Geology and Ore Deposits of the Jardine Mining District, Park County, Montana

Douglas M. Dowell

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GEOLOGY AND ORE DEPOSITS
OF THE JARDINE MINING DISTRICT,
PARK COUNTY, MONTANA

by
Douglas M. Dowell

A Thesis
Submitted to the Department of Geology
In Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
BUTTE, MONTANA
May 1940
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Figure 1. Relation of drag folds to a larger fold.  15

2. Diagram illustrating the approximate sequence of mineral deposition in the Jardine veins.  28
This report is based upon laboratory work accomplished during the 1939-1940 school year at the Montana School of Mines, supplemented by two days of field work conducted on March 22nd and 23rd in the Jardine district. The field work consisted of a general reconnaissance of the district and a more detailed study of the mineralized zone. It was necessarily limited owing to the fact that the study was undertaken during the winter months when the climate in this part of the country is rigorous, the snows deep, and any geologic work is consequently arduous and unsatisfactory.

The laboratory work consisted of microscopic examinations of the ores and rocks to determine the mineralogy and the mineralogical relationships of the ores and wall rocks. Special attention was given to the study of the
wall rocks as they presented many intricate problems regarding their origin and relationships.

Photomicrographs of the ores and wall rocks were made, as well as underground photographs of characteristic features of the veins.

LOCATION AND ACCESSIBILITY

The Jardine mining district is in the extreme southern part of Park County, Montana between the parallels of latitude of $45^\circ$ and $45^\circ\ 10'$ and the meridians of $110^\circ\ 30'$ and $110^\circ\ 40'$. Jardine is five and one-half miles northeast of Gardiner, Montana, the northern entrance to Yellowstone National Park.

This region is readily accessible from Livingston by the Park to Park Highway No. 89, to Gardiner, and the rest of the way by an improved dirt road, maintained by the county. Gardiner is the terminus of a branch line of the Northern Pacific Railroad which connects with the main line at Livingston. All roads are kept open throughout the year, except after a heavy snowfall, when they may be blocked for a few days.

TOPOGRAPHY

The town of Jardine lies in the deep, narrow valley of Bear Creek at an elevation of 6,450 feet above sea level.
It is in the Absaroka Range, which extends southward from Livingston to Yellowstone National Park, where it terminates against the broad volcanic plateau of the park. Palmer Mountain rises steeply above Jardine to an elevation of 9400 feet above sea level. The relief of the district varies about 4000 feet between Palmer Mountain, in the east-central part of the district, and the Yellowstone River which is at an elevation of 5400 feet.

The area is well drained by Bear Creek and its tributaries, most of which are flowing throughout the year. Bear Creek flows in a southwesterly direction through the town of Jardine, and joins the Yellowstone River near the Park boundary one and one-half miles east of Gardiner. It is fed by the North Fork, Pine Creek, and numerous small streams north of Jardine.

Bear Creek supplies an abundant supply of water, a small fraction of which has been diverted and piped down to the Jardine Mining Company's hydro-electric plant. A head of 800 feet is supplied to the pelton wheel generator which furnishes electricity for all operations of the Jardine Mining Company and the town of Jardine.

The Yellowstone River flows northward past Gardiner to Livingston and then eastward. It separates the Absaroka Range on the east from the Gallatin Range on the west. Beyond the turn in the river near Livingston,
the broad river valley separates the Absaroka Range from the Crazy Mountains on the north. High plateaus and table-topped ridges are found on the eastern part of the Absaroka Range. The surface of the plateau is mostly gneiss and is drained by the north-east flowing Boulder River and its tributaries. South of the gneissic plateau are flat-topped volcanic ridges of nearly horizontal beds and sheets of lava.

ACKNOWLEDGMENTS

The author gratefully acknowledges the helpful suggestions and comments by Dr. G. F. Seager of the Geology Department of the Montana School of Mines and wishes to thank him for his interest, cooperation and patience during this study. The plans of the underground workings were furnished by Dr. Seager, as well as thin sections of the rocks and some of the polished sections of the ores that were used in this study.

The author is also indebted to Dr. L. L. Sloss of the Geology Department for his instruction and assistance in the microphotographic work, and to Dr. E. S. Perry, head of the Geology Department, who contributed many practical suggestions on the composition of this thesis.

Acknowledgments are also made to Mr. W. H. Hax, president of the Jardine Mining Co. for his cooperation, and to
Ray Gilbert, Geologist of the Jardine Mining Co. for his help on the structural geology of the mine, and for many specimens which he supplied for study.

PREVIOUS WORK

The general geology of Park County was mapped by the United States Geologic Survey in 1894 (Powell, 8).* The maps and a description of the area, including the general geology, was published in the U. S. Geological Survey Folio No. 1 by J. W. Powell.

The Gardiner thrust fault, the largest fault in the district, was mapped by a party under the direction of C. W. Wilson Jr. in 1934 (Wilson, 15).

Several studies have been made in the Jardine and Crevasse districts. A general report on the Jardine mine was made in 1925 by E. H. Robie. It covered the general nature of the ore deposits and the mining and milling practices employed (Robie, 9).

Winchell made an examination of the tungsten minerals that occur in the Jardine mine.

An extensive examination of the Jardine and Crevasse Mountain area was made by Dr. George F. Seager for the Montana State Bureau of Mines and Geology. This included the mapping of the general geology of the area, as well

*Refer to bibliography.
as an extensive study of the mineralized zones.

GENERAL GEOLOGY

The rocks in the Jardine district include a series of metamorphic rocks of probable pre-Beltian age; a group of intrusive rocks including granite, and coarse and fine-grained diabase; and extrusive rocks including andesite porphyry, rhyolite, basalt, and andesite breccia.

METAMORPHIC ROCKS

The metamorphic rocks are here called pre-Beltian rocks, a term used for schists or gneisses which are older than the Belt formation which is found in many localities in Montana. They have never been correlated with areas of differentiated Archean and Algonkian rocks. The Jardine metamorphic rocks are dominantly of sedimentary origin as are the metamorphic rocks of the Cherry Creek series of the Tobacco Root Mountains, and may be of the same age. They are highly folded and metamorphosed and are exposed over a large part of the area.

Mica-Schist

The mica-schist is the most abundant rock in the district and is found in the mineralized zone. It varies in color from a brownish-gray in some varieties to a
grayish black in others. The brownish gray varieties are composed mainly of quartz, biotite and muscovite, with minor amounts of plagioclase, chlorite, apatite, zircon and in some cases magnetite or arsenopyrite. The grayish black schist is composed mainly of quartz and biotite.

Light tan colored schist composed of quartz and muscovite with minor amounts of other minerals are found grading into the darker varieties. Dark green schists containing a large amount of chlorite are also common.

In the average mica schist in this region quartz makes up about 70 per cent of the rocks and the mica about 25 per cent. The various accessory minerals constitute the remaining 5 per cent. The above percentages vary greatly in some of the different types found.

The textures vary from a highly foliated or schistose texture to a massive texture with little or no schistosity. The highly schistose texture in some of the rocks is caused by the parallel orientation of the cleavage planes of the mica.

Some of the schists, especially in the mineralized zone, contain prominent well-formed crystals of dark red garnet, giving the schists a texture simulating the porphyritic texture of some igneous rocks. The garnets range in size from microscopic-size crystals to about a half
inch in diameter.

These mica schists are rocks that have attained a high rank metamorphic condition. The original material from which most of them were derived was undoubtedly sedimentary, chiefly a quartzitic type with variable amounts of argillaceous material.

**Amphibole Schist**

The amphibole schist is very abundant in the Jardine district and occurs in mineralized zones in both the central and southern part of the mine, where it forms the wall rock of the veins. It is a fine-textured rock, dark gray or blackish in color. Some varieties of this rock appear very similar to a fine-grained igneous rock of dioritic character, but microscopic examinations show it to be probably of sedimentary origin. Other types have a foliated or schistose appearance caused by a localization of the metamorphic forces. It is composed mainly of amphibole and quartz, with minor amounts of biotite, plagioclase, chlorite, zoisite, and in some cases, magnetite.

The quartz in this rock is present in amounts which range from about 20 per cent to 30 per cent, whereas amphibole makes up from about 45 per cent to 80 per cent of the constituents. The type of amphibole in the rock varies in different parts of the district. In some of the rocks,
A. Amphibole (A) forming at expense of plagioclase (P)

B. Hornblende (H) replacing plagioclase (P)

C. Garnet crystal (G) in schist

D. Schist, containing tremolite band in hornblende, quartz and magnetite.

Plate III
the amphibole is a dark green to black hornblende; while in other rocks, a lighter colored amphibole which resembles cummingtonite is present. Under the microscope, thin sections show that in some cases the amphibole has developed by replacement of the plagioclase. This light-colored amphibole is abundant in some parts of the mineralized zone where it is impregnated with arsenopyrite and other ore minerals. Tremolite is also found as the amphibole in some of these schists. Near the ore zone dark red garnets are common in this rock.

IGNEOUS ROCKS

Both intrusive and extrusive igneous rocks are found throughout the district. They are common as dike, sill and flow rocks of many types. The extrusive rocks are later in age than the mineralization and in some cases cut the veins and faults which are of earlier age.

Intrusive Rocks

The intrusive rocks found in this district are granite, coarse-grained diabase, fine-grained diabase, and diorite porphyry. The diorite porphyry is believed to be an intrusive rock, although in some respects it resembles an extrusive rock.
Granite

The granite, which is of probable pre-Cambrian age, is the most abundant igneous rock in the district. It is a rather gneissic appearing, medium-grained hypidiomorphic rock, light-colored, containing large grains of muscovite or biotite. It varies in color, depending upon the kind of mica it contains, from a light brownish rock when muscovite is present, to a grayish rock when it contains biotite. A fine-grained, light-colored aplitic type occurs in the Conrad area. The quartz and feldspar is "peppered" with fine grains of muscovite.

A coarse-grained muscovite granite pegmatite, which originated from the salic residue of the granite magma, is found cutting the granite, as well as the neighboring schists.

Coarse-grained Diabase

A dark-colored, coarse-grained diabase, probably pre-Cambrian in age, is found on Crevasse Mountain. The dark color of this rock is caused by the high percentage of dark green amphibole that it contains.

Microscopically, it is seen to be composed chiefly of hornblende and plagioclase, with small amounts of biotite and ilmenite. The ilmenite has developed by replacement of plagioclase, and is present in the form of skeleton
crystals. No quartz was observed in thin sections.

**Diabase**

A fine-grained diabase, forming dikes and sills, occurs in many scattered parts of the Jardine district. The dike cutting the mineralized zone in the mine is formed of this rock. A very fine-grained diabase occurs on the divide between the North Fork and the main channel of Bear Creek, forming a bold outcrop which is visible from Jardine. It is also found in the Iron Duke area, and in the South Cut of the Jardine mine. A porphyritic diabase is abundant east of the road about one and one-half miles south of Jardine.

The diabase is a fine-grained, dark-colored, blocky appearing rock. Under the microscope, specimens from the Iron Duke area were seen to contain a light colored amphibole, probably actinolite; and plagioclase, with minor amounts of biotite, chlorite and zoisite.

Specimens from the South Cut showed a small amount of quartz in addition to the amphibole and the plagioclase. The porphyritic diabase contains plagioclase phenocrysts up to three-quarters of an inch in diameter. The microscopic examination of this rock showed that the plagioclase contained veinlets of quartz cutting the phenocrysts. The fine-grained matrix of this rock is composed of quartz,
Diorite Porphyry

Palmer Mountain is composed mainly of diorite porphyry. This is believed to be an intrusive rock, although it has some characteristics of extrusives. It has a light-colored microcrystalline matrix with very small phenocrysts of pyroxine.

Microscopically, this rock is seen to be composed chiefly of feldspar and quartz, with minor amounts of sericite and biotite. The feldspar has been somewhat sericitised, with the formation of sericite in and around the feldspar crystals.

Extrusive Rocks

Extrusive rocks are found in many parts of the district. Several types are found including andesite porphyry, rhyolite, basalt, and andesite breccia.

Andesite Porphyry

Andesite porphyry occurs on Mount Baldy east of the Snowshoe mine. It is also present west of the Watson claims. The color of this rock varies from dark-brown to black. The phaneritic matrix contains small phenocrysts
of pyroxene and lath-like phenocrysts of plagioclase which range up to half-an-inch in length.

Microscopically, this rock is seen to contain long narrow crystals of plagioclase, fine anhedral quartz, and small euhedral pyroxene crystals. A small amount of a black opaque mineral, probably magnetite, is present in this rock.

Rhyolite

This rock is common west of Jardine and west of the road approaching Jardine. It has a merocrystalline matrix containing small phenocrysts of quartz and feldspar. Examined under the microscope, the flow structure is easily seen. Small crystals of magnetite and sericite were observed.

Some rocks of the same composition with a vitrophyric texture are found with the rhyolites. These rocks have a black, glassy matrix containing medium-sized feldspar and quartz phenocrysts.

Basalt

Basalt occurs in the Decker flat region where it is found overlying schists and stream gravels. It is a dark gray or black, vesicular rock containing plagioclase
phenocrysts in a phaneric matrix. The vesicular texture makes this an easy rock to recognize.

Andesite Breccia

This rock is found in the area north of Pine Creek, in the region northeast of Jardine, and abundantly on the divide between the North Fork and the Main Fork of Bear Creek, north of the mapped area. The andesite breccia has a brownish or dark-reddish color. It has a very irregular fracture which is iron stained on weathered surfaces.

STRUCTURAL GEOLoGY

The schist of the metamorphic series in the Jardine mine are folded and contorted to a high degree. Slipping along between planes of weakness are evident, and drag folds are found throughout the schist. The drag or minor folds are controlled by the major folds. (Fig. 1)

Where drag folds are found, there is a thickening of the schist that probably represents a zone of weakness. It is probably best developed near the crests and troughs of the major folds, while thinning of the zone of weakness is likely to occur along the limbs.

In general, the folding of the schists has a north-south
strike, and dips about 45° W., with a southwest pitch.

Several faults cut the schist in the mine. The best known is the Bear Gulch fault, a very large fault which has been identified in many places in the mine. It has a strike of N. 20° E. and a dip of 40°-50° W. This fault is later in age than the other smaller faults that occur in the mine. It offsets the diabase dike in the mine, while the smaller faults were formed before the formation of the diabase dike. The early faults are designated by numbers, such as the 1209 fault. In general, they trend northwest and northeast.

The largest fault in the district is the Gardiner thrust fault, which has been traced from the northwest side of Cinnabar Mountain to three miles east of Mount Everts, a distance of thirteen miles. It has a strike of N. 60° W. and dips 35° to the northeast. Near Gardiner, the minimum throw is one mile and the minimum heave is one and a half
miles. This fault throws pre-Cambrian metamorphic rocks against the Paleozoic formations. Many tear faults connect with this major fault. Hot springs near the Yellowstone River rise to the surface along the fault plane. Travertine has been deposited from some of them.

A diabase dike, 30 feet thick, cuts the schist in the mine. It has a N. 15° W. strike and a dip of 80° W. The dike has been displaced by the Bear Gulch fault, but other faults do not displace it, showing that the dike is older than the Bear Gulch fault, but younger than the others. Another diabase dike has a north-south strike with a 45° W. dip. The north-south dike is probably a branch of the aforementioned dike. There seems to be no genetic significance to the dikes in relation to the ore deposits, but they may be connected with the relatively late volcanic activity in the area.

**GEOLOGIC HISTORY**

The observable geologic record of the Jardine district begins with events occurring presumably during pre-Beltian time, and therefore of early or middle pre-Cambrian date. Where observed in Montana, the Belt lies with marked discordance over the earlier metamorphic complex, and there is a great lapse of time represented, during which the ancient rocks were folded, intruded and
eroded before Beltian deposition.

The schists and gneisses differ greatly from the younger Belt formation; where known in Montana, the Belt is composed of thick beds of quartzite, sandstone, argillite, and limestone which has been only slightly metamorphosed. The schists in the Jardine district are thought to be pre-Beltian, as they resemble schists in other localities which are overlain by the altogether different Belt formation.

It was during this early age that these rocks, chiefly of sedimentary origin, were formed. Sometime after being raised above the sea, the sedimentary formations were intruded by both acidic and basic igneous rocks. It is possible that the ore deposits at Jardine were formed by mineralized solutions emanating from these pre-Cambrian igneous rocks. This was followed by dynamic activity, which produced a series of crumpled, metamorphosed rocks.

In the middle or upper part of the Cambrian period the region was inundated by shallow epi-continental seas. Numerous fluctuations in sea level occurred during the remainder of the Paleozoic and Mesozoic eras, and during the periods that the region was inundated, thick beds of sedimentary rocks were deposited. Because of the superincumbent load, the earlier complex undoubtedly
was further metamorphosed by static metamorphism.

Uplifting of this region began near the close of the Cretaceous period and continued into early Tertiary time. Since uplifting, the region has been subjected to erosion, and all the sedimentary rocks younger in age than pre-Beltian have been removed.

The time of the late igneous activity can not be definitely determined, but it probably accompanied and followed the uplifting of the region. Much of it is undoubtedly contemporaneous with the Tertiary volcanic outbursts which are represented by the volcanic rocks of Yellowstone National Park.

Pleistocene glaciation covered this district with a thick blanket of ice. Moraines, left by the receding glaciers, are found lying parallel to the sides of the valley along Bear Creek. Glaciation is also evidenced by granitic erratics which occur high on the slopes of Mount Baldy.

The ice sheet which once covered the Jardine area was probably the same mass of glacial ice which covered Yellowstone National Park. Giant granite boulders were left by the ice sheet on the brink of the Grand Canyon of the Yellowstone. A glacier capable of transporting such huge boulders must have been of tremendous size and scope.
ORE DEPOSITS

The ore deposits at Jardine have long been exploited for gold, and arsenic, and more recently for tungsten. The ore is found in mineralized lenses in the folded pre-Cambrian schists.

HISTORY OF MINING

Gold was discovered in the Jardine district in 1866 at the mouth of Bear Gulch. Placer mining operations were started and continued for a number of years. Long ditches were dug to divert water from the creek to the gold-bearing gravels on the creek banks.

Following the discovery of placer-gold in the stream, the surrounding mountains were prospected and the mineralized zone was discovered on the timbered slopes of Mineral Hill, near the junction of Bear Creek and the North Fork.

Development of the vein deposits began in 1884 by Major Eaton who installed a hydraulic power plant, a combined five-stamp mill, and a sawmill. Owing to the difficulties of transportation there was an early shutdown.

However, in 1890, five more stamps were added to the mill and mining resumed by Edgerton and Jewell,
of Helena. The mine was shut down during the crisis of 1893 and was idle for five years.

The present townsite of Jardine was laid out in 1898, when the Bear Gulch Mining Company was incorporated by Harry Bush. Many claims were bought up by this company and the mill was again enlarged, and good profits were made.

In the following years the ownership of the property changed hands several times, and in 1914 the Jardine Mining & Milling Company took over the properties through a landholders' foreclosure sale. A mass of litigation prevented reopening of the mine until 1917. The mine was purchased by the Jardine Mining Company in 1921 and refinanced.

Since 1936 the mine has been operated by Mr. W. H. Hax. A great deal of development work has been done since that time, both by tunnels (adits) and by diamond drilling. At the present time the mill is handling 175 tons of ore per day, and under the present management, the mine is being worked by a systematic method of mining for the first time.

MINERAL PRODUCTION

No official figures are available on the total production of the district. It is estimated that between
$3,500,000 and $5,000,000 in gold has been produced from the Jardine mine.

According to Ray Gilbert, $100,000 worth of Tungsten was mined around 1904-1905.

GENERAL CHARACTER OF DEPOSITS

The ore occurs as lenses in mineralized shear zones in the pre-Cambrian biotite-quartz schist. The zones are roughly parallel to the schistosity, to the original bedding, and to the slope of the mountain, although in some places they cut the schistosity of the wall rocks. The general strike of the veins is north and south, and the dip in most places is from 20°-35° W. The folding of the wall rocks is exceedingly complex, especially in the South mine. The veins follow very irregular anticlines and synclines whose axis pitch, in general, down to the southwest at varying angles.

The gold is found in several different types of ore. It is present in (1) massive sulphide ore, (2) in quartz ore as free gold, and (3) in altered schist rock with quartz and sulphides, the latter being chiefly oxidized. The above types vary considerably with the gradation of one type into another. Tungsten, in the form of scheelite, is found in pockets in the quartz veins.
DISTRIBUTION AND SIZE OF DEPOSITS

The ore deposits at Jardine occur in four main mineralized zones in the Jardine Hill. The mine has been divided into two sections, the North Mine and the South Mine; besides being a geographical division this designation has proven to be more or less geological as well.

The veins have a north-south strike throughout most of their length. The north end of veins No. 1 and No. 2, the most westerly veins, turn to the west and into the hillside in the South Mine. Veins No. 3 and No. 4 which are farther in the mine, have a N. 10° E. strike and may continue into the North Mine, although this connection has not been established. Because of certain northeast cross structures, the connection will be difficult to verify.

Number 1 vein is typically composed of three strands, and is quite narrow, varying from a few inches in width to a few feet. It is characterized by heavy arsenopyrite content. Where the sulphide strands of No. 1 vein changes direction and strikes northwest, there is a change in the mineral content of the ore. There is an increase in quartz and a corresponding decrease in arsenopyrite.

Number 2 vein is also a three strand vein, and has been one of the most productive veins of the mine. It
1000 LEVEL
JARDINE MINE
SCALE 1" = 100'
Plate IV.
typically carries quartz with free gold. Tungsten is also found in this vein.

Number 3 vein is a single-strand vein. It is essentially a quartz vein, with very little sulphides, and as a rule poor in gold content. It contains pockets of scheelite in the quartz. It varies in thickness, and is about 6 feet wide in places.

The No. 4 vein is a large single strand vein, being the largest vein known in the mine. It is over 800 feet long and has a vertical extent of 315 feet, and is 60 feet wide in some places. The average width is approximately 20 feet. (Robie, 9). This vein is essentially a quartz vein containing subordinate sulphides. Locally, vuggy quartz rich in megascopic gold is found. The vein averages from $3.00 to $6.00 gold per ton.

MINERALOGY OF THE ORES

Mineralogically the gold ores are of three types: massive sulphide ores containing gold, quartz with free gold, and altered schist with quartz and limonite with gold. The massive sulphide ores consist chiefly of arsenopyrite, subordinate marcasite and pyrite, quartz and gold. The gold is found both as inclusions in the arsenopyrite and as free gold in the quartz surrounding sulphide minerals. In the quartz ore, the gold is present as free gold
in the iron-stained quartz. The third type of ore is composed of soft, oxidized, iron-stained schist with limonite pseudomorphs formed by the replacement of arsenopyrite.

Ore Minerals

**Gold.**--Native gold occurs in finely disseminated particles in the quartz veins, and in quartz surrounding arsenopyrite. Gold also occurs as inclusions in crystals or arsenopyrite which can be observed under the microscope in polished specimens. (Plate VI)

The disseminated particles of gold are usually of very small size and are seldom observed in the ore. However, large specimens are sometimes found with the gold filling the cavities in the quartz.

**Arsenopyrite (sulpharsenide of iron).**--Arsenopyrite is the most abundant sulphide in the district. It occurs in fine and coarse textures, in large euhedral and subhedral octahedral crystals, and in large irregular masses. Beautiful crystals of it are formed in the quartz amphibole schist and in the quartz biotite schist. It is a common constituent of the quartz veins and occurs in the schists in quantities sufficient to make ore. Observed under the microscope, in polished specimens, tiny particles of gold are included in the arsenopyrite as well as in the surrounding quartz. (Plate VI) The crystals,
in larger masses, are fractured and cemented by quartz. The arsenopyrite decreases steadily in amount from the vein walls, in a direction away from the quartz.

Scheelite (calcium tungstate).--This mineral, which contains 80.6 per cent tungsten, occurs throughout the mine in small quantities. It is associated with quartz and the sulphide minerals. In some places almost pure chunks of it have been found. It is a brownish to reddish translucent mineral which can easily be identified by the use of a portable ultra violet ray machine. Iron-stained quartz may resemble scheelite, and mistakes can easily be made unless a test for fluorescence is made. The scheelite is commonly massive and cut by quartz veinlets. It is one of the early formed minerals and was fractured by later movement of the wall rocks, by faulting or by pressure, during late adjustments in the mineralized zone.

Pyrite (iron sulphide).--This mineral occurs in small quantities in the gold ore. (Plate VI) It is one of the early formed sulphides and is found in close association with arsenopyrite and gold. It usually is fractured, cemented, and veined by quartz, and in some cases, by galena. Early fracturing of the pyrite is characteristic of the Jardine ores.

The pyrite is not known to be gold-bearing. No gold
A. Gold, arsenopyrite and quartz

B. Arsenopyrite containing gold inclusion

C. Arsenopyrite, pyrite and galena in quartz

D. Arsenopyrite, pyrite and quartz

Plate VI
was observed in pyrite in microscopic examinations.

**Galena (lead sulphide).**—Galena is found in small amounts throughout the mineralized zone. Large cubical crystals are found in the quartz veins and in some cases it is found in irregular veinlets in and around arsenopyrite and pyrite. (Plate VI) It is one of the later formed minerals, being deposited near the close of the period of mineralization. Silver may be associated with the galena, although it is not visible under the microscope. Gold may also be associated with galena, but this has not been proven.

**Quartz (silicon dioxide).**—Quartz occurs as small lenses and irregular bands in the fissures and is the chief vein material. Almost pure quartz, lenticular and pillow-shapped masses, is found in the center of the mineralized zones in some parts of the mine.

Quartz was deposited throughout the mineralizing period. It contains disseminated particles of gold as well as the other metallic minerals present in the region. It is found filling cracks and as veinlets in arsenopyrite, pyrite and scheelite.

**Marcasite (iron sulphide).**—This mineral was observed under the microscope as a coating around arsenopyrite. It is one of the last minerals to be deposited and was probably present in solution in acid percolating waters.
at the close of the mineralizing period. It is found filling thin cracks in the schist in sheered zones.

Native Copper.--Disseminated particles of native copper have been observed in the mine by Gilbert*.

PARAGENESIS

The association of the minerals was determined by microscopic examination of polished specimens, megascopic examination of hand specimens, and by a limited study of the veins in the Jardine mine. The order of sequence of deposition is given in figure 2.

In all cases arsenopyrite was the first mineral to crystallize. This was followed closely by pyrite. Scheelite was deposited next and may be considered to be the last of the "early" minerals to crystallize. It was followed by galena which filled cracks and in some cases surrounded the early formed minerals. Marcasite was one of the last minerals to be deposited and is found as replacement coatings on arsenopyrite and as the material in narrow veinlets in the schist. The quartz was deposited throughout the mineralizing period, but probably not later than marcasite. Gold was introduced intermittently from the time of the deposition of arsenopyrite to the end of the mineralizing period.

*Oral communication.
<table>
<thead>
<tr>
<th>Mineral</th>
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<tbody>
<tr>
<td>Quartz</td>
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</tr>
<tr>
<td>Arsenopyrite</td>
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</tr>
<tr>
<td>Gold</td>
<td>---</td>
</tr>
<tr>
<td>Pyrite</td>
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</tr>
<tr>
<td>Scheelite</td>
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<tr>
<td>Galena</td>
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</tr>
<tr>
<td>Marcasite</td>
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Fig. 2. Diagram illustrating the approximate sequence of mineral deposition in the Jardine veins.

WALL ROCKS

The wall rocks in the mineralized area consist of folded and highly contorted, metamorphosed rocks of pre-Beltian age. Dikes and narrow tabular bodies of fine-grained diabase are found generally within the unit, but only one or two dikes occur in the mine workings. The metamorphic rocks consist of schists of various types. The most abundant wall rocks are quartz-mica schist, and dark gray or black amphibole quartz schist. Locally these rocks have been altered by the agency of solutions and by the localization of dynamic pressure. This has
A. Marcasite replacing arsenopyrite

B. Hornblende schist: (H) hornblende, (qtz) quartz, (P) plagioclase

C. Arsenopyrite replacing quartz and amphibole

Plate VII
resulted in the formation of garnet schist, chlorite schist, garnet-tourmaline schist, and many other varieties.

The greater part of the schists are believed to have been formed by the metamorphism of pre-Beltian sedimentary rocks. In some zones in the mine, banded schists have been found. They were probably formed by the metamorphism of evenly bedded sedimentary rocks. The thin light-colored bands are quartz, while the darker and thicker bands are mostly amphibole. The metamorphism of an iron-magnesium carbonate rock containing thin bands of sand could produce a banded schist of this description.

GENESIS OF DEPOSITS

The ore deposits of Jardine have been deposited from mineralized solutions which precipitated the ore minerals in north-south veins in the schist country rocks.

LOCALIZATION

The majority of the veins in the Jardine mine follow the schistosity of the wall rocks. In rare cases they transgress the schistosity and follow along joints or pre-mineral faults. The mineral bearing solutions,
originating at depth, followed open fault zones, and were injected by high pressure, into the schist which was forced apart along zones of weakness, forming the mineralized deposits.

Fault gouge is found on both hanging-walls and foot-walls of some of the veins which indicates that the veins were probably deposited in shear zones, along which movement had taken place. Some faulting probably occurred during the period of mineralization as well as after the formation of the deposits. Fragments of schist sometimes are found surrounded by quartz and sulphide minerals in the veins. Arsenopyrite crystals, formed by replacement, occur in the country rock in decreasing amounts away from the veins.

The observations cited above points to the fact that the ore bodies were formed in shear zones which were forced apart by high pressures acting on the viscous quartz solutions.

SOURCE OF METALLIZING SOLUTIONS

The metallizing solutions originated at depth from a cooling igneous intrusive mass. Granite occurs in the district and probably was the source of the solutions. The veins in the Crevasse area are essentially pegmatites, containing glassy and massive high temperature quartz
with feldspar and some tourmaline. Pegmatites are considered to represent the last unconsolidated portions of an intrusive magma.

TEMPERATURE OF FORMATION

The mineral bearing solutions were deposited under conditions of high temperatures. The deposition under hypothermal conditions is shown by the presence of essentially high-temperature minerals such as garnet, tourmaline, arsenopyrite, scheelite and others. Low temperatures at the close of the mineralizing period is evidenced by the presence of galena which was one of the last minerals to be deposited.

AGE OF MINERALIZATION

Although the schists in the Jardine district have never been correlated with areas of differentiated Archean and Algonkian rocks, they are very similar to other Montana pre-Beltian schists, which are believed to be of Archean or Algonkian age.

The vein material shows evidence of faulting and shearing after the formation of the ore deposits. In many places, early formed quartz veins have apparently been deformed by folding of the wall rocks, resulting
in quartz pods and lenticular quartz masses. The quartz pods, in some cases, have been sheared and drawn out by folding and faulting after crystallization. Arsenopyrite crystals, in association with quartz pods, are shattered in some cases, indicating that folding has followed the deposition of the arsenopyrite. Microscopical examinations of the ores shows shattered arsenopyrite with quartz filling cracks in the arsenopyrite.

The folding and deformation of the schists probably occurred during pre-Cambrian time. The ore deposits are believed to have been deposited before the end of the period of deformation, and are thus pre-Cambrian in age. Later disturbances, such as occurred during Laramide time would not produce folding such as that found in the Jar-dine district.