains (Myers, 1952; Geach, 1972).

Myers (1952) measured a thickness of 10,000 feet for the Missoula Group near Argenta, but observed that it rapidly thinned to 2,000 feet. The unit consists of a lower, red, cross-bedded, arkosic quartzite and an upper, light-colored quartzite (Geach, 1972).

The lower unit is the Bonner Formation, which consists of pink or red arkosic quartzite in beds ranging in thick-

System	Thickness (feet)	Formation or Group	Description
Cretaceous	1,000 +	Colorado Group	Gray, locally cross-bedded, arkosic sandstone and basal, black, shale.
	1,000 +	Kootenai Formation	Red, green, and maroon quartzites, argillites, and limestones. Basal pebble conglomerate.
Triassic	300 - 500	Dinwoody Formation	Light gray and brown, thin-bedded, silty, argillaceous limestone; brown siltstone; brown, fine-grained sandstone; and gray-green shales.
Permian	0 - 200	Phosphoria Formation	Upper bedded chert, middle oolitic phosphorite and lower quartz sandstones, dolomites, and cherts.
Pennsylvanian	several hundred	Quadrant Formation	Light yellow, medium-grained, well sorted, siliceous quartz sandstone. Some cherty dolomites.
	0 - 110	Amsden Formation	Upper thin-bedded, fossiliferous limestone. Lower bright red to purplish red shales, siltstones and shaley dolomites.
Mississippian	1500	Madison Group	Upper light blue to blue-black, very thick-bedded limestone; dolomitic towards top. Lower black, dense, thin-bedded, fragmental, cherty limestone. At Argenta lower unit is light gray, massive, coarse-grained limestone. Recrystallizes to white, coarse-grained limestone.
Devonian	145(?) to 221(?)	Three Forks Shale	Upper 1/3 of formation is a yellow and orange, sandy limestone and calcareous sandstones. Lower 2/3 is composed of gray-green, clayey shale and orange, yellow and maroon shaley dolomite and limestone.
	150 - 600	Jefferson Dolomite	Upper member is a dark gray, brown, blue, or black, fetid, saccharoidal, thin- to very thick-bedded dolomite. Lower member is a dark brown, dolomitic limestone.

Figure 2. Regional stratigraphy of the Pioneer Mountains. Compiled from varied published sources referenced in text.

System	Thickness (feet)	Formation or Group	Description
Cambrian	0 - 40	Red Lion Formation	Brightly colored maroon to yellow-brown dolomite and calcareous mudstones. Red and green shale is present.
	100 - 425	Pilgrim Formation	Buff, light gray, brown, gray, medium- to very thick-bedded dolomite. Sandy at top.
	0 - 150	Park Formation	Green-gray, purple-gray, brown-gray, micaceous shale. Interbedded with limestone or dolomite at top; may be composed of quartz sandstone. Metamorphoses to green-gray quartzite interbedded with brown clay laminae.
	0 - 600	Meagher Formation	Buff, light gray and white, thin- to thick-bedded dolomite. Shale or quartz sandstone found in upper part of formation. Metamorphoses to dolomitic marble with quartzite members. Sucrosic member near top; cliff-former.
	125 - 200	Wolsey Shale	Greenish gray, brownish gray or purplish gray shale. Brown-gray sandstone interbedded near base and brown-gray dolomite interbedded near top. Glauconite and chlorite common. Metamorphoses into quartzites and hornfelses.
	75 - 125	Flathead Sandstone	Dark purple and dark brown through pink, vitreous quartzite or quartz sandstone; grains are angular to subangular and medium to coarse-grained; thin- to medium-bedded. Glauconite common.
Pre-cambrian	2,000 to 10,000	Missoula Group	Upper green-gray argillite which contains mica and montmorillonite. Lower red, cross-bedded, arkosic quartzite. Beds are from 1 in. to 6 ft. thick.

Figure 2 (con't). Regional stratigraphy of the Pioneer Mountains. Compiled from varied published sources referenced in text.

ness from 1 inch to 6 feet. The formation exhibits a cross-bedding that is accentuated by color variations; indistinct light green layers and thin red argillite beds mark the bedding planes. Grain size ranges from  $\frac{1}{4}$  mm. to 12 mm. Some montmorillonite and illite are found in the quartzite (Smith, 1980).

The upper unit, the Garnet Range Formation, is a green-gray argillite containing notable quantities of detrital mica and montmorillonite (Smith, 1980).

Other Precambrian Belt formations are entirely absent from the Pioneer Mountains or are thin and rare. A total maximum thickness of 12,000 feet was given for the Precambrian Belt in this region (McMannis, 1965).

Flathead Sandstone. The Flathead Sandstone is of Middle Cambrian age and is generally 75 feet to 125 feet thick in the Pioneers; a 500-foot thick Flathead section occurs west of Argenta (Karlstrom, 1948; Sloss and Moritz, 1951; Hanson, 1952; McMannis, 1965). The Flathead rests disconformably upon the Precambrian Belt.

The color of the rock varies from dark purple-drab and dark brown through pink and light gray; the pink or brown color is commonly due to staining by iron oxides. The Flathead is a vitreous quartzite at Argenta, but at other areas

in the Pioneer Mountains it is a friable sandstone.

Grain size is from fine-grained to pebbly, though it is usually medium- to coarse-grained. Grains are angular to subangular except near the base where pebbles are rounded.

Strata in most places are very thin- to medium-bedded, although they locally range up to very thick-bedded. The beds containing pebbles are thin and lenticular, whereas the other beds commonly show cross-bedding and ripple-marks.

Quartz is the predominant mineral, but glauconite and hematite are common constituents. The grains are cemented with silica.

Wolsey Shale. The Wolsey Shale of Middle Cambrian age is typically 125 to 200 feet thick, though it is known to be absent in places within the Pioneer Mountains (Karlstrom, 1948; Sloss and Moritz, 1951; Hanson, 1952; McMannis, 1965). The Wolsey conformably overlies the Flathead Sandstone and is transitional with the Flathead.

The Wolsey Shale is a greenish gray, brownish gray, purplish gray, or maroon shale which is interbedded with brownish gray sandstone near the base of the formation and is interbedded with brownish gray dolomite near the top. The green color of the shale is caused by glauconite and chlorite.

The Wolsey is mostly a micaceous shale, but locally may be an arenaceous shale or an argillaceous sandstone. The middle of the formation in places contains a limestone member that can be up to 100 feet thick. At Hecla the Wolsey has been metamorphosed into phyllites and slates; the sandstone members are metamorphosed into quartzites and the impure calcareous members are metamorphosed into hornfels. The Wolsey Shale forms soil-covered slopes or occupies stream valleys.

Meagher Formation. The Meagher Formation is of Middle Cambrian age and it varies from 0 to 600 feet thick (Karlstrom, 1948; Sloss and Moritz, 1951; Hanson, 1952; McMannis, 1965). The Meagher Formation rests conformably upon and is transitional with the Wolsey Shale.

The Meagher Formation, which is a limestone throughout most of Montana, is a dolomite west of Dillon, Montana. The Meagher is buff, light gray and white, is thin-bedded to very thick-bedded, and is composed of interbedded shale and dolomite at the base. The middle of the Meagher commonly exhibits a thin-bedded or shaly interval, and the top of the Meagher is interbedded with greenish gray, micaceous shale. At Hecla, the Meagher is a dolomitic marble with quartzite members.

Dolomitization of the Meagher has obscured or has destroyed the typical "black and gold" mottling. The Meagher is commonly found as a cliff or ridge former.

Park Formation. The Park Formation is of Middle Cambrian age and is from 0 to 150 feet thick. It conformably overlies and is transitional with the Meagher Formation (Karlstrom, 1948; Sloss and Moritz, 1951; Hanson, 1952; McMannis, 1965).

The Park is a greenish gray, purplish gray, brownish gray or tan, fissile, micaceous shale with intercalated beds of dolomite at both the top and bottom of the formation. The middle of the formation may consist of a thick, buff dolomite. Flat pebble conglomerate is a distinguishing feature of the Park (Sloss and Moritz, 1951). At Hecla, the Park is a dark green to greenish gray quartzite interbedded with brown clay laminae.

In the Pioneer Mountains the Park is the site of locally important intra-Cambrian unconformities. The unconformities may be well developed in one location and absent in another location. The Park can lie unconformably on all the underlying Cambrian formations. The Park is typically a valley former when it occurs as a shale.

Pilgrim Formation. The Pilgrim Formation is of Late

Cambrian age, is 100 to 425 feet thick, and is conformable and transitional with the Park Formation (Karlstrom, 1948; Sloss and Moritz, 1951; Hanson, 1952; McMannis, 1965). The Pilgrim is most commonly overlain unconformably by the Jefferson Dolomite, although it is sometimes conformably overlain by the Red Lion Formation.

The Pilgrim is a limestone throughout most of Montana; however, dolomitization has converted it to a white, light gray, or brown-gray dolomite in the Pioneer Mountains. Dolomitization has destroyed the textures and structures of the original limestone.

The Pilgrim is medium-bedded to very thick-bedded, becoming thin-bedded toward the top of the formation. The Pilgrim weathers to platy surfaces with a sugary appearance. The uppermost part of the formation ranges upward from a white dolomite to a yellow dolomite which is intercalated with beds of thin, bluish black limestone or dolomite. Intraformational conglomerates are common near the top of the formation. The Pilgrim is a ridge and slope former.

Red Lion Formation. The Red Lion Formation is of Late Cambrian age and is present only in the very northern part of the Pioneer Mountains (Karlstrom, 1948; Sloss and Moritz, 1951; Hanson, 1952; McMannis, 1965). The Red Lion, where

present, rests conformably upon the Pilgrim Formation and is unconformably overlain by the Jefferson Dolomite.

The Red Lion consists of brightly colored beds of maroon to yellow-brown dolomite and similarly colored calcareous mudstones. Red and green shale is also present in the formation.

Jefferson Dolomite. The Jefferson Dolomite is Late Devonian in age and is between 150 and 600 feet thick (Karlstrom, 1948; Sloss and Moritz, 1951). The Jefferson has a major unconformity below it and may lie upon any of the Cambrian formations, most commonly the Red Lion Formation or the Pilgrim Formation. The Jefferson normally is divided into a lower limestone member and an upper dolomite member.

The Maywood "Formation" of other regions of Montana is considered to be part of the lower limestone member of the Jefferson in the Pioneer Mountains (Sloss and Moritz, 1951). This lower member is limited to a small area of the Pioneers and consists of a few feet to a few tens of feet of dark brown, dolomitic limestone. Zones of light gray and yellow, silty limestone are found near the base.

The upper member of the Jefferson is a dark gray, brown, blue, or black dolomite which is finely to coarsely saccharoidal. A fetid odor is often associated with the

upper member of the Jefferson. The unit is thin-bedded to very thick-bedded and contains brecciated zones formed by solution of evaporite strata (Sloss and Moritz, 1951). At Hecla the Jefferson is composed of blue to black, finely-crystalline limestone in which the bedding planes are not prominent. The Jefferson is typically a slope or ridge former.

Three Forks Shale. The Three Forks Shale is Late Devonian in age (Karlstrom, 1948; Sloss and Moritz, 1951). The Three Forks rests conformably upon the Jefferson Dolomite with the contact changing from very thick-bedded dolomite to thin-bedded dolomite interbedded with shale.

The lower third of the Three Forks consists of gray-green, clayey shale and orange, yellow and maroon shaly dolomite and limestone. The carbonates may contain evaporite-solution breccia.

The upper third of the Three Forks contains the Sappington Sandstone member which consists of yellow and orange, sandy limestones and calcareous sandstones.

The formation is generally found as a soil-covered slope or as a valley between the Jefferson Dolomite and the Madison Group.

Madison Group. The Madison Group is of Early and Mid-

dle Mississippian age and is approximately 1,500 feet thick in the Pioneer Mountains. It rests conformably on the Devonian Jefferson Dolomite beds. The Madison Group is divided into the lower Lodgepole Formation and the upper Mission Canyon Formation (Karlstrom, 1948; Sloss and Moritz, 1951).

The Lodgepole Limestone is composed of black, dense, thin-bedded, fragmental, cherty limestone that is alternately bedded with shaly limestone and calcareous shale. The Lodgepole grades upward into the Mission Canyon Limestone.

The Mission Canyon Limestone is a light blue to blue-black, very thick-bedded limestone, except for the upper part which is a light gray to brown, sucrosic dolomite. The Madison Group is a cliff-forming limestone.

Amsden Formation. The Amsden Formation is Late Mississippian to Pennsylvanian in age and is up to 110 feet thick (Sloss and Moritz, 1951). The Amsden rests disconformably upon the Madison.

The Amsden is a bright red to purplish red unit of shale, siltstone, and shaly dolomite which grades upward into a thin-bedded to very thick-bedded, fossiliferous limestone. A red unit of thin dolomite and sandy dolomite is above the limestone (Sloss and Moritz, 1951). The Amsden

forms a valley or a slope.

Quadrant Formation. The Quadrant Formation is Pennsylvanian in age, is typically several hundred feet thick (Sloss and Moritz, 1951; Geach, 1972), and is transitional with the Amsden Formation and conformably overlies it.

This formation consists of white to light yellow, rusty brown-weathering, very well indurated to friable, medium-grained, well sorted, siliceous quartz sandstone. Some light gray, dense, thin beds of cherty dolomite occur in the formation. The Quadrant is a ridge forming unit in the Pioneers.

Phosphoria Formation. The Phosphoria Formation is of Permian age and is from 0 to 200 feet thick (Sloss and Moritz, 1951). The Phosphoria rests conformably on Pennsylvanian units.

The lower half to two thirds of the Phosphoria is composed of a quartz sandstone, limestone or dolomite, and a chert members. Above these units, the formation is composed of an oolitic phosphorite and an oil-shale member. The uppermost Phosphoria consists of bedded chert. The Phosphoria is a ledge forming unit in the Pioneer Mountains.

Dinwoody Formation. The Dinwoody has few exposures in the Pioneer Mountains and all of these exposures are on the

east flank of the range (Moritz, 1951). This formation is Triassic in age, is between 300 and 500 feet thick, and conformably overlies the Phosphoria Formation.

The Dinwoody consists of light gray and brown, thin-bedded, silty, argillaceous limestone, brown siltstone, brown, fine-grained sandstone, and gray-green shale. Shale predominates in the lower half of the formation and limestone predominates in the upper half.

Kootenai Formation. The Kootenai Formation is of Early Cretaceous age and is over 1,000 feet thick (Karlstrom, 1948; McMannis, 1965; Geach, 1972). It unconformably overlies the Dinwoody Formation.

The Kootenai is composed of red, green, and maroon quartzite, argillite, and limestone. The base of the formation is marked by a pebbly conglomerate. The formation changes upward from the lower conglomerate through interbedded quartzite, argillite, and limestone to arenaceous limestone. The formation is characterized by the alternating red and green members, and by the thin, distinctive, thick-bedded, gastropod-bearing, freshwater limestone present at the top of the formation (Karlstrom, 1948). The Kootenai occurs as subdued ridges in the Pioneer Mountains.

Colorado Group. The Colorado Group has not been well

studied in the Pioneer Mountains; however, the group is known to be of Early Cretaceous age and is over 1,000 feet thick.

At Hecla (Karlstrom, 1948) the Colorado Group consists of a basal, black, fissile shale and a gray, iron-stained, thinly laminated, locally cross-bedded, arkosic sandstone which grades upward from variegated shale at the base of the formation.

In the Ruby River Valley of Beaverhead County (Klepper, 1950; Geach, 1972), the Colorado Group consists of more than 1,000 feet of gray, green, and black shale interbedded with sandstone. Beds of light-colored tuffs, impure bentonite, and bentonitic shale occur near the base. The Colorado Group forms soil-covered valleys with low sandstone ridges.

Tertiary Sediments. The Tertiary sediments range up to over 10,000 feet thick and were deposited within intermontane basins (Geach, 1972). They are composed of poorly consolidated beds of conglomerate and sandstone, clay, freshwater limestone, and volcanic tuff. Basaltic volcanic flows occur locally within the Tertiary sediments (Geach, 1972).

Quaternary Sediments. Unconsolidated Quaternary deposits mantle most of the basin floors and most of the mountain slopes. Quaternary deposits consist of terrace

gravel, stream-bed alluvium, landslide deposits, glacial drift, and lake deposits (Karlstrom, 1948; Geach, 1972).

### Plutonic Rocks

The bedrock of the Pioneer Mountains is composed primarily of the Pioneer batholith which is located midway between the Idaho batholith and the Boulder batholith. In the eastern lobe of the Pioneer Mountains the batholith crops out for over 200 square miles and along the western edge it is exposed across over 150 square miles (Figure 3).

The Pioneer batholith is a porphyritic biotite-hornblende-quartz monzonite in the Elkhorn mining district (Winchell, 1914). In the Hecla mining district the batholith consists of a quartz monzonite which grades from coarse-grained to fine-grained as the contact of the igneous body is approached (Karlstrom, 1948). In the Birch Creek mining district, the pluton is of biotite granodiorite composition and at Rock Creek Canyon it is a coarse-grained, porphyritic, biotite granite (Willis, 1978).

Age dates for the batholith (Table 2) indicate that it was emplaced during the Late Cretaceous. Recent work by Zen and others (1980) has also shown that a 2-mica granite was emplaced during the Paleocene.

Sills and Dikes. The following rocks are found as

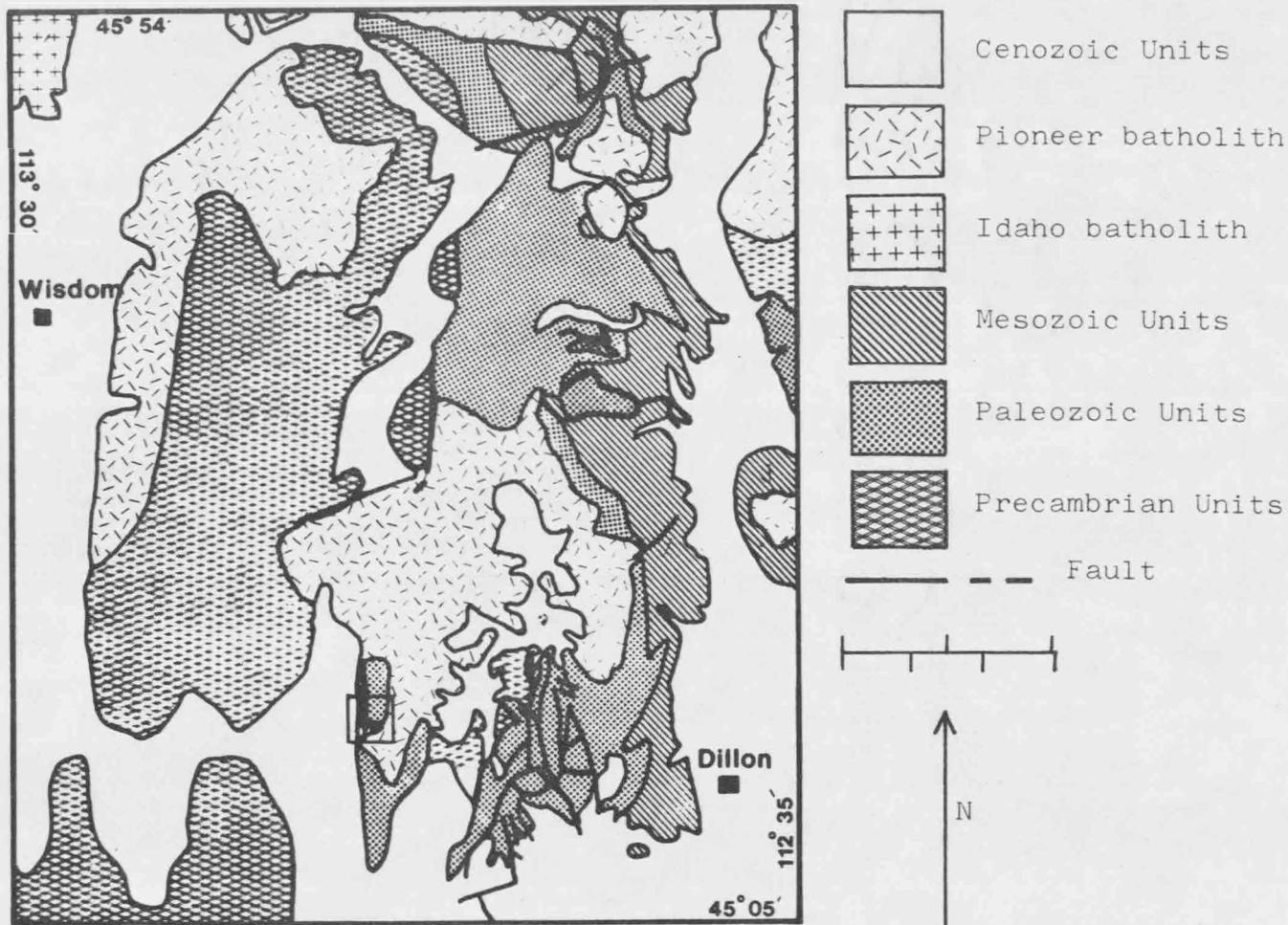


Figure 3. Regional geology of the Pioneer Mountains. Study area outlined in bottom half of diagram. Modified from Ross, C.P., Andrews, D.A., and Witkind, I.J., 1955.

Table 2. Age Dates for the Pioneer Batholith, Vipond Park Quadrangle, Montana. After Zen and Others, 1975.

Rock type, field no.	Location (lat N., long W.)	Analyzed minerals	K <sub>2</sub> O (%)	(moles/g)	Ar <sup>40</sup> * total Ar <sup>40</sup>	Age (m.y.) ± 2
Quartz diorite DR	45°35'36" 112°57'10" Kiokirk Mtn.	Biotite	8.93	9.496 x 10 <sup>-10</sup>	.95	71.0 ± 2.4
		Hornblende	8.87 0.887	1.021 x 10 <sup>-10</sup>	0.86	76.5 ± 2.1
Porphyritic granodiorite BH 9850	45°35'18" 112°56'55" Barbour Hill	Biotite	0.887 9.40 9.42	1.028 x 10 <sup>-10</sup> 9.888 x 10 <sup>-10</sup> 9.888 x 10 <sup>-10</sup>	0.65 0.90	77.0 ± 2.2+ 69.9 ± 2.4
		Hornblende	0.915 0.915	0.9243 x 10 <sup>-10</sup>	0.81	67.2 ± 1.9
Coarse granite BHS	45°35'14" 112°56'55" South Barbour Hill	Biotite	9.30 9.32	9.886 x 10 <sup>-10</sup>	0.90	70.6 ± 2.4
Tonalite IVP	45°31'15" 112°50'20" N. Lake Agnes	Biotite	9.12 9.08	9.712 x 10 <sup>-10</sup>	0.94	71.0 ± 2.7
		Hornblende	0.627 0.627	0.6405 x 10 <sup>-10</sup>	0.80	68.0 ± 1.9
Porphyritic granodiorite BC	45°25'0" 112°51'12" Lower Birch Creek	Biotite	8.77 8.73	9.049 x 10 <sup>-10</sup>	0.93	68.8 ± 2.3

sills and dikes within the Pioneer batholith or within the sedimentary rocks near the batholith (Geach, 1972). Aplite is found mainly as small dikes, pegmatites are reported to occur with minor ore deposits, minette has been found as a dike in dolomite at Hecla, and andesite is commonly present as sills and dikes which may be either dense or porphyritic. The major rock types of the Pioneer batholith are commonly expressed as sills and dikes (Geach, 1972).

Little information has been published on the metamorphic effects produced by the Pioneer batholith. Skarn and tactite (Geach, 1972) occur in limestone. No skarn has been observed in dolomite. The Madison Group is the most commonly metamorphosed limestone, although the Amsden is reported to occur as skarn (Myers, 1952; Geach, 1972). Argillite, hornfels, and metaquartzite occur (Karlstrom, 1948); however, it is not known if these were metamorphosed regionally or by the Pioneer Batholith.

### Regional Structure

Aside from a few general regional studies of structural geology of the Pioneer Mountains, most work has involved small, detailed investigations of mining districts. The following discussion has been adopted from the literature.

The eastern edge of the Pioneer Mountains (Figure 3)

consists of a doubly plunging synclinerium that is elongate north-south (Ross and others, 1955). The southeastern edge of the Pioneers is dominated by the Humbolt Mountain anticline which extends from the Bannack mining district (Figure 1) to the Birch Creek mining district. The western edge of the Humbolt Mountain anticline is bounded by a large thrust fault. The overthrust trends to the north or northeast and it extends from Idaho across the east side of the Pioneers and northward to the Lewis and Clark lineament (Geach, 1972).

A large north-south trending thrust(?) fault extends through the center of the Pioneer Mountains separating Paleozoics on the east side of the fault from Precambrian Missoula Group on the west side of the fault (Ross and others, 1955). The northern end of the Pioneer Mountains is heavily folded and faulted and dominated by a major east-west trending fault (Ross and others, 1955; Geach, 1972).

A drainage map of the Pioneers illustrates a rectangular drainage pattern with prominent north-south and east-west trends. On parts of the drainage map, a northeast trend and a northwest trend are found. The structural trends from the various mining districts (Geach, 1972) reveal faults that strike N-S, N85E+5, N45E+15, N40W+15.

The overall structural pattern was determined by the

emplacement of the Pioneer batholith which intruded older rock by faulting, thrusting, and assimilating (Winchell, 1914).

Pardee and Schrader (1933) summarized the structural history for southwest Montana in the following five phases. More recent age dating (Zen, E-an, and Arth, d.G., 1980) has altered the time that the phases occurred, but not the sequence.

- |  |                                    |
|--|------------------------------------|
| 1. Folding and uplift  | Late Cretaceous<br>to Early Eocene |
| 2. Thrust faulting   | Early Eocene                       |
| 3. Intrusion of the Pioneer batholith  | Early or Middle Oligocene          |
| 4. Gentle warping and faulting that produced shallow depressions areally coextensive with present intermontane valleys.                  | Early or Middle Oligocene          |
| 5. Uplift of present mountains and continued depression of the intermontane basins and at the same time an uplift of the general region. | Miocene or Pliocene                |

Klepper (1950) determined that the structure of the Pioneer Mountains was controlled by the Laramide orogeny and that the structures developed in two stages. The first stage consisted of the warping of rocks into broad folds and of faulting. Following this stage, the rocks were uplifted as

a result of differential block faulting. Klepper reported that major folds trend slightly east of north and that the folds are up to 50 miles long.

Geach (1972) reported that the adjacent Centennial Range was bounded by high angle faults. He stated that linear valleys are controlled by high-angle faults and that elliptical basins are produced by down-warping.

Harrison and others (1974) believed that the crustal weaknesses formed in the Precambrian have controlled the major structural development up to recent times. The structural development of the Pioneer Mountains, therefore, began with folding and thrusting during the Late Cretaceous. The Pioneer batholith was intruded during the Late Cretaceous and then followed by extensional faulting during the Tertiary.

#### Regional Mineralogy and Paragenesis

Geach (1972) described the mineralogy and chemistry of the various ore districts in Table 3. Most of the mining districts produce gold, silver, lead, copper, and zinc. Typically the districts (Figure 1) are most famous for their silver and lead. Exceptions are: Bannack, which is known for its high production of gold; Badger Pass, at which small quantities of gold were mined; and the Baldy Mountain, Birch

Table 3

Vein Mineralogy of the Pioneer  
Mountain Mining Region  
(Compiled from Geach, 1972)

	Argenta	Badger Pass	Baldy Mountain	Bannack	Birch Creek	Blue Wing	Elkhorn	Hecla	Polaris	Rock Creek	Vipond Park
<u>Ore Minerals</u>											
anglesite		x	x	x		x					
argentite						x					x
arsenopyrite	x										
azurite		x			x	x		x			
bindheimite						x					
calamine						x					
caledonite						x					
cerargyrite						x					
cerussite	x			x		x		x			x
chalcopyrite	x			x		x	x	x			x
chrysocolla					x	x					
covellite						x					
cuprite					x						
galena	x	x		x		x	x	x	x		x
gold	x	x		x							
jamesonite						x					
linarite						x					
malachite		x			x	x		x			
melaconite					x						
molybdenite					x		x				

Table 3 (continued)

	Argenta	Badger Pass	Baldy Mountain	Bannack	Birch Creek	Blue Wing	Elkhorn	Hecla	Polaris	Rock Creek	Vipond Park
plumbojarsite	x										
polybasite						x					
powellite		x			x						x
pyrargyrite						x			x		
psilomelane			x								
rhodochrosite						x					
scheelite		x	x		x					x	x
smithsonite				x		x					
sphalerite	x					x	x	x	x		
tetrahedrite	x					x	x				x
wolframite											x
<u>gangue</u>											
barite	x										x
calcite						x			x		
chalcedony		x						x			
chlorite					x						
fluorite	x										
goethite		x			x						
gypsum						x					
iron oxides	x			x	x	x		x			
jasper	x	x		x		x					
magnetite		x			x				x		
manganese-Ox	x	x				x		x	x		
muscovite		x									
pyrite	x	x				x	x	x	x		x
quartz	x	x		x	x	x	x	x	x		x
siderite						x					

Creek and Rock Creek mining districts, all of which produced tungsten or molybdenum in addition to silver.

In these districts, galena, cerussite, and anglesite are the common ore minerals from which lead is mined. Malachite and azurite are the ore minerals from which copper is extracted. Zinc and tungsten are found in, respectively, sphalerite and scheelite. The major silver minerals are tetrahedrite, native silver, pyrargyrite, and polybasite. Quartz, pyrite, chalcopyrite, iron oxide, manganese oxide, and chalcedony are important gangue minerals.

The Rock Creek, Birch Creek and Baldy Mountain mining districts define a central zone of molybdenum and tungsten which formed under contact metasomatism. The rest of the Pioneer region is a zone of silver and lead or gold and silver associations. Berger and others (1979) report that the districts in the Pioneer Mountains illustrate an early stage of contact metasomatism (400°C to 600°C). Solutions at this stage contained high amounts of molybdenum and tungsten, and were deficient in base metals. During the second stage, solutions formed vein deposits of gold, silver, copper, lead and zinc. Replacement deposits are the most common, but some deposits consist of open space filling.

## LOCAL GEOLOGY

### Stratigraphy of the Polaris Mining District

The local stratigraphy is based on field observations made by the author and on thin sections prepared from each formation. Cox (oral communication) and Breit (oral and written communication) mapped this area and it is noted where they agree or disagree with the author. A comparison of the regional stratigraphy and the local stratigraphy is provided in Figure 4. Metamorphism from the Pioneer batholith has made the stratigraphy of the Polaris mining district difficult to interpret; however, detailed field observation has enabled the author to arrive at a revised interpretation.

Missoula Group. The Precambrian Missoula Group has an exposed thickness of 5,800 feet in the Polaris mining district. In general, the Precambrian beds strike northeast and dip southeast.

Color of the rocks is very light gray to medium gray and brown. The Missoula Group is a dense and very well indurated quartz sandstone that forms ridges and steep slopes. The beds range from thinly-laminated to very thick-bedded and exhibit cross-lamination and cross-bedding.

Grain size is from very fine-grained to medium-grained. Grains are very well sorted and vary from subrounded to

Formation or Group	Regional Section	Polaris Section
Madison Group	Upper light blue to blue-black, very thick-bedded limestone; dolomitic towards top. Lower black, dense, thin-bedded, fragmental, cherty limestone. At Argenta lower unit is light gray, massive, coarse-grained limestone. Recrystallizes to white, coarse-grained limestone.	White, bluish white, and very light gray to medium dark gray, thin- to thick-bedded, fine- to medium-grained, locally dolomitic limestone. Massive white marble around veins. Ridge-former.
Pilgrim Formation	Buff, light gray, brown, gray, medium- to very thick-bedded dolomite. Sandy at top.	Buff, dark gray, yellow-brown, white dolomite; fine- to medium-grained. Slope-former.
Park Formation	Green-gray, purple-gray, brown-gray, micaceous shale. Interbedded with limestone or dolomite at top; may be composed of quartz sandstone. Metamorphoses to green-gray interbedded with brown clay laminae.	Light gray to green-gray and reddish brown quartzites, and hornfelses. Composed of quartz and chlorite. Slope-former.
Meagher Formation	Buff, light gray and white, thin- to thick-bedded dolomite. Shale or quartz sandstone found in upper part of formation. Metamorphoses to dolomitic marble with quartzite members. Sucrosic member near top; cliff-former.	Buff to white to medium dark gray dolomite; thick- to very thick-bedded. Quartz sandstones and a sucrosic dolomite occur near top of formation. Cliff and slope-former.

Figure 4. Comparison of local and regional Paleozoic stratigraphy. Regional Paleozoic stratigraphy compiled from varied published sources referenced in text.

rounded. The cement is usually siliceous though argillaceous cement is found.

Quartz is the most common mineral present and it composes most of the rock. Biotite is a minor constituent in most samples and feldspathic beds are locally significant. The feldspathic beds have an argillaceous cement, are only moderately indurated, are sometimes conglomeratic and are poorly sorted.

In the Pioneer Mountains at Argenta (Myers, 1952), the upper Missoula Group has an exposed thickness of 6,000 feet; no other formation or group has a similar lithology or is thick enough to account for this gray quartzite (Smith, 1980; McMannis, 1965). The Missoula Group near Argenta contains more feldspar and is coarser-grained than the unit found in the Polaris mining district, but the rock types are otherwise alike. Both Cox and Breit mapped this unit as Precambrian Belt, but neither subdivided it further.

Meagher Formation. The Meagher Formation has an exposed thickness of approximately 300 feet around Polaris and is colored from white to buff and light pinkish gray to medium dark gray. The dolomite weathers to yellowish gray, and a thick, yellowish, calcareous soil often marks this formation.

Outcrops, in the form of large cliffs, occur mostly in

the upper part of the formation and exhibit well indurated, thick- to very thick-bedded dolomites. Mine tunnels in the middle of the Meagher cut through very thin- to thick-bedded dolomite.

The upper part of the formation contains a member of white, pink to red, dense, very well indurated, very fine-grained, very well sorted, siliceous quartz sandstone. The base of this unit is interbedded with dolomite. The upper part of the formation also contains a white, thick(?) -bedded, medium-grained, sucrosic dolomite. Most of the dolomite rhombs in the Meagher are fine-grained and range from 0.25 mm. to 0.5 mm. The Meagher has an overall north-south strike and is a slope and cliff former.

The unit described here is considered to be the Meagher Formation on the basis of the light buff dolomite which contains quartz sandstone beds, and the sucrosic dolomite bed. The Meagher at Polaris is similar to the Meagher section described at the Hecla mining district (Karlstrom, 1948). The Meagher at other areas in southwest Montana forms massive dolomite cliffs (Hanson, 1952) and thin-bedded to very thick-bedded, buff dolomite (Sloss and Moritz, 1951).

Park Formation. The Park Formation consists of approximately 150 feet of white, light gray to green-gray and red-

dish brown metaquartzite, medium gray evaporite, and light green to dark green-gray to black hornfels. This formation weathers to orange-brown, yellowish, and light olive-brown.

The base of the Park is predominantly hornfels which intercalate upward with quartzite. Anhydrite, which has not been observed outside of the Polaris district, occurs as lenses in the upper 1/3 of the formation and is believed to be a product of metamorphism of dolomite. The bedding, of this formation, is commonly thickly-laminated to medium-bedded, although some thick-bedded quartzites are present.

The grains in the metaquartzites range from very fine- to medium-grained, are well sorted to very well sorted. The metaquartzites are composed of over 90% quartz; some chlorite was found in them. The hornfelses are composed of 50% silt-sized quartz grains and 50% chlorite(?). The Park strikes approximately north-south and forms slopes and knobs.

This formation has been determined to be the Park because of its position between two large, buff, dolomite formations. The Park is the only formation which is positioned in the stratigraphic column in this manner (Figure 2 and Plate 1). The Park was described at Hecla (Karlstrom, 1948, p. 23-24) as green to greenish gray quartzite beds positioned between two large, buff dolomite formations. The

Park at Hecla is a metamorphosed impure fine-grained quartzite; the thick quartzite beds contain clay laminae.

Pilgrim Formation. The Pilgrim is a dark gray to yellow-brown to white dolomite which weathers to yellow and red. This formation is located very close to the Pioneer batholith where recrystallization and jointing have obscured the bedding, but bedding appears to range from thin to thick. The rock is moderately to well indurated.

The dolomite is fine- to medium-grained with the crystals ranging in size from 0.25 mm. to 1.5 mm. The rock is composed of almost 100% dolomite and a scattering of opaque minerals. The formation is a slope former.

The Pilgrim is similar lithologically to the Meagher Formation and is distinguished on the basis of its stratigraphic position. The Pilgrim lacks the prominent cliffs produced by the Meagher, weathers to a reddish color, and lacks the quartz sandstones of the Meagher.

The Pilgrim was described to be a buff dolomite by Sloss and Moritz (1951). This description was expanded at Hecla where Karlstrom (1948) noted that in places the Pilgrim weathers to yellow and red. Hanson (1952) described a sandy zone of a few feet thick to 100 feet thick near the top of the Pilgrim. This sandy zone does not occur at Pola-

ris, so that the top of the Pilgrim appears to be missing.

Breit (written communication) believed that the units here considered in this paper to be Meagher, Park and Pilgrim are the Amsden formation. The Amsden, however, is known to be only up to 110 feet thick in the Pioneer Mountains (Sloss and Moritz, 1951). This Cambrian sequence at Polaris is, however, over 900 feet thick. The Amsden is a bright red unit and no bright red rocks occur at Polaris; however, dull red does occur as a result of weathering of the Pilgrim or within the quartz sandstone "member" of the Meagher. The Amsden, furthermore, contains siltstone and shaly dolomite which do not occur in the Polaris mining district.

Cox named the units described here as Meagher, Park, Pilgrim, and part of the Madison Group, as the Pilgrim, because of lack of mottling. However, both the Meagher Limestone and the Pilgrim Limestone show mottling, except when they occur as dolomite, in which case dolomitization has destroyed mottling (Hanson, 1952). Furthermore, the Pilgrim of the region does not contain quartzites; therefore, these beds are better considered to be part of the Park formation.

Cox believed that the Pilgrim is a limestone and that

the buff dolomites are a result of the intrusion of the Pioneer batholith. Hence, he has named most of the Madison Group the Pilgrim Formation; however, in this region of Montana, the Pilgrim is a dolomite (Hanson, 1952). The igneous intrusion is also in contact with the Madison limestone and no dolomitization has occurred (Plate 1).

Madison Group. The Madison Group is a white, bluish white, and very light gray to medium dark gray limestone which weathers to a white or gray soil. The rock is a thin- to very thick-bedded, fine- to medium-grained, locally dolomitic, limestone. White and gray streaks are intermingled in the Madison; it is not known whether this is a primary or a secondary feature. The Madison is well indurated in outcrop and is a ridge former.

At Argenta, Myers (1952) described an upper light to dark gray limestone which is fine- to medium-grained and which grades upward into a dolomitic limestone which is locally sandy and cherty. The lower limestone is massive, white to gray, and coarse-grained. The lower limestone recrystallizes readily near intrusives to a massive white marble. The above description is characteristic of the Madison at Polaris, except that there is no sand or chert. The Madison exposed at Polaris is predominantly the lower unit.

Sloss and Moritz (1951) describe the very top of the Madison as grading to a dolomite. No dolomite was found in the Madison Group at Polaris, supporting the belief that the uppermost Madison Group has been eroded off.

Breit mapped this unit as the Big Snowy Formation and the Madison Group. The Big Snowy, however, is absent in the Pioneer Mountains (McMannis, 1965). The lithology, furthermore, shows no variation from what Breit has mapped as Big Snowy and what he mapped as Madison.

Quaternary Deposits. Quaternary deposits in the Polaris mining district consist of colluvium and some alluvium. The colluvium is composed of angular blocks of limestone or dolomite supported by a calcareous soil. The deposits of colluvium are over 15 feet deep in places. The alluvium is composed of rounded pebbles which are confined to the present drainage system.

#### Structure of the Polaris Mining District

The Polaris mining district is highly faulted. Small folds are common, but a large anticline occurs across the northern part of the district and a large syncline is present in the central part of the district (Figure 5). Faults and folds have been named by the author to aid in their discussion. The faults in the Polaris mining district occur in

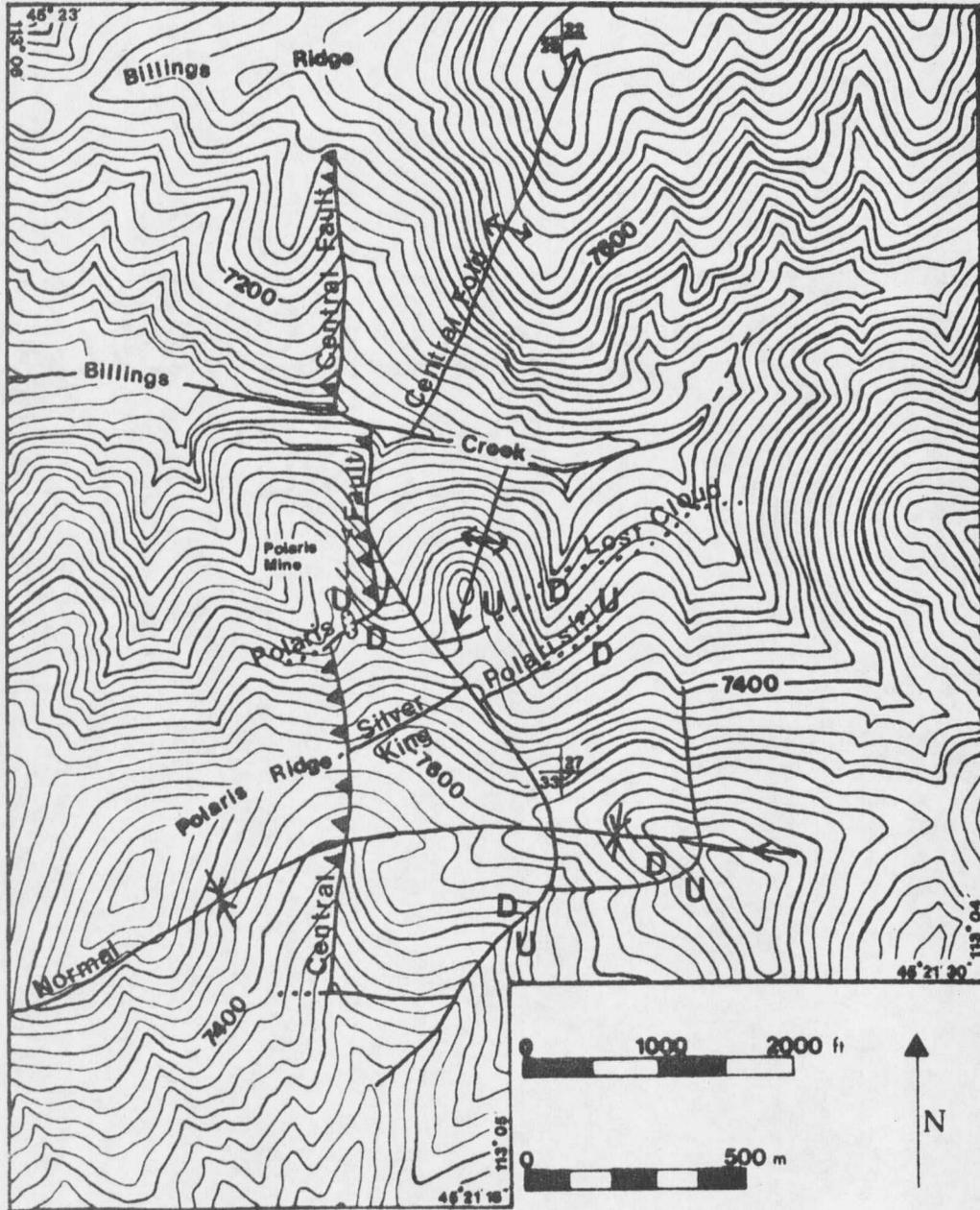


Figure 5. Major structures in the Polaris mining district. Teeth mark upper plate of thrust fault. U indicates upthrown block, D indicates downthrown block.

the following temporal order: N33W, N-S, E-W, N60E, N40E, and north-south (Table 4). The evidence for this sequence of faulting is discussed below.

Faulting. The first episode of faulting (Figure 5) formed one N33W 90 fault which cuts only the Missoula Group. The fault has been exposed by two bulldozer cuts near the open cut at the Polaris mine, and exhibits a grayish orange fault gouge. The fault parallels a prominent ridge and several steep-sided valleys within the Precambrian.

The second episode of faulting (Figure 5) created a major north-south fault, the Central fault. The Central fault has a vertical dip as determined from its surface trace. It displaces the Missoula Group against the Meagher Formation and the Madison Group. The minimum vertical displacement possible is 200 feet. The Central fault is probably a thrust fault as it is one of the first faults formed and thrust faults were the first faults to form during the compressional phase of the Laramide orogeny (Myers, 1952). The Central fault is believed by the author to be a listric thrust fault in which the leading edge is curved upward until it is vertically dipping.

The third episode of faulting is represented by a series of nearly east-west striking, vertical faults. The first of

Table 4

## Summary of Geologic Events

1. Northwest faulting episode.
2. Central fold formed, followed by the formation of the Central fault.
3. East-west faults formed.
4. N60E fault episode; probably due to same stress as that which formed east-west faults.
5. N40E fault episode.
6. Splay fault formed. No evidence whether Splay came before intrusion of batholith.
7. Intrusion of Pioneer batholith; skarn formed at this time (contact metasomatic deposits).
8. Ore emplaced along N60E faults.
9. East-west fold formed. Exact relation of fold to batholith unknown. Folding of Polaris vein?

these faults is the Billings Creek fault (Figure 5). This fault offsets the Central fault and cuts Precambrian and Cambrian rocks. The Billings Creek fault curves; however, the absence of folding on the sedimentary rock on either side of the curve of the fault rules out folding. The curving of the Billings Creek fault must be a primary feature. This fault is the only east-west fault which is expressed topographically.

An east-west striking, vertical fault is exposed only in the Polaris mine. This fault contains a green gouge zone, four feet wide, within Madison Group rocks. Another east-west fault offsets the Central fault in the southern part of the mining district.

The N60E fault trend is made up of three known faults (Figure 5) striking N60-65E and dipping from 45°NW to vertical. These faults were formed during the fourth episode of faulting.

The first of these faults is the Polaris fault which strikes N60E and dips variably from 45°NW to vertical. The Polaris fault has displaced the Madison Group down relative to the Pilgrim Formation by reverse-slip. This displacement has offset the Central fault, and the Polaris fault, therefore, post dates the Central fault.

Another fault which has placed the Madison Group next to the Pilgrim Formation is believed to be the Polaris fault which is indicated on Figure 5 with a question mark. Both faults are cut by the Splay fault (Figure 5) and both faults have displaced the same units.

The Silver King fault, named by Breit (written communication), is found within the Madison Group. The fault is exposed only in and around the old mine workings of the Summit claim. The Silver King fault appears as a zone of intense fracturing with numerous slickenslides. The fault strikes N60E and dips 85°W. The amount of net movement is small as no gouge zone is observed. All other faults in the Madison Group, which have measurable displacement, have a chlorite gouge zone developed. The Silver King does not show any offset of the Central fault, but the amount of movement is believed so small that noticeable displacement did not occur. The intersection of the Central fault and the Silver King fault is covered.

The third fault in this trend is the Lost Cloud fault (Figure 5) which exhibits a N65E strike; the dip of the fault could not be determined. The Lost Cloud places the red quartz sandstone, near the top of the Meagher Dolomite, against a dolomite which is interpreted as the Pilgrim For-

mation because of the yellow and red staining. Dips within the dolomites are in opposite directions on opposite sides of the fault. The Pilgrim was, according to the author's interpretation, downfaulted relative to the Meagher.

The east-west faults are believed to be formed from the stresses which formed the N60E faults. The east-west faults occur temporally before the N60E faults, because the Polaris fault has cut an east-west trending fault in the Polaris mine. However, the 30 degree difference between strikes suggests that the two fault trends are conjugate and therefore contemporaneous. The Billings Creek fault and the Polaris fault also offset the Central fault by the same amount.

The fifth episode of faulting developed the Cross fault (Figure 5) the plane of which strikes N40E and dips 30°NW. The fault displaces Precambrian rocks next to Precambrian and Mississippian rocks. The Cross fault is a normal fault.

Another N40E fault with a 70°NW dip occurs in the Polaris mine. This fault cuts the Polaris fault, therefore, assuming all N40E faults to be a product of the same stress, these faults occur after the N60E faults.

The last episode of faulting was the development of a north-south striking normal fault that dips from 20° W to

vertical (Figure 5). This fault is unusual because it has a shallow dip for a normal fault. This fault, the Splay fault, cuts the N40E faults, an east-west fault, and the Polaris fault. It cuts Precambrian to Mississippian rocks in the Polaris mining district and merges into the Central fault laterally and vertically. The Splay fault is easily traceable on the surface and forms stream valleys.

A number of small faults cut the rocks on top of the Polaris Ridge. These faults extend for very small distances because fault traces are only present on one side of the Polaris Ridge. The strikes and dips of these faults cannot be determined.

The second through fifth episodes of faulting are Post-Mississippian. Myers' (1952) study of the Willis quadrangle showed that the first significant post-Mississippian deformation was during the Laramide orogeny. The batholith post-dates the faulting, with the possible exception of the Splay fault. The second through fifth stages, therefore, are presumed to be Laramide and the Splay fault is either Laramide or post-Laramide.

Folds. Folds exposed in the Polaris mining district are represented by a large N20E trending anticline, a large east-west trending syncline, and many small folds.

The large anticline, referred to here as the Central anticline, is asymmetrical and doubly plunging. The west limb dips between  $30^{\circ}\text{W}$  and  $40^{\circ}\text{W}$ ; the east limb dips between  $45^{\circ}\text{E}$  and  $85^{\circ}\text{E}$ . Dips of the beds decrease considerably northward along the east limb where the anticline crosses the top of Billings Ridge, north of Billings Creek. The fold gradually plunges more steeply to the northeast. The fold, which is cut by the Billings Creek fault, plunges to the south just before it is cut by the Lost Cloud fault. It is not known whether this plunge is caused by drag along the Lost Cloud fault.

A large doubly plunging syncline, here named the Normal syncline, trends east-west through both the Missoula Group and Madison Group. The northern limb dips from  $45^{\circ}\text{S}$  to  $60^{\circ}\text{S}$  and the southern limb dips from  $35^{\circ}\text{N}$  to vertical. Dips along the eastern edge of the syncline were measured in an area that was heavily faulted. The effect of these faults on the orientation of the limestone beds is unknown. The fold plunges to the east  $\frac{1}{4}$  mile west of the map area.

Several small folds trending  $\text{N}20\text{E}$  to  $\text{N}60\text{E}$  were exposed in Cambrian and Precambrian rocks, both on the surface and in the Polaris mine. These folds occur throughout the district, but individual folds are not areally extensive.

The Polaris vein is folded (Corry, 1918), but this fold is expressed only underground (Figure 6). Therefore, folding may be more extensive and complex than it appears in the surface geology. The trend of this fold is unknown.

The Central anticline pre-dates the Billings Creek fault while the Normal syncline post-dates all faulting (Plate 1). It is unknown when the small folds were formed.

Joints. Joint measurements were taken within the map area, the mine, and outside the map area. The joints do not show a relationship to the local structure; therefore, the joints are probably a result of regional tectonics. Figure 7 exhibits the joint trends found.

### Igneous Rocks

The Pioneer batholith and the dikes extending from it are the only igneous rocks found in the Pioneer mining district.

The Pioneer batholith is a light gray, holocrystalline, hypidiomorphic, fine- to medium-grained, biotite quartz monzonite to quartz monzonite porphyry, which weathers to rounded, grayish orange boulders. The batholith is very close to granodiorite in composition and exhibits kaolinization on the surface.

Quartz composes 50 to 70% of the batholith; the highest



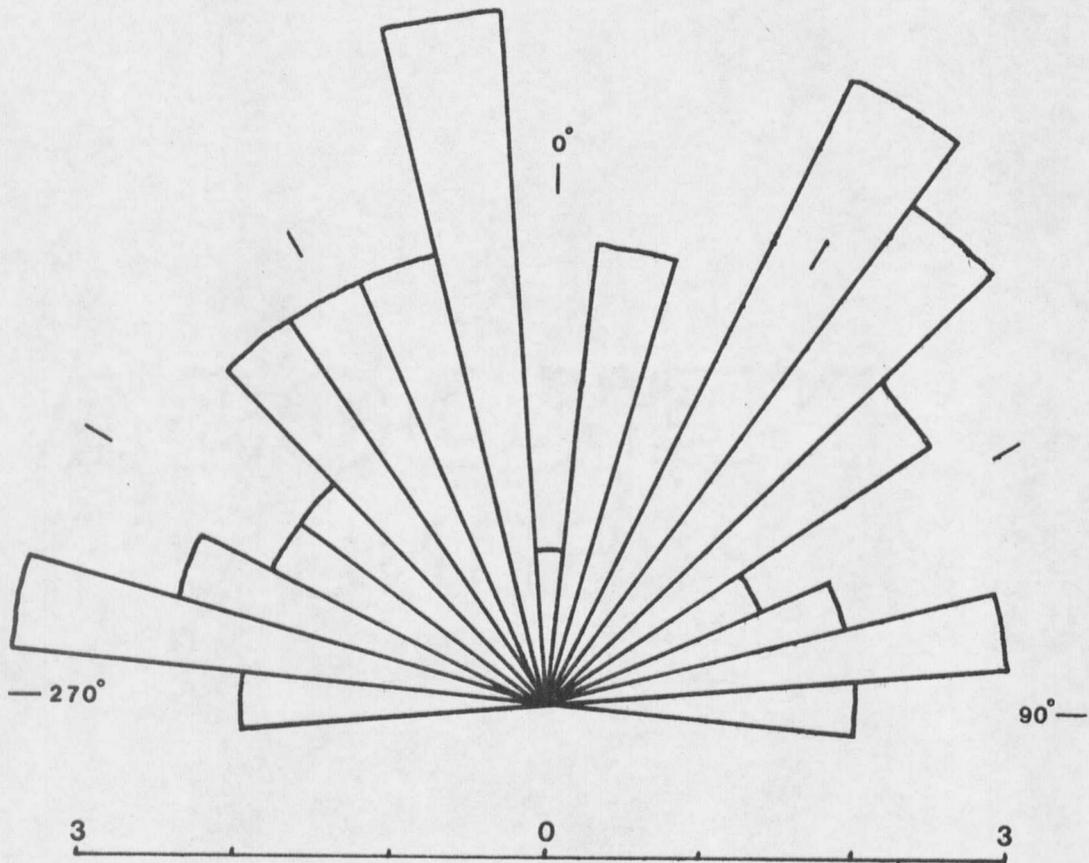


Figure 7. Joint trends in the Polaris mining district.  
Scale indicates number of joint measurements.

quartz content occurs next to the Precambrian Belt Supergroup. Quartz crystals vary in size from 0.05 mm. to 4.5 mm. and are anhedral to subhedral in shape. Plagioclase composes 15 to 20% of the igneous rock, ranges from 0.2 mm. to 3 mm., and is euhedral to anhedral. The composition of plagioclase ranges from oligoclase to andesine. Two to 20% of the quartz monzonite is euhedral to subhedral microcline, which is from 0.2 mm. to 3 mm. large. Orthoclase composes 1 to 5% of the igneous rock, ranges in size from 1 mm. to 3 mm., is anhedral, and often exhibits zoning. Anhedral to subhedral biotite composes 7% of the rock and ranges from 0.5 mm. to 2.5 mm. Pyroxene, which composes 1 to 2% of the quartz monzonite, ranges from 0.25 mm. to 1.0 mm., and is subhedral to anhedral in shape. Hornblende composes 1% of the batholith, varies from 0.25 mm. to 3.5 mm., and is subhedral to euhedral.

Xenoliths are found along the western edge of the Pioneer batholith at Polaris. The xenoliths contain crystals of biotite and feldspar which appear to have formed by metasomatism; this suggests that the Pioneer batholith magma was volatile-rich.

A skarn was formed where the Pioneer batholith came into contact with the Madison Group. The skarn is exposed

only in old mine dumps. Very coarse-grained, euhedral idocrase composes 90% of the skarn. Diopside makes up the rest of the skarn as green to dark green, zoned, coarse- to very coarse-grained, euhedral crystals. The skarn formed either because the Madison Group was a favorable host or because the magnesium, aluminum, iron and silica-rich fluids were channeled into this area. No skarn occurs along the Pioneer batholith--Pilgrim contact.

Quartz monzonite forms numerous apophyses, is not chilled at its contact with sedimentary rocks, and cuts all faults it comes in contact with (Plate 1). These facts imply that the batholith magma was an assimilating body of magma which was intruded during the Laramide orogeny (Table 4). During its intrusion it heated and metamorphosed(?) the sedimentary rocks were heated up enough so that the magma was not chilled when the two came into contact. The metamorphism that occurred may have formed as a result of the batholith or from regional metamorphism.

Brecciation, faulting, and folding are not related to the batholith, suggesting that in the Polaris district the intrusion was not forceful at the level of observation. At greater depths, however, the batholith may have created stresses above it which caused these structures to develop.

## MINE WORKINGS

Many small mining operations were conducted in this district, but only the Polaris mine is still operating and offers access to its underground workings. The abandoned operations can only be investigated upon the surface because of the caving in of the workings.

### Polaris Mine

Most of the mine passages were developed before 1923 and have since collapsed (Figures 8 and 9). Present operations at the mine have opened up the 260 foot level (Plate 3). Some of the old workings from the 320 foot level to the surface were accessible for examination, but it was not possible to map these workings due to large numbers of partially caved areas and the large number of winzes and inclined raises. In the fall of 1980, miners were planning to cease operation on the 260 foot level and open up the 570 foot level.

When fault gouge and the heavily fractured Missoula Group are exposed by mining, they collapse into the workings around the ore face in a matter of days, posing a danger of a cave-in. An unknown thickness of ore, therefore, is temporarily left next to the Polaris fault in order to support the "bad ground". This ore will be removed when operations

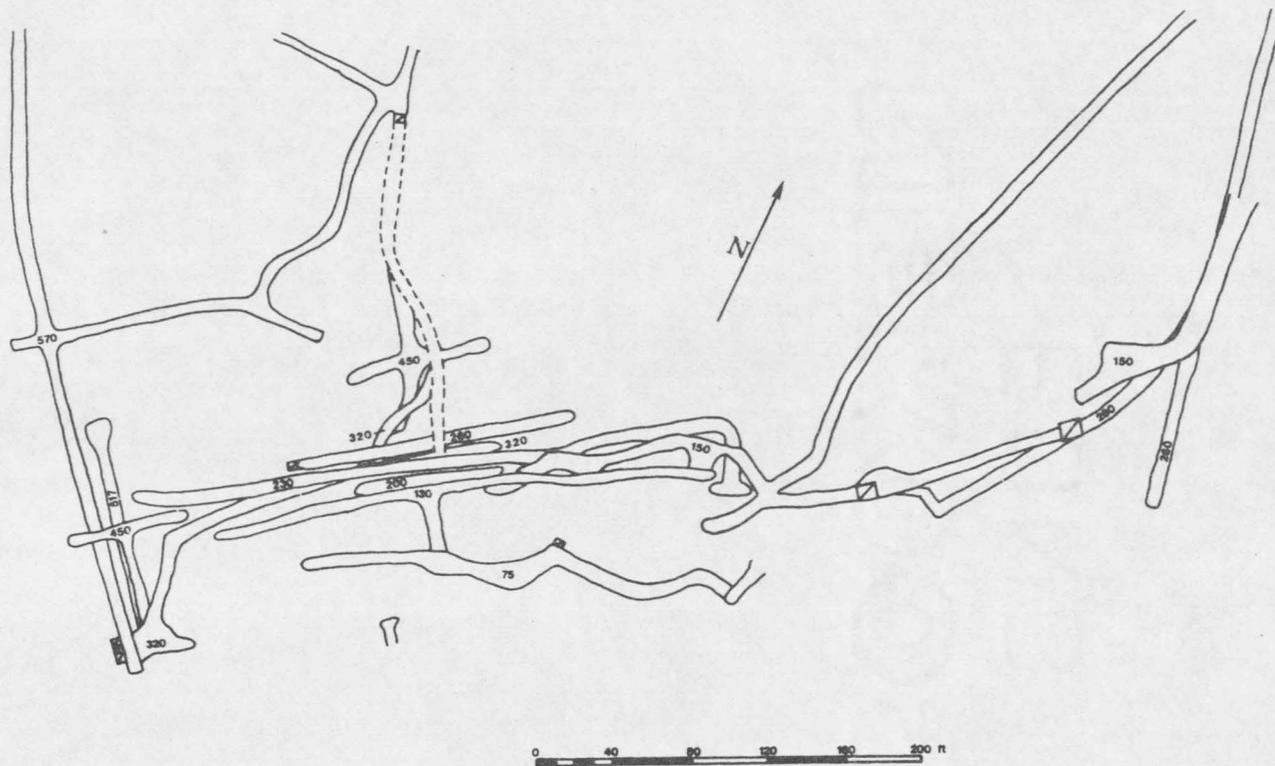


Figure 8. Plan view map of the Polaris mine. Dashed line is an inclined raise (Courtesy of Midnight Mines, Inc.).

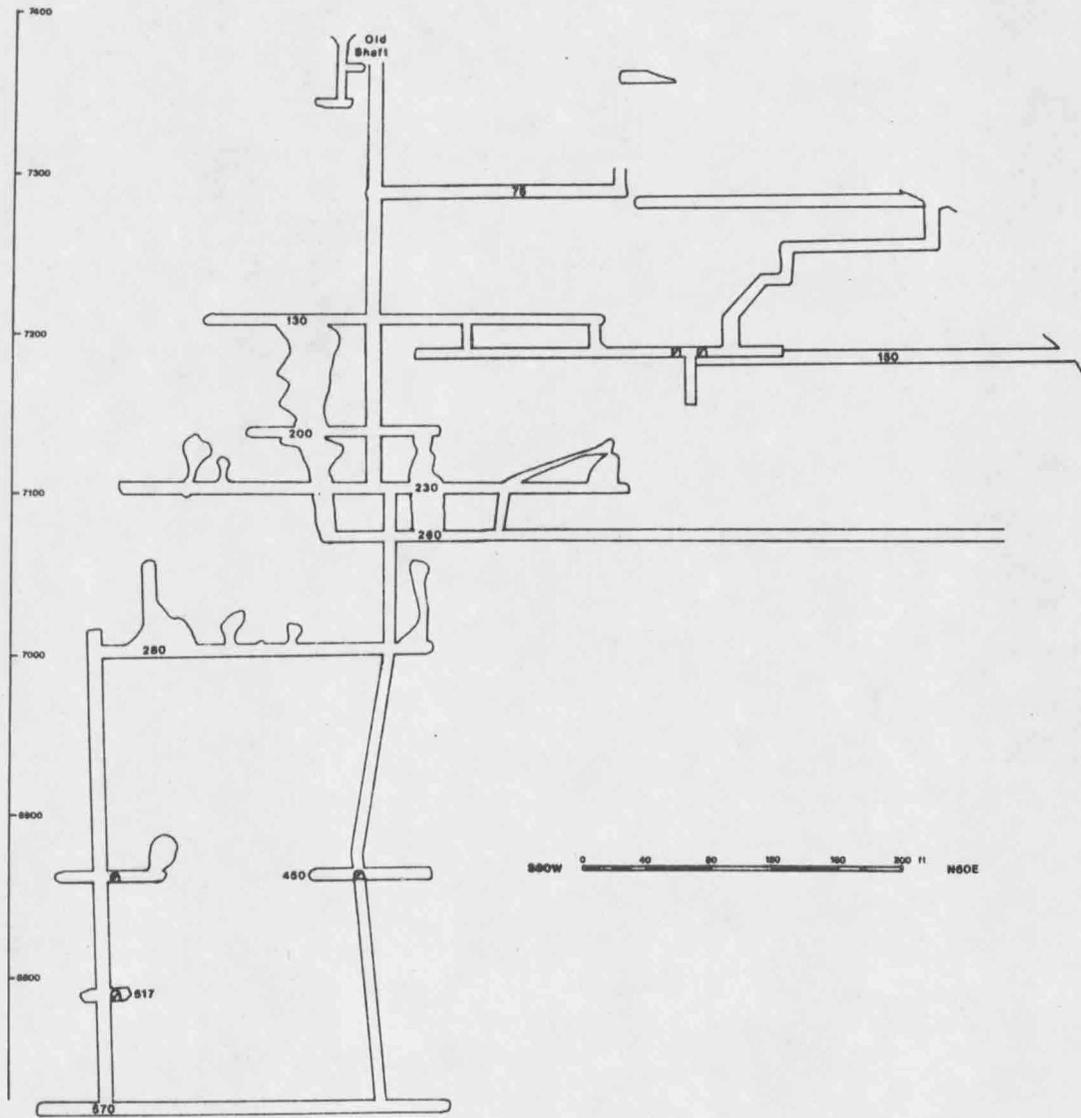


Figure 9. Longitudinal section of the Polaris mine in plane of vein looking N30W (Courtesy Midnight Mines, Inc.).

cease on this level. Operations are kept in the limestone as much as possible.

The Polaris fault strikes N60E and dips 60° to 70°NW on the 260 foot level. A winze in the western edge of the mine allowed the author to view the fold of the Polaris fault which occurs in the lower levels. The Polaris fault contains a pure(?), white, calcite gouge which is thoroughly slickenslided, includes fragments of high grade ore, and contains vugs lined with calcite crystals. The white gouge is an anomaly as all other faults contain a green fault gouge which is composed of calcite and chlorite(?).

The Polaris fault offsets Madison Group rock next to the Missoula Group (Plate 3) in the mine. Breccias occur at the intersection of the Polaris fault within the Madison and is a replacement deposit shaped as lenses and pods. In the western end of the mine the ore is composed of visible galena; throughout the rest of the mine the ore appears as black streaks. The ore, which normally extends for only a few feet from the fault, is associated with brown limestone. Blue, green and yellow colors are often found on the rocks around the ore. Silicification is always associated with the ore.

An open pit which was dug along the Polaris fault in

the NE $\frac{1}{4}$  SW $\frac{1}{4}$  SE $\frac{1}{4}$  sec 28, R12W, T5S.. Two inclined shafts extend from the bottom of the open pit. Geach (1972) reported that east-trending quartz-filled veins extend from the Polaris fault into the Madison Group, but mining has since removed any evidence of these veins. Geach believed that these veins were formed by displacement along the fault prior to mineralization. One fracture contains ore along the sides and therefore must have served as a conduit for the mineralizing fluids. The limestone was replaced on both sides of this fracture. Next to the main vein the limestone has been altered to a yellow-orange or a yellow-brown color for about 75 feet.

#### Surface Prospects

The following discussion describes the location, the geology, the ore mineralogy, and the reasons, if known, for the location of the various workings within the Polaris mining district which are outside the Polaris mine proper and which are no longer accessible underground. The following descriptions start with the northern part of the mining district. The location numbers correspond to the numbers on Figure 10. These mine prospects are all small and abandoned unless otherwise stated.

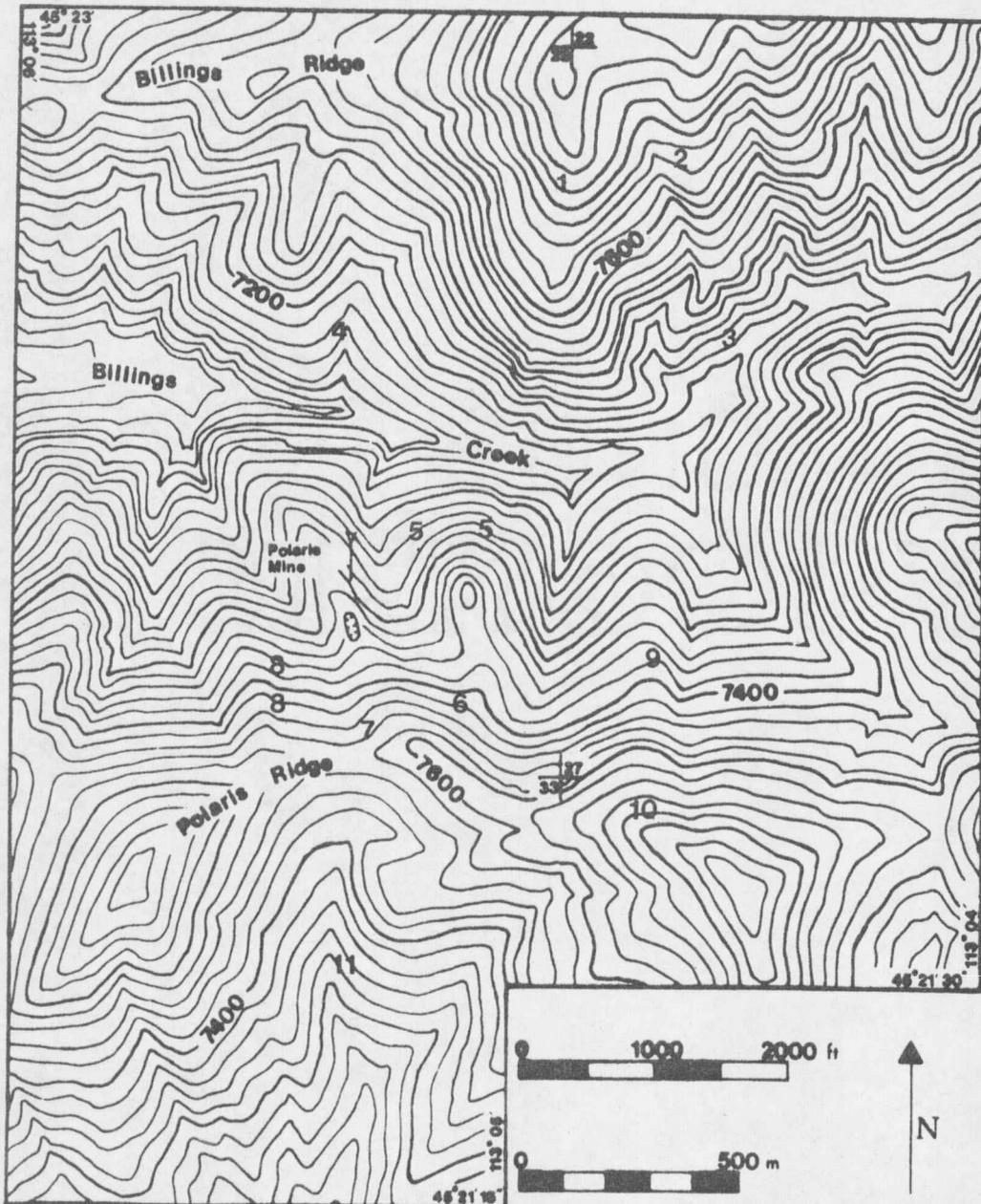


Figure 10. Location of surface prospects. Section corners are located.

Location 1. In the SW $\frac{1}{4}$  NW $\frac{1}{4}$  NW $\frac{1}{4}$  sec 27, R12W, T5S an open adit is located in the Meagher Formation near the Meagher-Park contact. The tunnel trends N5E and is located high on the west limb of the Central anticline. Copper mineralization in a white, vuggy, coarsely crystalline dolomite, and red and brown, iron-stained quartz occur on the mine dump. No evidence for faulting is present, but the small vein exhibits open space filling; therefore, it is assumed that the mineralization follows a joint.

Location 2. In the E $\frac{1}{2}$  NW $\frac{1}{4}$  NW $\frac{1}{4}$  sec 27, R12W, T5S are several tunnels and two shafts driven in the Pilgrim Formation near the Pioneer batholith contact. The tunnels are now caved in, but the two shafts are still open. The mine dumps contain white to yellow-brown; coarsely-crystalline dolomite which is stained a dark purple-red by iron. Open spaces have been formed in these rocks by water leaching some unknown substance from dolomite. These workings were most likely developed in order to test whether the iron-staining indicated ore; there is no evidence of structural control.

Location 3. In the SW $\frac{1}{4}$  SE $\frac{1}{4}$  NW $\frac{1}{4}$  sec 27, R12W, T5S a tunnel follows the bedding of the Pilgrim Formation. The beds strike N17W and dip 60° NE. The Pilgrim is heavily

fractured and is marmorized; the Pioneer batholith is approximately 50 feet to the west. No signs of mineralization were found in the mine dump.

Location 4. In the SE $\frac{1}{4}$  SW $\frac{1}{4}$  NE $\frac{1}{4}$  sec 28, R12W, T5S an adit was placed into the Central fault. The tunnel reportedly curves west into the Missoula Group and contains "mineralization" (Brown, 1980). The prospect was located in the early 1970's on the basis of exploration similar to that of "water witching" with a forked stick.

Location 5. In the NE $\frac{1}{4}$  SE $\frac{1}{4}$  sec 28, R12W, T5S a large number of prospect pits, caved tunnels, and caved shafts penetrate into the Meagher Formation. Many of these workings are located near the large quartzite member; others are located where there is no apparent structural or stratigraphic control for ore deposition. All of the mine dumps lacked evidence of mineralization and many dumps were completely decomposed. The prospects near the quartzite may have been dug into a presumed fault. A large number of prospects were dug in attempts to find extensions of the Polaris fault (Brown, oral communication).

Location 6. In the S $\frac{1}{2}$  SE $\frac{1}{4}$  SE $\frac{1}{4}$  sec 28, R12W, T5S are two collapsed adits which were dug into the Madison Group. These tunnels are much more extensive than most of the pros-

pects because the mine dumps are larger than most other mine dumps. The tunnels were driven 50 feet above the junctions of the Splay fault with the Silver King fault and with the Polaris fault. No evidence of mineralization occurs on the mostly decomposed dumps. It is unknown why these mines were placed at this location.

Location 7. In the  $S\frac{1}{2}$   $S\frac{1}{2}$   $SE\frac{1}{4}$  sec 28, R12W, T5S are a number of caved tunnels and shafts within the Madison Group. These mines are located along the Silver King fault and are part of the Silver King mine system. The limestone is seen to be heavily fractured along the fault, as well as marmorized next to the fault. Blue-green staining is visible in some of the mine dumps. The ore on the dumps has been removed since 1972 (Brown, oral communication), however, the ore in these mines has the same mineralogy and appearance as the ore found within the Polaris mine.

Location 8. In the  $E\frac{1}{2}$   $SW\frac{1}{4}$   $SE\frac{1}{4}$  sec 28, R12W, T5S are several collapsed tunnels and a small shaft located in the Madison. One collapsed tunnel was found in the Missoula Group. Some blocks of Missoula Group rocks on one dump contain quartz filled fractures. The mine dumps, which contain limestone, are mostly decomposed. These mines probably were placed along the Central fault in the belief that the fault

was a continuation of the Polaris fault.

Location 9. In the c SE $\frac{1}{4}$  SW $\frac{1}{4}$  sec 27, R12W, T5S two caved tunnels and one open tunnel are located in Madison Group rocks near the Pioneer batholith. One of the dumps contains a dense, idocrase skarn. A piece of ore, showing the black streaks typical of high grade ore from the Polaris mine, was found by the dump around the open tunnel. These mines were probably created in the search for a contact metasomatic deposit. The tunnels, now collapsed, were much more extensive than most workings in the district. Winchell (1914) mentioned two mines in operation around 1886 which extracted a considerable amount of ore along a quartz monzonite-limestone contact. Log cabins in the area appear very old and wooden rails were found in the open adit, suggesting that this area fits that time period.

Location 10. In the N $\frac{1}{2}$  NW $\frac{1}{4}$  NW $\frac{1}{4}$  sec 34, R12W, T5S several collapsed tunnels and several open tunnels were found in the Madison Group. These mines are located on the northern slope of Polaris Ridge. These dumps vary from decomposed to well preserved. No evidence of mineralization was seen. It is not known why these mines were emplaced.

Location 11. In the SE $\frac{1}{4}$  SW $\frac{1}{4}$  NE $\frac{1}{4}$  sec 33, R12W, T5S several relatively large, collapsed workings were found in Mad-

ison Limestone. Exposures of the limestone showed extensive fracturing and some slickenslides. The limestone is very white, but it is not known whether this is due to diagenesis or bleaching from ore solutions. No ore was seen on the mine dumps.

MINERALOGY OF THE POLARIS  
MINING DISTRICT

The mineralogy of the Polaris mine was determined by means of thin sections, polished surfaces, and an Auger microprobe. The metallic minerals are pyrite, sphalerite, galena, pyrargyrite(?) and native silver. Calcite and quartz were found as gangue in the vein.

Pyrite is found within quartz, is isotropic, has a yellow color and high reflectance, and shows a cubic habit. It appears in places as islands surrounded by sphalerite, and locally is cut by fractures which are filled with sphalerite (Figure 11). The sphalerite shows a preferred association with pyrite and is commonly found as cubic pseudomorphs. The sphalerite is a medium gray which shows red pits under crossed nicols. The sphalerite replaces pyrite outward from fractures.

Galena is an isotropic, highly reflective, white, cubic mineral which shows triangular pits (Figure 11). The galena occurs in a gangue of quartz. Fractures within galena are filled with pyrargyrite(?). The pyrargyrite(?) is a blue-gray, anisotropic, and under cross nicols it is a bright orange. Pyrargyrite(?) replaces galena on grain borders and along internal fractures (Figure 11). Quartz is also found in the center of these fractures. Relicts of galena are

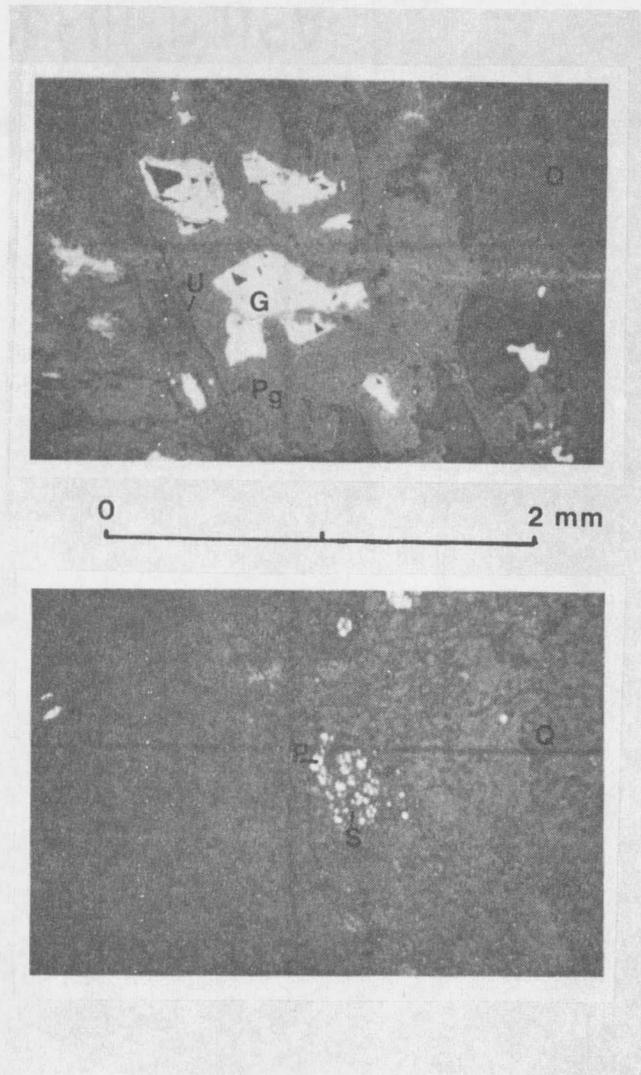


Figure 11. Photomicrographs of the ore mineralogy in the Polaris mine. Upper photomicrograph shows that galena(G) was replaced by pyrrargyrite(Pg) along internal fractures. The unknown (U) replaced pyrrargyrite along fractures at this location. Quartz(Q) occurs as gangue. In the lower photomicrograph pyrite is replaced by sphalerite(S).

isolated within the pyrargyrite(?). Microprobe results show that silver occurs within the galena.

Native silver was not observed in polished sections, but it was found in hand samples as flakes in highly colored ore.

An unidentified gray mineral is seen to replace pyrargyrite in polished section (Figure 11). This mineral is anisotropic and has no distinguishing features.

The limestone around the vein has been silicified. Blue-green stains were found, but there were no associated copper minerals. Copper minerals were reported (Geach, 1972), but none were seen by the writer; copper was mined from the upper levels.

The Auger microprobe of the Montana State University Physics Department was used to determine the elements present in the ore samples. The microprobe measures the energies given off from a sample bombarded with electrons. These energy measurements are then used to determine what elements are present. Any element which is in concentrations of less than 1% by volume cannot be detected by the microprobe. The samples were polished surfaces which measured less than  $\frac{1}{2}$  of a square centimeter. The galena registered strong lead, sulfur, and silver peaks. The black streaks,

which are mined as ore, did not register any metallic elements, suggesting that the silver, if present, is dispersed throughout the sample in concentrations of less than 1% by volume. The pyrargyrite registered a silver peak and antimony(?) peak. The results for the pyrargyrite are questionable due to a build-up of electric charge upon the specimen.

It could not be determined whether the galena was formed at the same time or at a later time than the sphalerite. The paragenetic sequence is shown in Figure 12.



## CONTROLS ON ORE DEPOSITION

From observations made in the Polaris mining district, it is believed that there are several controls over ore deposition. Faulting is the predominant structural control and lithology is the predominant chemical control.

### Structural Controls

The most apparent structural control upon ore deposition are the N60E faults. The two ore bodies in the district occur along the Polaris fault and Silver King fault respectively. These two veins have produced most of the silver from the Polaris mining district (Geach, 1972; Brown, oral communication).

East-west faults were present during ore deposition, but contain no ore. The east-west faults and the N60E faults differ only in their trends; therefore, the N60E faults are believed to have been oriented parallel to maximum compressive stress at the time of ore deposition and became an area of low pressure, while the east-west faults were closed by a component of the stress. Although it is possible that the N40E faults were present at the time of ore deposition, because in other mining districts in the Pioneer Mountains, ore deposition followed emplacement of the Pioneer batholith (Berger and others, 1979). In the Polaris mining district

the batholith was emplaced after the N40E faults. It is believed, therefore, that a  $20^{\circ}$  difference occurred between the maximum principal compressive stress (N60E) and the N40E faults. This difference was sufficient to cause a component of the stress to seal off these faults from the ore-bearing solutions.

Fault gouge may act as a barrier which channels ore-bearing solutions along the fault in the heavily fractured wall rock.

Though the Polaris fault provided a pathway for the migration of ore-bearing fluids, other structural controls helped to form an economic deposit. Protore is emplaced along most of the fault, but ore is usually found at the intersection of the Polaris fault with cross-structures (Figure 13). The ore increases in grade and in volume where joints intersect the Polaris fault (assay values courtesy of Midnight Mining Corporation), and the ore becomes extremely rich and wide where the Polaris fault intersects another fault; the Montreal stope (Figure 13) is a good example of this, as well as the eastern edge of the vein on the 230 foot level. The stopes in the mine were developed along the intersection of these faults. In the Polaris mine the east-west faults contain rich ore at their intersections with the

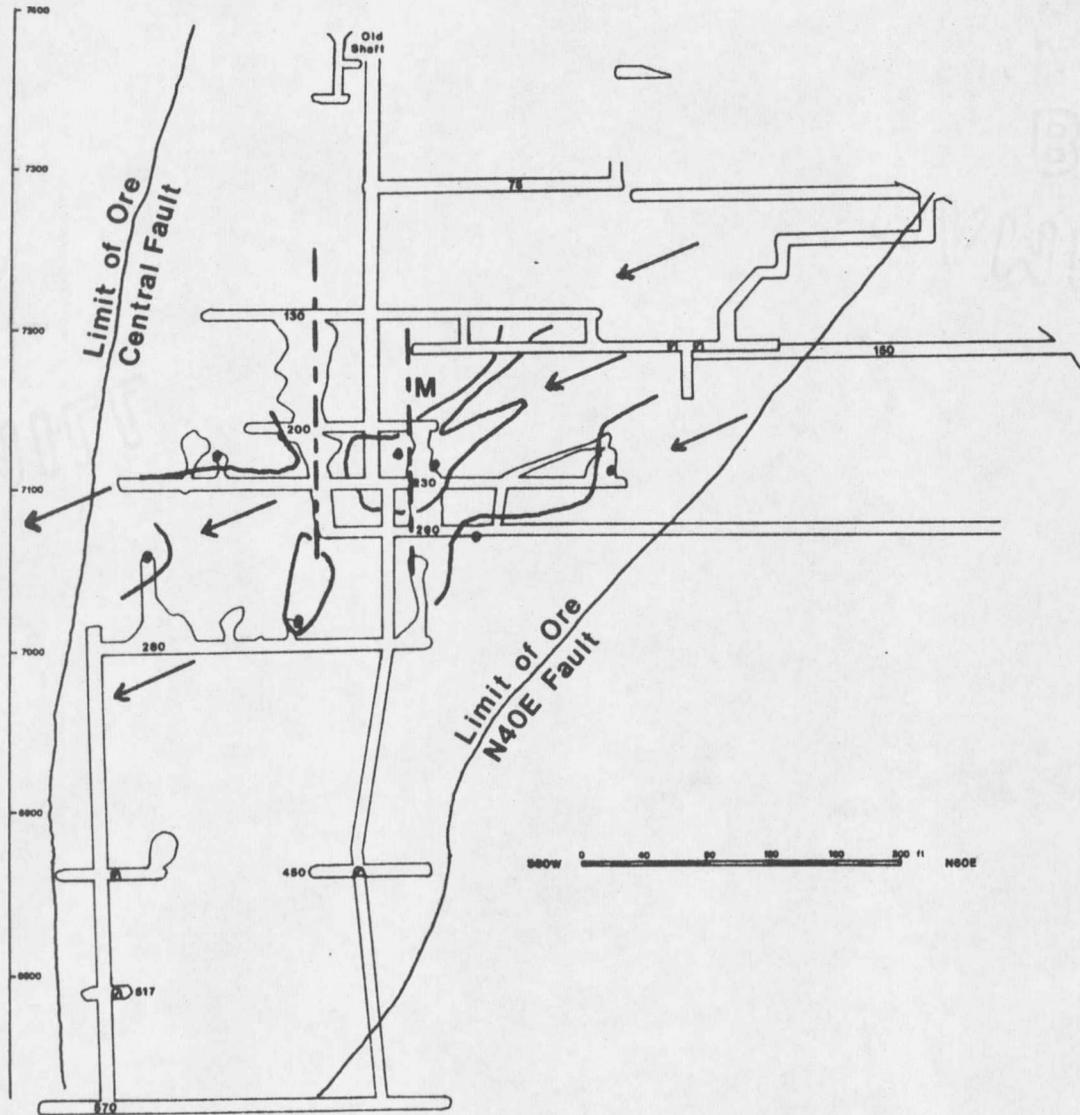


Figure 13. Longitudinal section in plane of Polaris vein (Polaris fault). View looks  $N 30^{\circ} W$ . Polaris fault intersected by E-W faults (dashed lines) and by  $N 45^{\circ} W$  faults (arrows). M is above Montreal stope. Solid curved lines contour silver values at 50 oz/ton; black dots show areas of over 100 oz/ton silver. Richest ore is located at the intersections of the 3 fault systems.

Polaris fault (Figure 13). Small N45W faults are formed within the Polaris mine, but are not visible on the surface. The intersection of these faults with the Polaris fault produces lines of intersection which plunge  $22^{\circ}$ SW. This plunge matches a trend of the ore bodies (Figure 13). Ore occurs as discontinuous pods along this linear trend, which suggests that the highest grade ore is formed by an intersection of three faults: the Polaris fault, the east-west system, and faults of the N45W system. It could not be determined what effect, if any, the Polaris fold has upon the grade of the ore. The fold did occur after the faults, so the attitude of the orebodies will change as they enter the lower levels.

Breccias which are found at the intersection of faults within the Polaris mine provided a large, low pressure pathway for ore fluids which exposed a large surface area of limestone to be replaced by ore-fluids. Limestone clasts which are supported by a calcite matrix compose the breccia.

The boundaries of the Polaris vein are determined by the structure. The northeastern limit of the Polaris vein occurs where a N40E fault cuts the Polaris fault; the plunge of the intersection of these faults coincides with the easternmost extent of the ore. The northwestern edge of the

Polaris vein is located at the intersection of the Central fault with the Polaris fault. The vein ends where the Madison Group is displaced by the Central fault. The intersection of the vertical western boundary with the eastern boundary determines the depth to which the vein may extend, to approximately 6,500 feet above sea level (Figure 13). The mine has been extensively developed above the 260 foot level.

Should the levels below the 280 foot level be opened it would be worthwhile to determine if the small folds near the fault (Plate 3) have an effect on ore deposition. Detailed mine maps of more than one level would give a more accurate prediction of where to find ore.

The ore is not a result of structural control alone. Some ore lenses are found next to the Polaris fault where no structure is apparent. These lenses are a result of chemical control as discussed below.

#### Chemical Controls

The most important regional chemical control is the presence of a carbonate unit. In the Pioneer Mountains the Madison Group, the Jefferson Dolomite, and the Cambrian dolomites are the most important ore-bearing formations (compiled from Geach, 1972). In the Polaris mining dis-

trict, ore is not found in the Precambrian Belt, even though ore will occur across the Central fault in the Madison Group.

In the Polaris district certain beds of limestone, within the Madison Group, are more receptive to the deposition of ore even though adjacent limestone beds appear similar in every respect. It was not determined why these beds are more favorable for ore deposition.

Silicification has affected the wall rocks surrounding the Polaris fault. The silicification may have promoted extensive fracturing and brecciation before ore deposition.

Ore fluids presumably originated from volatiles concentrated during the final stage of formation of the Pioneer batholith. Work done by Berger and others (1979) in the southern Pioneer Mountains showed that veins were formed after the batholith had intruded into the area. Ore fluids were under pressure, such that they could be injected along joints for distances of a few feet.

Pressure and temperature may have caused a zonal arrangement of metals in the Polaris mine. Sphalerite and galena are reported by Geach (1972) to occur mainly in the lower levels. These minerals also are found mainly along the western edge of the Polaris vein in the 260 foot level. Copper was not found in the 260 foot level, but Geach (1972)

reported that copper was found in the open cut. The zones of the vein downward from the surface are: (1) copper and silver, (2) silver, and (3) lead, zinc, and silver.

In conclusion, the major controls upon ore deposition are: a N60E fault, the Madison Group, and faults and joints which intersect the N60E faults. In some districts in the Pioneer Mountains the Cambrian dolomites serve as an ore-bearing unit; however, it was not determined whether they are favorable for ore deposition in the Polaris mining district.

## SUMMARY

In the Polaris mining district, ore occurs in Madison Group limestone. However, the Cambrian dolomites may carry ore in other parts of the district when they are cut by N60E faults.

The structures in this district were formed during six episodes of faulting and several episodes of folding. The N60E faults, which are a major host for ore deposition, were formed during the fourth episode of faulting.

The Pioneer batholith, which cuts the first five episodes of faulting, created a skarn along its contact with the Madison limestone. The skarn was reported to yield high grade silver ore (Winchell, 1914). The ore emplaced along faults is closely related temporally and spatially to the batholith. The Madison is recrystallized along faults where hydrothermal activity was important. Iron was the first metallic element to be deposited, followed by lead and zinc, and then silver. The paragenetic sequence from youngest to oldest is: pyrite, sphalerite, galena, pyragyrite(?), and native silver. Supergene enrichment does not appear to be significant or extensive.

In the Polaris mine, silver and lead orebodies are disc-shaped next to the plane of the Polaris fault and extend several feet into the Madison Group on the footwall

side of the fault. The discs are generally aligned along a linear  $22^{\circ}$  S60W trend and a vertical trend, and are probably controlled by intersections of the Polaris fault with the N45W and the east-west faults respectively.

## RECOMMENDATIONS

Several areas within the Polaris mining district show potential for the production of silver. These areas are located (Figure 14) and methods for further exploration are proposed. Faults discussed below are located on Figure 5.

### Polaris Mine

The lower workings of the Polaris mine offer the best potential for silver ore since the lower half of the vein has not been extensively mined (Figure 9). The strong association of pyrargyrite(?) with silver-bearing galena, and Geach's (1972) observation of higher galena concentrations in the lower levels further suggests that a favorable grade of ore will be encountered below the 280 foot level (location A, Figure 14).

### Other Mines

The Silver King mine is a site of extensive, past ore production and should be carefully examined (Figure 14, location B). The workings at location C (Figure 14) should be examined since they have been extensively mined. The trend of the fault zone is unknown.

### Surface

The Lost Cloud fault (Figure 14, location D) and the displaced segment of the Polaris fault (Figure 14, location

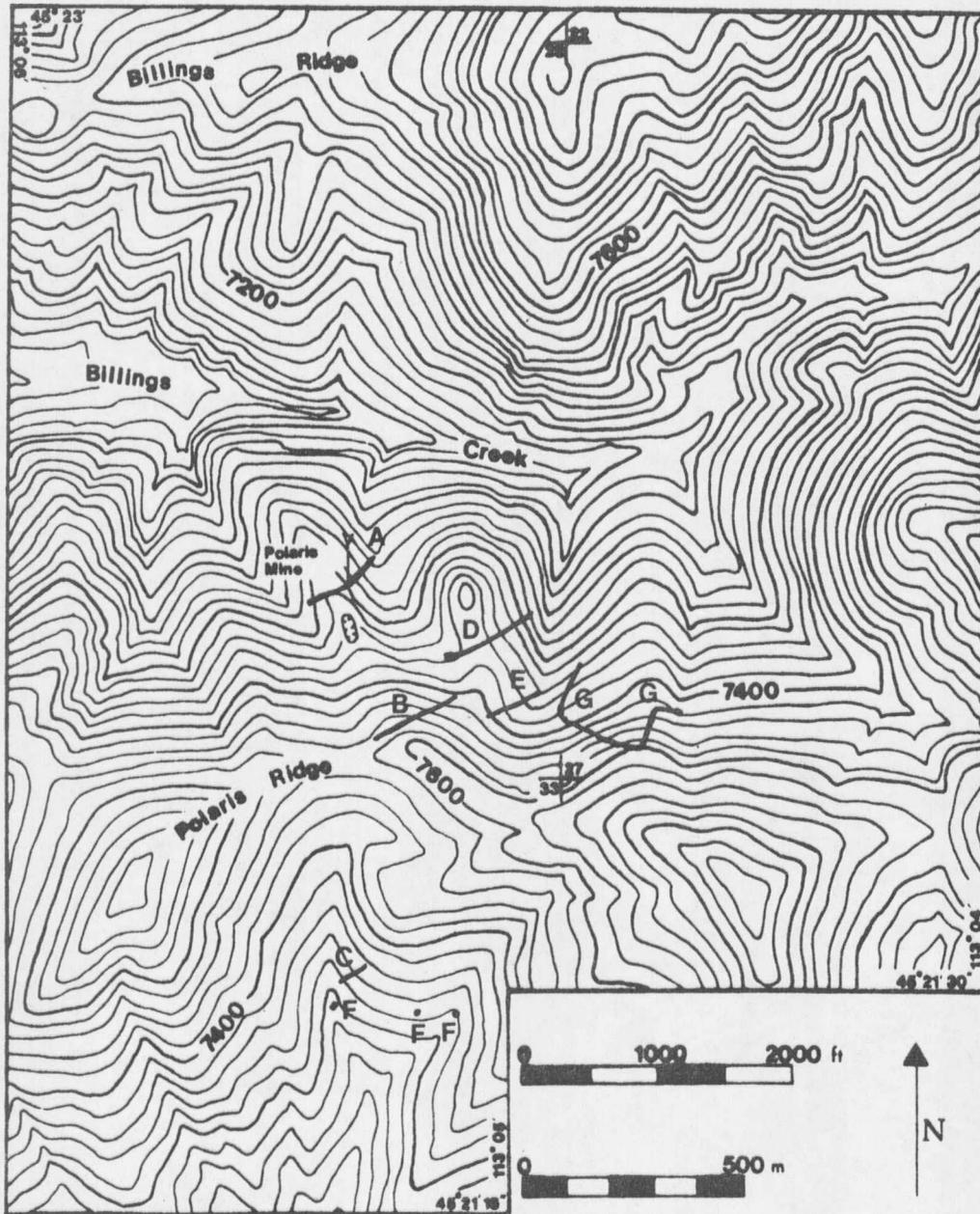


Figure 14. Location of exploration targets. Faults with a favorable N60E strike are represented by letters A through E, probable location of breccia pipes are represented by F, and G indicates a favorable skarn developed in the Madison Group.

E) should be tested for indications of silver ore. The faults contain carbonate units of both the hanging wall and the footwall, increasing the potential for a large deposit of silver ore. Mining operations would avoid the incompetent Missoula Group which is found in the Polaris mine.

Another, less favorable, possibility for ore formation would be along possible breccia pipes formed at fault intersections (Figure 14, locations F). If a carbonate host rock is brecciated to produce open space, then a silver deposit might be found due to migration of solutions into the resulting low pressure zones.

The largely covered contact between the Pioneer batholith and the Madison Group (Figure 14, location G) could be prospected for tungsten, molybdenum, and silver. No favorable alteration of the quartz monzonite, such as greisen, was found. The contact is promising because of Winchell's (1914) report that silver was found there and because of the occurrence of tungsten and molybdenum in nearby mining districts.

The area north of the Polaris mining district has not been mapped, but it does have Cambrian dolomites in contact with the Pioneer batholith. It is believed this area would be under the same structural and chemical controls as the

Polaris mining district; furthermore, Cambrian dolomites have been mineralized in other parts of the Pioneer region.

### Exploration

A closely-spaced electric or electromagnetic survey might reveal small faults which are not evident on the surface. The Polaris mine has demonstrated that many small faults are present. A gravity or magnetic survey would possibly determine the depth to the Pioneer batholith. This would be important near the batholith where an orebody might be found, but which could be cut off at a shallow depth by the batholith.

A close-spaced geochemical soil survey in the immediate vicinity of all favorable prospects (Figure 14) may reveal mineralization. The survey should test for lead, zinc, copper, and silver; along the Pioneer batholith the survey should also test for tungsten and molybdenum.

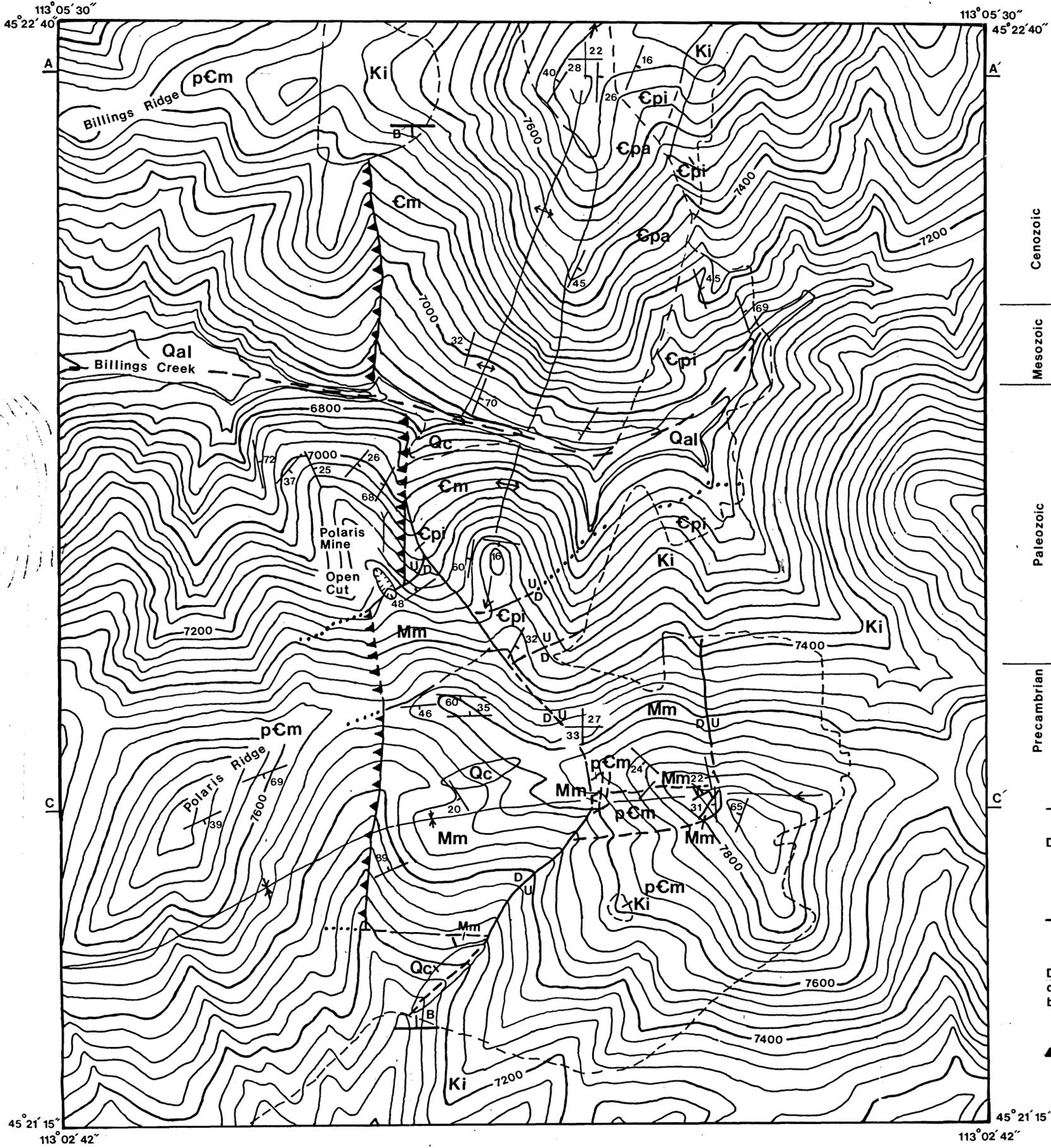
Limestone is always stained a brown color next to the ore, but this zone is only a few feet thick. The Madison is easily recrystallized to a white limestone and may indicate a fault or a nearby igneous intrusion. White Madison Group rocks occur along the Silver King fault (Figure 14, location B) and the prospect in SE $\frac{1}{4}$  SW $\frac{1}{4}$  NE $\frac{1}{4}$  sec 33, R17W, T5S (Figure 14, location C). The Madison Group limestones are the most

favorable host rock for ore deposition throughout the Pioneer Mountains..

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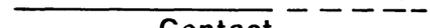
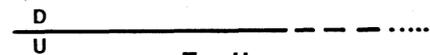
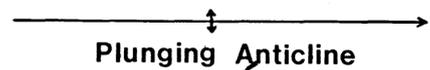
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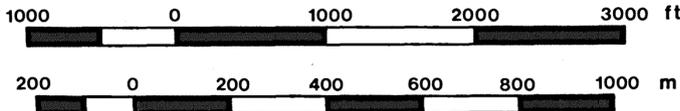


**Plate 1**

**MAP EXPLANATION**

Cenozoic	Qal	Alluvium
	Qc	Colluvium
Mesozoic	Ki	Pioneer Batholith
	Mm	Madison Group
	Cpi	Pilgrim Formation
Paleozoic	Cpa	Park Formation
	Cm	Meagher Formation
	pCm	Missoula Group
Precambrian		

- 
**Contact**  
 Dashed where approximately located.
- 
**Fault**  
 Dashed where approximately located; dotted where inferred. U marks upthrown block, D marks downthrown block.
- 
**Thrust Fault**  
 Teeth are placed on the upper plate.
- 
**Plunging Anticline**
- 
**Plunging Syncline**



Contour Interval 40 Feet

**GEOLOGIC MAP OF THE POLARIS MINING DISTRICT, PIONEER MOUNTAINS, BEAVERHEAD COUNTY, MONTANA**

By  
 Thomas Edward Davis  
 1980

Submitted in Partial Fulfillment for the Degree of Master of Science in Earth Sciences at Montana State University

33 / Strike and dip

# Plate 2

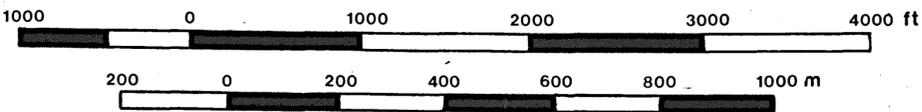
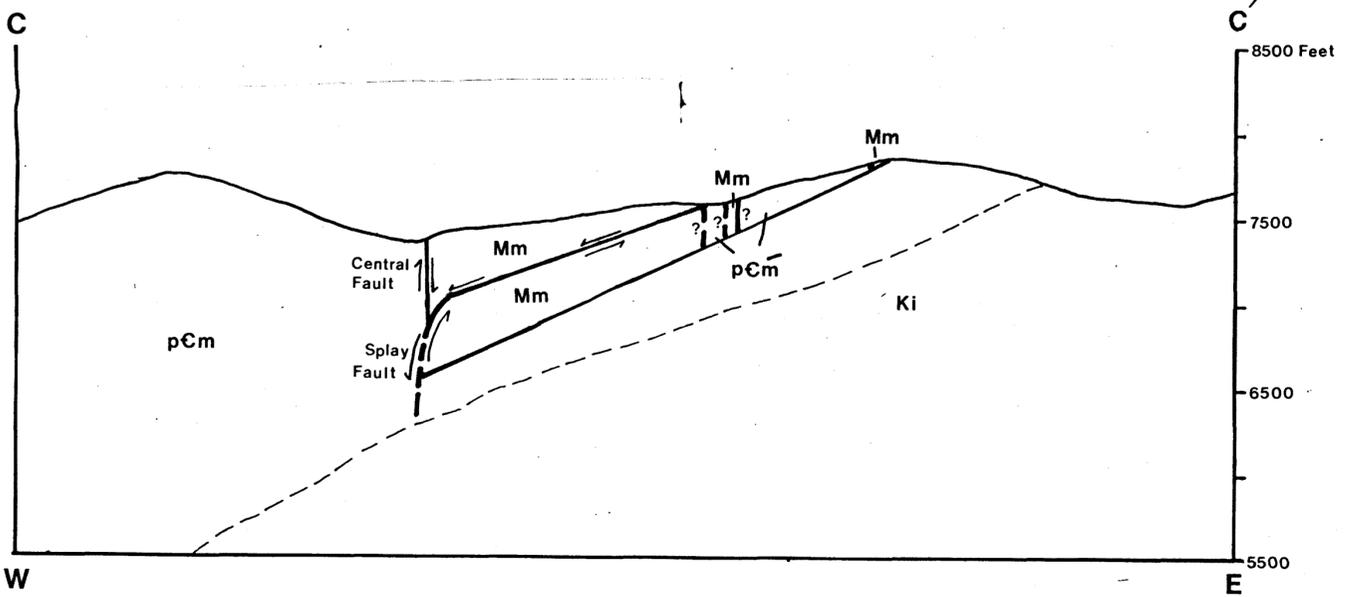
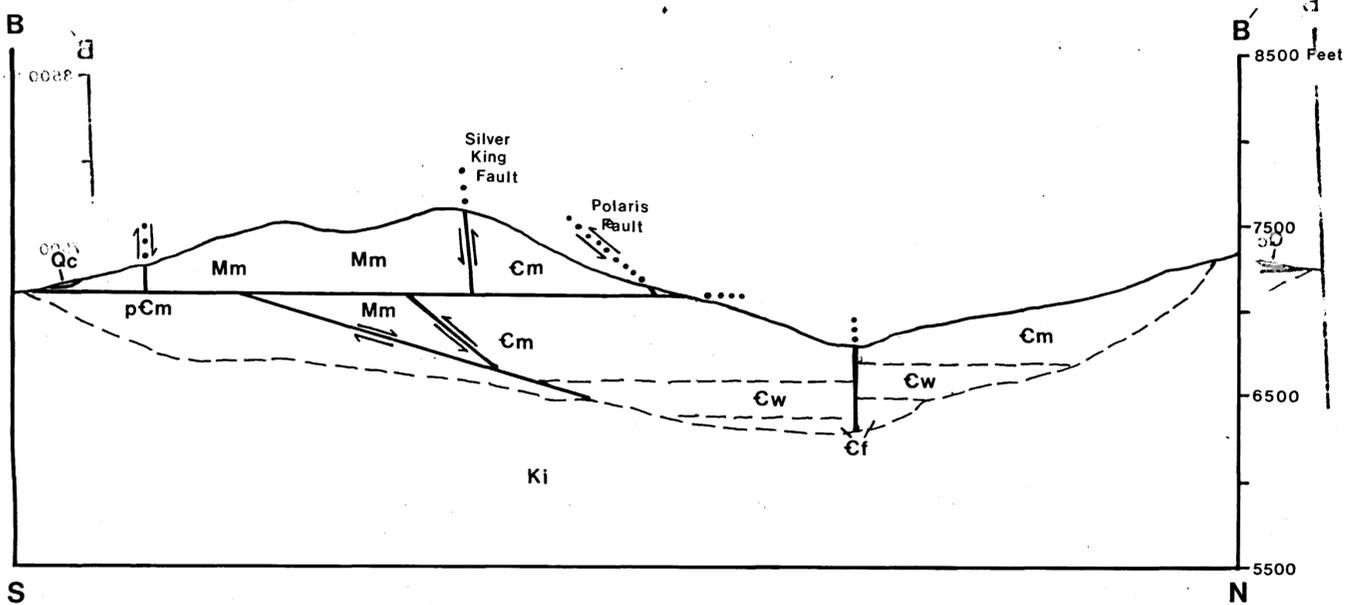
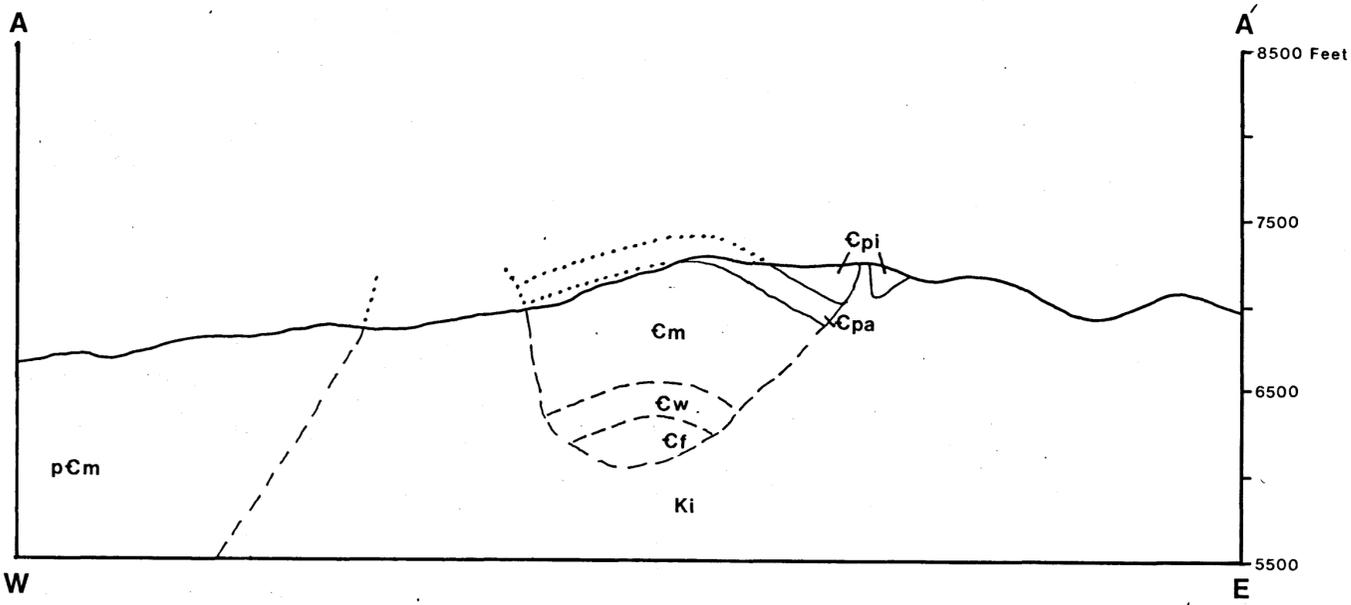
## MAP EXPLANATION

Cenozoic	Qal	Alluvium
	Qc	Colluvium
Mesozoic	Ki	Pioneer Batholith
	Mm	Madison Group
Paleozoic	Cpi	Pilgrim Formation
	Cpa	Park Formation
	Cm	Meagher Formation
	Cw	Wolsey Formation
	Cf	Flathead Formation
Precambrian	pCm	Missoula Group

**Contact**  
Dashed where approximately located.

**Fault**  
Dashed where approximately located.

Submitted in Partial Fulfillment for the Degree of Master of Science in Earth Sciences at Montana State University  
By  
Thomas Edward Davis  
1980



No Vertical Exaggeration

GEOLOGIC SECTIONS OF THE POLARIS MINING DISTRICT, PIONEER MOUNTAINS, BEAVERHEAD COUNTY, MONTANA





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