THE DETAILED MINERALOGY
OF THE NUMBER THREE VEIN
AT THE PRIVATEER MINE
ZEBALLOS, B. C.

Submitted in partial fulfillment
of Geology 409, a part of the
course leading to the degree
of Bachelor of Applied Science
in Metallurgical Engineering

Robert J.C. Tait

University of British Columbia

April 10 1948

Acknowledgment

This work was carried on under the direction of Dr. H. V. Warren, whose cheerful assistance was generously given at all times. The author is also grateful to Dr. H. C. Gunning for invaluable information on the geology of the Zeballos area, and particularly on the geology of the Privateer Mine. Equal thanks are due to Mr. J. A. Donnan for his work in superpolishing; to Mr. N. E. McConnell for providing the ore samples; and to Professor W. M. Armstrong of the Department of Mining and Metallurgy for the use of microscopes and photographic facilities.

Table of Contents

Abstract

The detailed mineralogy of Privateer No. 1 Vein, and of the auriferous veins of the Zeballos Camp in general, have been described by previous investigators. The No. 3 Vein has only been discovered and explored recently, and its mineralogy has never before been examined in detail. This investigation has revealed certain marked differences between this mineralization and that described in other reports. Of these, the most significant is the relative age and mode of occurrence of pyrrhotite, and its relation to the deposition of gold. Directly related to this is the extreme scarcity of galena which has always been noted as the sulphide most strongly associated with gold in this district. Also, and particularly in comparison with the No. 1 Vein, this vein differs in the particle size of its gold. Whereas, previous investigators reported over 65 percent of the gold as coarser than 100 mesh, at least 70 percent of this gold is finer than 200 mesh, and a considerable amount is less than 10 microns in size.

Dr. J. S. Stevenson of the British Columbia Department of Mines, has classified the pyrrhotite as the oldest mineral of all, and noted its occurrence only in occasional irregular lenses in the No. 1 Vein at the Privateer Mine. He also commented on the scarcity of galena in association with pyrrhotite. This investigation shows clearly that in No. 3 Vein, the pyrrhotite is quite late, being roughly contemporaneous with, and extensively intermingled with both sphalerite

and chalcopyrite. This report further shows that these three sulphides, accompanied by quartz, are the chief constituents of a late period of mineralization which accounted for the deposition of a major part of the gold in the ore.

As regards the gold itself, most of it is definitely post pyrite in age; much of it accompanied the late sulphides, notably the sphalerite, and some of it appears to be still later than the latest sulphides. The order of deposition of the sulphides in this ore is approximately as follows: arsenopyrite, pyrite, sphalerite, pyrrhotite, chalcopyrite and galena. The last mentioned occurs only occasionally in minor amounts, usually replacing sphalerite.

Approximately 40 percent of the gold occurs free in quartz, 40 percent occurs at quartz-sulphide grain boundaries, probably 15 percent is contained by sphalerite, and the remainder by other sulphides. Complete details of paragenesis and association of minerals are contained in the text of this report.

This occurrence and relationship of pyrrhotite is most unusual. The findings of other investigators have been verified by experience many times. Ore containing much pyrrhotite and little galena has in the past always yielded low assays. Here, however, sulphide masses which appear to be largely pyrrhotite, give very high assays. Where there is one exception there may be others. Obviously, then, this mineral association is one which can no longer be disparaged or overlooked.

THE DETAILED MINERALOGY
OF THE NUMBER THREE VEIN
AT THE PRIVATEER MINE
ZEBALLOS, B. C.

Problem

1. To discover the mode of occurrence and mineral association of the gold in Privateer No. 3 Vein.

2. To compare the detailed mineralogy of this vein with that of the original No. 1 Vein.

3. To relate mineralogical differences to noted differences in milling characteristics.

Introduction

The detailed Mineralogy of the Privateer Mine has to date been studied and discussed by two authorities. The details of the first investigation are contained in a report issued in 1939 by the Testing and Research Laboratory of the Department of Mines and Resources, where a complete paragenesis was worked out during extensive mill tests on 1560 pounds of high grade ore. The second discussion, which is general rather than particular, is embodied in a paper given by Dr. J. S. Stevenson of the British Columbia Department of Mines at the Annual Western Meeting of the C.I.M.M. November, 1939. Dr. Stevenson presents in his paper a paragenesis based on examination of polished specimens from several different veins on several different properties which were available for examination at that time. The two parageneses agree fairly closely, but since the latter is general and covers specimens from several different veins, complete agreement cannot be expected.

Data for both these reports was compiled long before No. 3 Vein was discovered. The No. 3 Vein is similar in type and structure to most of the fissure veins in the district, but the mineralization as viewed in a hand specimen shows certain marked differences from that of the No. 1 Vein, on which the specific mill tests were performed. The noticeable differences are as follows:

1. Extreme scarcity of galena which in the No. 1 Vein and other high grade veins of the area is the infallible indicator of high values.

2. Virtual absence of visible native gold.

3. Heavy concentrations of massive pyrrhotite which are nearly always accompanied by high

assays. Heavy pyrrhotite mineralization in the No. 1 Vein nearly always indicated low assay values.

The presence of heavy pyrrhotite, the lack of galena and heavy native gold in ore running in excess of eight ounces per ton were the main factors which prompted the author to begin an investigation which is long overdue. The No. 3 Vein now forms the major source of ore at the Privateer Mine, but so far, no detailed mineralogical work has been done on it. This investigation could doubtless have been performed more quickly and completely if placed in more experienced hands. Much time has been lost due to the author's lack of skill and unfamiliarity with microscopic technique. Much detail may have been missed that would not have escaped a more experienced observer. However, it is felt that the salient points have been observed, and it is hoped that this work may be of value, if only as a rough spring board for more detailed examination in more experienced hands.

Location and History of the Privateer Mine

The Privateer Mine is located on Spud Creek which is tributary to the Zeballos River, four and one half miles from the Village of Zeballos on the West Coast of Vancouver Island. Zeballos lies approximately 195 nautical miles north of Victoria, and is part of the Alberni Mining Division. The area received very little attention until the winter of

1934-35 when a small group of prospectors began to ship small amounts of high grade gold ore from the White Star property. The vein which later became known as the Privateer No. 1 Vein was found in August, 1936 by John Roy Ilstad, and assayed 55 ounces of gold per ton at the surface. The Privateer group of claims was optioned and later purchased by the Nootka Zeballos Gold Mining Syndicate which was subsequently reorganized and registered as Privateer Mine Limited (N.P.L.) capitalized at 2,500,000 shares without nominal or par value.

Preliminary exploration began in a small way in March, 1937, followed by intensive development until September 1938, when the mill was installed. The mine paid for all its development costs by shipments of ore from development drifts and raises without any stoping whatever.

From September, 1938 until April, 1943, more than $5,000,000.00 bullion were produced at a milling rate of 75 to 90 tons per day. Most of this production came from No. 1 Vein which rarely exceeded one foot in width but which was remarkable for the length and persistence of its ore shoots.

On April, 1943, lack of labor necessitated shut down, and the mine was not reopened until early in 1946. Milling commenced at reduced tonnage in November, 1946, and is continuing at present at approximately one half of pre-war production. Most of the ore now being milled is from the No. 3 Vein.

Geology

(a) General Geology and Mineralogy

The general geology of the Zeballos area, which has been described in detail by Clothier, Gunning, Bancroft and Stevenson, is roughly as follows: The oldest rocks are Triassic lavas, fragmentals and sediments. They include a thick group of Andesitic lavas and tuffs known as the Karmutsen volcanics. These are overlain by the Quatsino limestones which range up to 2000 feet in thickness. In the active mining area, these are only exposed near the Central Zeballos Mine.

The Quatsino formation is overlain by a mass of volcanics and sediments known as the Bonanza group. Parts of this group contain limestone, argillite and tuff, with recognizable bedding.

All the above rocks were finally intruded by the Zeballos Batholith of quartz diorite and by associated dykes.

Folding of the older rocks occurred before and during the intrusion, with the result that, in the region as a whole, major folds trend northwest.

In many places near the batholith, the older rocks are intensely altered. In particular, along Spud Valley the bedded rocks of the Bonanza group were converted to skarn and hornfels by the formation of such high temperature silicate minerals as garnet, diopside, wollastonite, vesuvianite, axinite, feldspar, biotite, epidote, etc. These rocks are well exposed in the Privateer workings.

Both the batholith and the older rocks are cut by small dykes. Some of these are diorites, closely related to the batholith. Others are finer grained and may be described as felsites.

Following the intrusion of the dykes the region was subjected to stresses that produced faults and fractures. At this time, two important sets of fissures were formed. These fissures contain all the gold bearing veins of the area. One set strikes within a few degrees of east. The Privateer veins belong in this set, as do the veins of the Prident and Central Zeballos properties. The other set strikes approximately northeast and is represented by the veins of most of the other mines in the district.

The ore minerals were introduced into the fissures by heated solutions from some unknown source at depth. Whether they were introduced during the period of stress that produced the fissures or at a later date cannot be proven; however, considerable movement took place after the veins were formed. This is shown by the brecciated nature of some of the earlier minerals, by sulphide banding and by the presence of gouge and traces of movement on vein walls.

The type and structure of the auriferous veins in the district have been accurately and minutely described by Dr. Stevenson. His excellent description is briefly summarized as follows:

The veins occupy well defined fissures that maintain a fairly uniform strike and dip over considerable lengths. Smooth walls, often marked by films of gouge, are characteristic of the vein fissures; frozen walls are the exception.

The quartz-sulphide ore itself may occur within the fissures as follows:

1. As tabular veins completely filling the fissures and ranging from one quarter inch to twelve inches in width.

2. As lenses in a fissure, usually accompanied by considerable crushed rock and gouge. The lenses of quartz-sulphide ore are often separated by stretches of barren fissure containing nothing but crushed rock and gouge.

3. Occasionally as sheeted zones up to four feet in width which consist of joints spaced two to eight inches apart, containing either gouge films or one eighth inch to one half inch quartz-sulphide stringers.

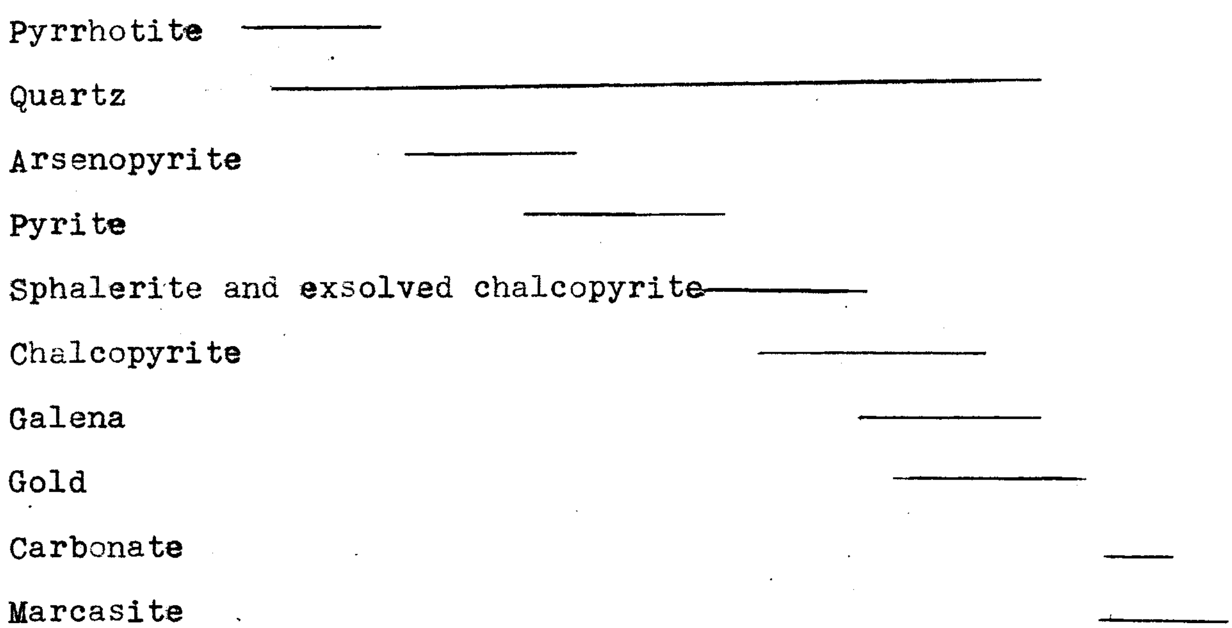
Banded and comb textures characterize the veins, particularly when sulphides are abundant. Bands of coarse sulphides one to two inches in width are often separated by crystalline vuggy quartz. In such cases, the quartz projects inwards from both sides in a comb structure. The crystals from each direction may interlock, in which cases the interstices between the crystals may be filled by sulphides and sometimes by coarse native gold; or they may fill only part of the space leaving open vugs in the middle. In other cases, they fill the spaces between main sulphide bands in a solid crystalline mass containing neither vugs nor sulphide inclusions.

The proportions of sulphides in a vein may vary from a very small fraction to at least three quarters of the vein filling. Dr. Stevenson suggests that, on the average, sulphides comprise one third of the vein matter. In order of abundance, the sulphides include: pyrite, sphalerite, arsenopyrite, chalcopyrite, galena, pyrrhotite and marcasite. Dr. Stevenson observed the pyrrhotite occurring only in occasional lenses within the vein at the Privateer. Quartz is the chief gangue mineral, but some late calcite also occurs, usually only as thin veinlets, but sometimes as coarse rhombs filling larger vugs in the quartz bands. Although not mentioned as such by Dr. Stevenson, this latter association was a common occurrence in the Privateer vein on the 900 level. As regards native gold, the following statement by Dr. Stevenson is an accurate description:

> "Visible gold, though not constituting the major portion of the total amount of gold in the ore, is of rather common occurrence. Large masses of hackly gold have been found in portions of the vein on the Privateer property, intimately associated with the sulphides, and beautiful specimens of crystalline gold occur in several of the veins. However, it is the gold that occurs between and along the fractures in the various sulphide aggregates that contributes mostly to the value of the ore."

A description of the general mineralogy of the area would not be complete without mention of Dr. Stevenson's Paragenesis which is shown in graphical form below. It should be borne in mind that this paragenesis is not restricted to Privateer ore, but covers examinations of specimens from the entire district.

PARAGENESIS OF VEIN MINERALS (after Stevenson)



Dr. Stevenson comments on his paragenesis as follows:

"Pyrrhotite, occurring with sphalerite and chalcopyrite, is considered early because:

1. It occurs in lenses and not in bands as do the other sulphides.

2. The sphalerite associated with the pyrrhotite differs from that in the banded ore in that it contains no exsolved chalcopyrite.

3. In the pyrrhotite lenses, galena is almost entirely absent.

"The formation of the pyrrhotite appears to be closely related to that of the last-formed minerals of the high-temperature replacement stages, as previously described.

"The earliest quartz,is a fine-grained, dark grey variety containing dutys arsenopyrite and pyrite. This material is common on the walls of many of the veins.

"Following the earliest quartz, there began a series of repeated stages of deposition and intra-vein fracturing and opening; the several stages being represented by a succession of quartz-sulphide bands within the width of the vein.

"The polished sections studied indicate that the sequence of events in any one quartz-sulphide band was as follows:

1. The deposition of quartz, pyrite and arsenopyrite.

2. The abundant fracturing of these minerals and development of openings within the band.

3. The formation of pyramid-shaped crystals of quartz in the open spaces.

4. The deposition of the later sulphides, sphalerite, chalcopyrite, and galena, partly contemporaneous with, but mainly antedating, the deposition of gold.

"As a last manifestation of the main vein mineralization, the quartz-sulphide bands have been traversed by irregular veinlets of late quartz--quartz that carries no sulphides and apparently no gold.

"The late deposition of calcite in veinlets transecting all previously deposited minerals, and the partial alteration of some of the pyrrhotite to marcasite, indicate the presence of acid solutions during the latest stages of mineralization. (1.) Whether the solutions responsible for the main gold-sulphide-quartz mineralization were largely colloidal (2.), or alkaline (3.) or acid (4.), constitutes a problem in ore genesis concerning which there is still a diversity of opinion.

"Two outstanding microscopic features of the ores should be mentioned:

1. The intense brecciation of both the arsenopyrite and pyrite.

2. The varied mineral associations of the gold, among which may be mentioned:

(a) Gold pseudomorphic after arsenophrite.

(b) Gold replacing pyrite

(c) Gold replacing galena

(d) Gold at contact of quartz and galena or sphalerite or pyrite.

(e) Gold occasionally as cusp-shaped areas in a field of quartz, moulded around the ends of pyramid-shaped crystals of quartz.

(b) Geology and Mineralogy of the Privateer Mine

All the veins encountered so far at the Privateer Mine occupy a set of fissures, the general strike of which is a few degrees north of east. The important structural feature of these veins is that they occupy fissures in the silicated zone of the Bonanza group. Originally, this zone probably consisted of limestone, argillaceous limestone, bedded tuff and some andesitic lava, all cut by volcanic dykes. These have since been extensively altered by contact metamorphism, due to the intrusion of the batholith. The tuffs, lavas and dykes have in general produced dense to very finely crystalline hornfels of white, green or brown color. The limey beds have been altered to granular mixtures of various high temperature silicates such as wollastonite, vesuvianite, diopside, and garnet, with various proportions of calcic plagioclases, axinite and quartz. The bedding of the strata is commonly preserved in a crude color banding due to bands of different silicates.

The zone is cut by dykes and irregular bodies of quartz diorite. The vein fissures are later than these and cut right through them without displacement, with the result that stretches of vein have quartz diorite walls, although for the most part the wall rock in the Privateer Mine is silicated. In a number of places, the silicated rocks have been mineralized during the contact metamorphic period, with pyrrhotite and chalcopyrite, and occasionally with sphalerite and molybdenite. These sulphides occur as disseminations or fairly solid masses of some size, but belong to an earlier period of mineralization than does the auriferous vein filling, and in general, carry no appreciable values. Hence, all wall rock can be discarded as waste.

The important feature of the silicated zone is that the rocks are more uniformly hard and brittle than the adjoining quartz diorites and volcanics, so that when fractured and subjected to subsequent dynamic forces, they formed more regular and continuous fissures, which were much better receptacles for the auriferous vein filling than the fissures in the other rocks. The quartz diorite also favored the formation of straight continuous fissures, but being softer, was converted more easily to gouge, that clogged the fissures. As a result, the vein fillings in quartz diorite are more lenticular, the lenses being separated by poorer stretches in which the gouge partly or completely fills the fissure. This is particularly noticeable at the Prident Mine which is also operated by Privateer Mine Limited. The net result is that, being situated in the silicated zone, the Privateer fissures were more admirably suited to filling by continuous rich veins. This mine has consequently shown superior grade and continuity of ore ~~than~~ to any other in the district.

The veins themselves are the tabular veins, completely filling fissures which are the first type mentioned by Dr. Stevenson. They rarely exceed one foot in width. Their form, texture and mineralogy, according to Dr. Stevenson, denote medium temperature conditions, but the widespread occurrence of arsenopyrite and pyrrhotite indicates relatively high temperatures in the earlier stages of formation. To quote Dr. Stevenson once more:

> "More accurately then, deposition in these veins may be considered to have taken place under conditions of temperature and pressure intermediate between those prevailing for high and medium temperature veins."

<u>The Paragensis of Privateer No. 1 Vein</u>
(as published by Testing and Research Labortory, Ottawa)

Before discussing the work done on the suite of ores from No. 3 Vein it is of interest to note the paragenesis worked out by the investigators of the mineral dressing laboratories at Ottawa.

The characteristics of this ore are as described below:

"The gangue consists largely of white translucent vein quartz, locally mottled light grey by impurities. Some hand specimens contain a considerable quantity of calcite. The white quartz, mottled light grey quartz, and the carbonate quartz show a prounounced tendency to occur along parallel zones, as do also the sulphides, thus imparting to the ore a coarsely banded appearance. Locally coarsely-cyrstalline quartz surrounds open cavities, the inner surfaces of which are lined with well-formed prisms of quartz that has obviously grown in free space.

"The metallic minerals present in the ore are, in their order of abundance: pyrite, arsenopyrite, sphalerite, galena, chalcopyrite, pyrrhotite, marcasite, and native gold.

"Pyrite is moderately abundant as coarse grains and masses. It is considerably fractured, and is veined by sphalerite, galena, chalcopyrite, and native gold. A smaller quantity of arsenopyrite occurs as disseminated crystals, often associated with pyrite. The relationships between the pyrite and arsenopyrite are usually those of contemporaneous deposition but in rare instances veinlets of gangue in pyrite are seen to carry arsenopyrite. Galena and sphalerite also vein arsenopyrite.

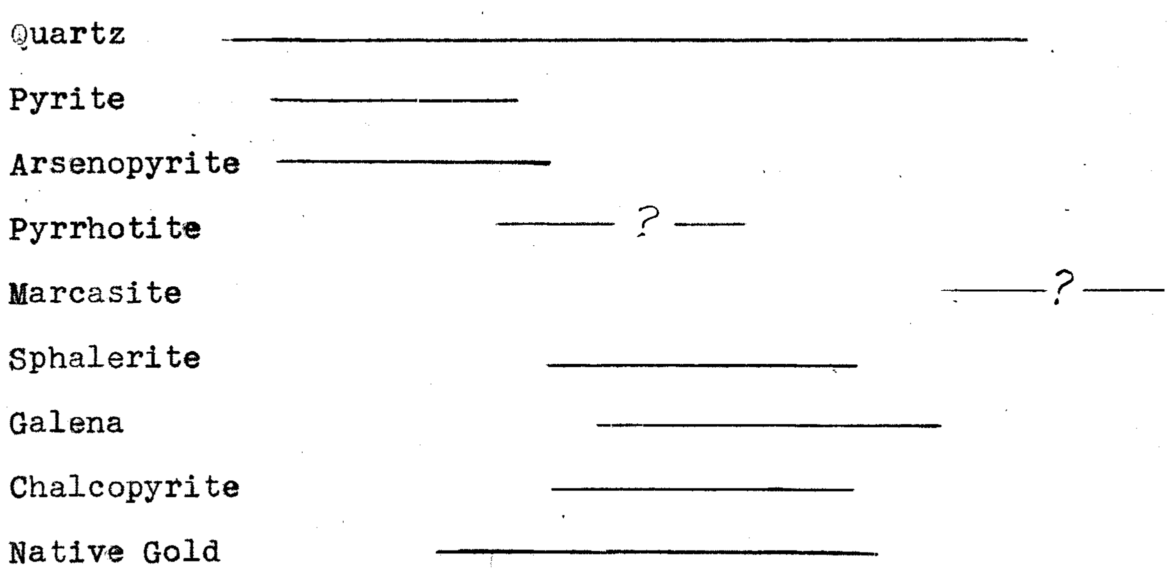
"Sphalerite and galena are common, occurring as coarse grains and small masses. They are often seen together, where their relationships suggest their depotition at the same time, although in some places the galena appears to have attacked and enclosed remnants of sphalerite. The latter contains tiny dots and rods of chalcopyrite parallel to its cyrstallographic directions. Chalcopyrite, in relatively small quantity, occurs as noted under sphalerite, and as small masses and grains associated with the other sulphides. A small quantity of pyrrhotite is present as small masses and grains, usually rimmed by a thin layer of well crystallized pyrite; the structure would indicate that the pyrrhotite had filled a cavity that had previously been lined with pyrite. There is a slight alteration of the pyrrhotite, usually along cleavage fractures, to marcasite.

"Native gold appears to be consistently associated with the sulphides, although it occurs to a large extent in the gangue in close proximity to these rather than within them.

Paragenesis

"Considerable information regarding the order of deposition of the metallic minerals is furnished by the microscopic examination and by the occurrence of certain sulphides among the quartz cyrstals that line the cavities in the massive quartz. Pyrite and arsenopyrite appear to have been deposited at about the same time; sphalerite, galena and chalcopyrite are definitely later, and are also later than the last quartz cyrstals, which line the cavities, for they occur among them. Native gold has probably been deposited trhoughout much of the period of mineralization for it is partly contemporaneous with pyrite, arsenopyrite, and quartz, partly contemporaneous with the later sulphides. Probably the greater part of gold deposition was post-pyrite. The following table represents graphically the deductions as to paragenesis of the minerals:

PARAGENESIS OF THE MINERALS, PRIVATEER MINE LIMITED



Conclusions from Microscopic Examination

"The gold is largely moderately coarse. There is, however, a portion, probably about 1 to 2 per cent, which may prove refractory, and some of this is in dense pyrite and arsenopyrite. The mineralization of the gold is closely related to that of the sulphides, which latter should be a good idicator of gold in the mine."

It is of interest to note that in this ore 65.2 percent of the gold occurred in quartz with sulphides, but not enclosed by them, and that of the remaining 34.8 percent which were contained by sulphides, almost one half was contained by galena and most of the remainder was associated with pyrite. Sphalerite contained only 5.0 percent of the total gold, arsenopyrite 0.9 percent, chalcopyrite apparently none.

The size distribution of the gold is equally interesting: 26.1 percent was coarser than 65 mesh, and 61.5 percent was coarser than 100 mesh. What is most significant is that only 18.6 percent of the total gold was minus 200 mest.

The Number Three Vein

The No. 3 Vein is similar in general type and structure to the vein just described. The wall rock is for the most part siliceous. The ore shoots are shorter, and the ore is not of quite such high grade. The details of the laboratory determination of the mineralogy of No. 3 Vein are set forth in the following pages.

Examination of Ore from No. 3 Vein

(a) Macroscopic Examination

Ten large hand spedimens, having a total weight of about thirty pounds were received from Mr. N. E. McConnell, Managing Director of Privateer Mine Limited. The specimens were selected at random from various working places in No. 3 Vein, and ranged from the 1003 level to the 1303 level, covering a depth range of over 400 feet on the vein.

The specimens were thoroughly washed and examined macroscopically with a 10 power hand lens. The minerals noted in the order of their abundance were as follows: pyrite, sphalerite, pyrrhotite, chalcopyrite, arsenopyrite, galena.

Some of the specimens were very sparsely mineralized. Others contained as much as eighty percent sulphides. The average amount of sulphides was probably about thirty percent. Certain characteristic features of mineralogical structure and texture were observed, some of which have been observed by Dr. Stevenson in his general description of the veins.of the district. The most notable features are:

1. Coarsely banded structure as described by Dr. Stevenson and others.

2. Segregation of various combinations of minerals in the different bands. Notable in this respect are

   (a) Arsenopyrite. This mineral tends to segregate in finely crystalline masses in massive quartz, at the exterior edges of the specimens (i.e.)next to the vein walls) and is usually separated from the other mineral aggregates by wide bands of quartz. In some narrow sections, the principal mineralization is a narrow band of massive arsenopyrite interspersed with coarse grains of pyrite. Both minerals are extensively fractured and compressed.

(b) Sphalerite and pyrrhotite occur intermixed in coarsely crystalline masses, occasionally with considerable amounts of chalcopyrite, and very little gangue.

(c) Pyrite occurs in large, irregular blotches, usually nearer the central portions of the specimens. The pyrite masses often run into and intermingle with the more regular bands of the other sulphides. Some more finely grained pyrite borders upon, and mingles with the finely crystalline arsenopyrite near the edges.

(d) Crystals of pyrite and sphalerite, often occur together filling vugs and cavities in the quartz. This is the principal mineralization in some of the less heavily mineralized specimens. The vugs in the quartz form more or less distinct straight lines so that this association gives these specimensa finely banded appearance. In some very narrow specimens the only mineralization consists of very fine grained sphalerite and pyrite filling long cracks or joint planes in fine granular to amorphous quartz, giving a layered appearance to the ore.

(e) Galena is very scarce, but when visible, is always intimately associated with sphalerite in the heavy sulphide bands.

(f) Quartz is the principal gangue mineral, occurring much as described by Dr. Stevenson in his general report.

To one familiar with the appearance of the ore from No. 1 Vein, the following main differences are apparent in the specimens from No. 3 Vein:

1. As previously mentioned, galena is rare.
2. Pyrrhotite is much more common, occurring in intimate association with chalcopyrite and sphalerite, and not in the isolated lenses mentioned by Dr. Stevenson.
3. Chalcopyrite is more common.
4. Coarse native gold was not observed.

5. Calcite was not observed.

6. The quartz is much less vuggy, and when it is distinctly crystalline, the crystals are smaller. Bands of smoky quartz are not common. The comb structure is less pronounced.

Except for the above noted differences, the vein filling is similar in texture and structure to that of any of the fissure veins in the district.

Preparation of Polished Sections

Following hand examinations, sections were cut so as to include as many different features of mineralization as possible. When more than one band of sulphides occurred in a specimen, and when the bands showed different mineral association, sections were prepared to represent each aggregation. Altogether, eleven sections were prepared, to give a general representation of all the varied mineral associations in the suite of specimens.

Sections were mounted in demar, and hand-polished carefully by standard methods. All eleven sections were then examined at fairly low magnification to give a general picture of the mineral associations. From this preliminary examination several basic features were immediately apparent. Some of these have been noted by previous investigators. Others appear to be peculiar to this particular suite of ore. The most apparent are here enumerated:

1. The arsenopyrite and pyrite were approximately contemporaneous and represent an earlier period of mineralization than do the other sulphides.

2. The pyrrhotite in this ore is not early pyrrhotite, but is contemporary to both the sphalerite and the chalcopyrite. The sphalerite was the first mineral to complete deposition and contains both chaloopyrite and pyrrhotite in exsolution. In many instances, both of the other two sulphides were seen to be in exsolution in the same mass of sphalerite.

3. Both the pyrrhotite and the chalcopyrite vein and replace the sphalerite. In other instances, mutually rounded boundaries confirm contemporaneous deposition of all three.

4. At this stage of examination, the only gold observed occurred free in quartz, replacing sphalerite at quartz-sphalerite contacts, or directly enclosed by sphalerite. It is significant to note that the largest gold particles noticed measured only about 90 microns, i.e., -150 +200 mesh of the Tyler Screen series.

5. At least two periods of quartz deposition were apparent.

6. No galena was positively identified at this stage.

7. The intense brecciation of the pyrite and arsenopyrite as mentioned by the other investigators was notieed in this ore.

Following this examination, four sections were selected for more detailed investigation. These sections represent the intricate sulphide bands from the most high grade specimens of the suite, and represent all the sulphides in their most complex associations. Not only do they show more detail than any of the other sections, but they were the most suitable for superpolishing. In the more sparsely mineralized specimens, the quartz is, for the most part, badly cracked and fractured, and the sulphides are brittle and loosely held. They were difficult to polish properly, even by ordinary methods.

The four high grade sections were remounted in bakelite, superpolished, and carefully examined under high magnification. For this work, Bausch & Lomb Metallurgical microscopes were used, with a strong, constant light source. A carbon arc lamp with a medium indigo blue filter gave the best results.

All the points noticed in the preliminary investigation were verified. In addition, the following evidence was revealed by superpolishing:

1. Considerable quantities of fine to moderately coarse gold appear, replacing chalcopyrite at quartz chalcopyrite boundaries.

2. The third and final period of quartz formation noted by Stevenson was evident. However, in these specimens, this quartz contains some fine gold.

3. The brecciated masses of pyrite and arsenopyrite are veined and filled by quartz containing late sulphides, and in at least one instance, the arsenopyrite was observed to be veined and replaced by gold.

4. A few very minor occurrences of galena were seen. In most instances, the galena replaces sphalerite at irregular quartz-sphalerite boundaries.

5. At high magnifications (650 or greater) specks of extremely fine gold can be found in pyrrhotite, but this is very uncommon. One such occurrence was photographed at approximately 1080 magnification, but unfortunately, the picture was badly blurred.

6. One minute rounded and somewhat pitted speck of gold was found as a deep inclusion in old pyrite. This was photographed at 650 magnification as a curiosity. Whether it represents old gold or the transverse section of a replacement is not known.

7. No gold was observed to be included in arsenopyrite.

8. Very minute inclusions of an unidentified mineral were observed, principally in exsolution in sphalerite. The largest was only observed at 650 magnification and did not permit of a hardness test or etch testing. The mineral was a bluish grey in color. It appeared soft. The largest spot was observed in exsolution in sphalerite, and contained a minute central core of pyrrhotite. It was mildly anisotropic, and showed a brown play of colors when revolved. It was brought to the attention of Dr. Warren. Time did not permit complete determination.

Paragenesis

On the basis of the complete examination, the following paragenesis is submitted:

Arsenopyrite was probably the first metallic mineral to be deposited. It was very closely followed by pyrite. These two minerals were deposited during the earliest of three phases of quartz intrusion. Pyrite deposition probably continued for some time after the arsenopyrite deposition had ceased. There is certainly some later pyrite which may have accompanied the second period of silicification, but which is still older than the later sulphides. Certainly, violent periods of movement must have occurred to account for the intensive shearing and brecciation of the pyrite prior to the introduction of the copper-zinc-iron mixture.

The deposition of the sphalerite, chalcopyrite and pyrrhotite probably occurred during the late stages of the second quartz deposition. The more coarsely crystalline nature of this quartz as it appears between the sulphide bands would seem to indicate that the mixture was being introduced at lower temperature. The three minerals mentioned were certainly contemporaneous, as is shown by the exsolved chalcopyrite and pyrrhotite in the sphalerite. That the zinc phase was the most short lived is indicated by veining and replacement of sphalerite by each of the others. During this zinc phase, some gold was occluded in the sphalerite and probably deposited in quartz cavities as well.

The formation of pyrrhotite here was probably due to sulphur deficiency rather than to conditions of high temperature. The zinc and copper, having higher affinity for sulphur, had to be satisfied first. Had excess sulphur been present in the melt, doubtless pyrite, rather than pyrrhotite, would have been formed.

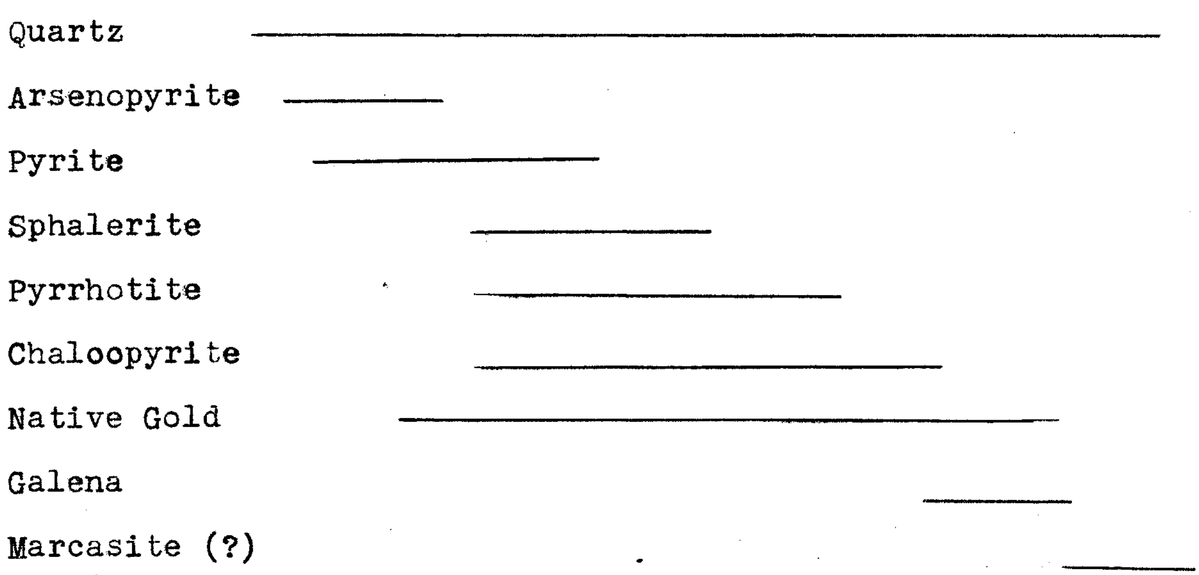
Whether chalocpyrite or pyrrhotite persisted longer is difficult to determine. However, it is probable that the chalcopyrite was the last to freeze out.

While these three sulphides were freezing out of the melt, gold was probably being deposited intermittently. Certainly some gold post dates both the chalcopyrite and sphalerite since it replaces them. Minor amounts of galena were probably introduced at approximately the same time as this late gold.

The last sulphide deposition was followed by a final phase of quartz intrusion corresponding to the third phase mentioned by Dr. Stevenson. In this instance, the late quartz seems to have brought some small amount of gold with it. Specs of free gold have been seen at high magnification in veinlets of glassy quartz cutting the sulphides.

As regards marcasite, this mineral was not positively identified. The pyrrhotite has in places been altered to resemble a lighter, brighter mineral with different surface properties, but time did not permit its accurate determination.

On the basis of this discussion, the paragenesis as put forth by the author is shown graphically below:



Conclusion

There are three main differences between the mineralization of the No. 3 Vein and that of the No. 1 Vein. The first of these is the age of the pyrrhotite and its economic significance. There can be no doubt that in No. 3 Vein the pyrrhotite is contemporaneous with the sphalerite and chalcopyrite and, as a result, roughly contemporaneous with the deposition of much of the gold. The pyrrhotite has been found to actually contain minute amounts of gold, but this is not usual, and its role as a gold carrier is negligible. It may, however, be regarded as a strong gold indicator in this particular ore body, since it is so intimately associated with sphalerite and chalcopyrite which do carry important amounts of gold. What at first appear to be massive concentrations of pyrrhotite nearly always prove to be well laden with sphalerite. This is a feature that should not be overlooked in future exploration of the Zeballos Area. In general, Dr. Stevenson's observations on pyrrhotite have been the rule throughout the district, and most of the veins, if containing pyrrhotite at all, seem to conform to his statements. However, where there is one exception, there may well be more, and the presence of this distinctively colored, easily identifiable sulphide can no longer be lightly dismissed.

The second important difference is the virtual absence of galena. This, of course, is tied in with the presence of pyrrhotite. Dr. Stevenson mentions particularly that the occurrence of galena with pyrrhotite is uncommon. Sulphide mixtures rich in galena have, in the past, automatically been classed as high grade. From now on, the absence of galena and the presence of pyrrhotite can no longer be disregarded.

The third major difference is the particle size of the gold. Whereas, 65 percent of the gold in the best portions of No. 1 vein was coarser than 100 mesh, in all the sections examined from No. 3 vein, the coarsest gold encountered was smaller than 150 mesh. Perhaps 30 percent of the gold in No. 3 Vein may be coarser than 200 mesh, but certainly not more. Indeed, much of it is probably less than 10 microns in size.

A rough estimate of the distribution of this gold is as follows:

Free Gold in Quartz	40 percent
Gold at Quartz-Sphalerite and Quartz-Chalcopyrite Boundaries	40 percent
Gold in Sphalerite	15 percent
Gold in other Sulphides	5 percent

The differences in the milling characteristics of the two ores are directly related to their mineralogical differences. Both ores are free milling to the extent that recoveries of 97 to 98 percent can be made by amalgamation and cyanidation. A Denver jig in the grinding circuit between ball mill and classifier produces a concentrate of coarse metallics, which is reground and amalgamated in an amalgam barrel. Classifier overflow is pumped directly to the primary thickener in the cyanide circuit. The difference in gold particle size shows up in the ratio of recovery in amalgam to recovery by cyanidation. For a period of approximately two years of milling of ore from No. 1 Vein, an average of 58 percent of the recovered gold was picked up by amalgamation. This ratio was sometimes as high as 80 percent for short periods. In the author's experience during four months of continuous milling of ore from No. 3 Vein, the ratio remained consistently at approximately 30 percent, 70 percent of the gold being extracted by cyanide.

The other important difference is in the consumption of cyanide. The cyanide consumed by the ore from No. 3 Vein is considerably in excess of past consumption. This can be accounted for by the presence of pyrrhotite which oxidizes readily once the ore is broken. Oxidized pyrrhotite is a noted cyanicide. Chalocpyrite, which is also a cyanicide, to a certain extent, is also more prevalent in this ore.

Close control of grinding will obviously be more critical in the milling of this ore, since the gold is more finely divided. Any excess consumption of cyanide that can be offset by the use of cheaper reagents without impairing extraction may well effect noticeable lowering in milling costs.

Photography

Photomicrographs at various magnifications have been taken to illustrate some of the varied mineral associations encountered. These were taken using a Bausch & Lomb metallurgical microscope with a Bausch & Lomb camera. The photographs with accompanying descriptions are displayed in the following pages.

Fig. 1.

Gold and sphalerite in quartz. The small white dots in the sphalerite are exsolved pyrrhotite.

Magnification - x240

Fig. 2.

Shattered pyrite and arsenopyrite veined by quartz containing sphalerite and gold. Sphalerite shows exsolved pyrrhotite. Note the small speck of free gold below arsenopyrite, bottom centre.

Magnification - x240

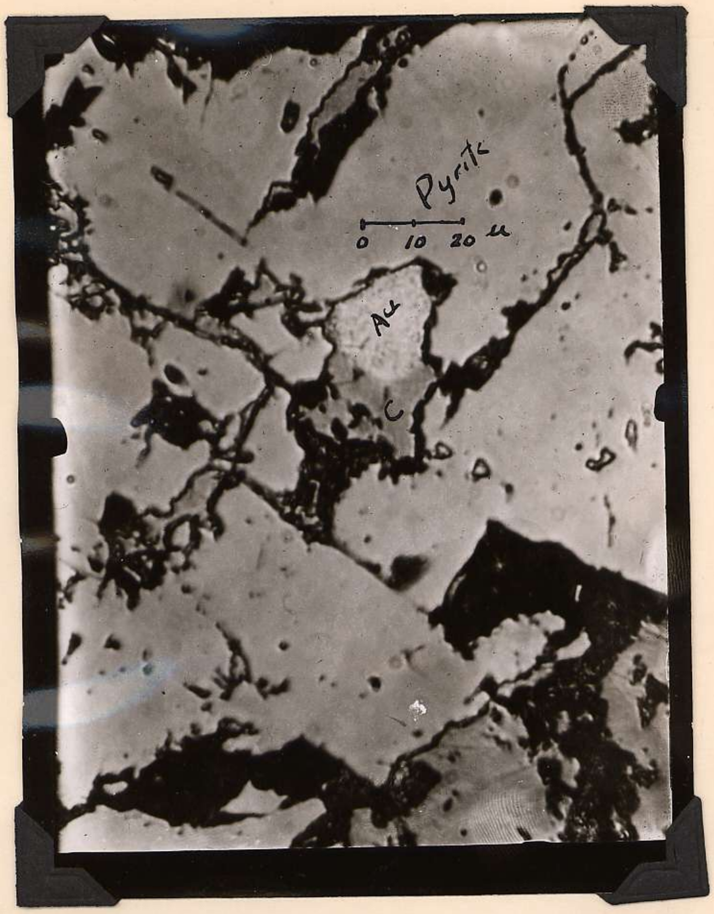


Fig. 3.

Gold and chalcopyrite, in quartz veining brecciated pyrite.

Magnification - x650

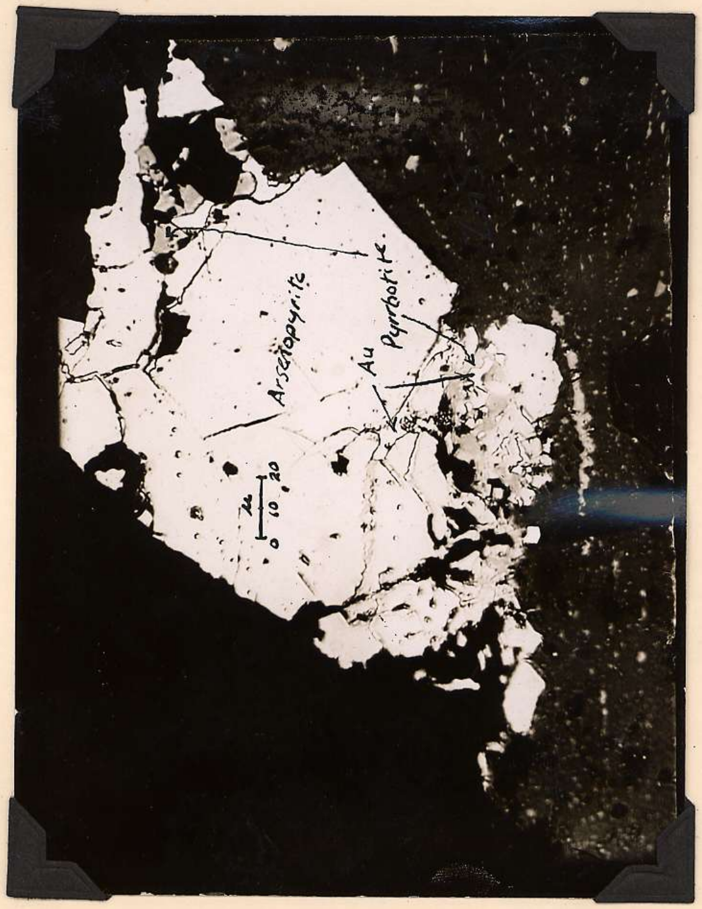


Fig. 4.

Gold and pyrrhotite veining and replacing arsenopyrite. The dark mottled material is sphalerite with pyrrhotite in exsolution.

Magnification - x400

Fig. 5.

Pyrite containing gold. Veined by quartz containing chalcopyrite (c)

Magnification - x650

Bibliography

"Geology and Ore Deposits of the Zeballos Area, British Columbia" by John S. Stevenson
(C.I.M.M. Transactions Vol. XLII, 1939, pp. 225-237)

Geological Survey Paper 40-12
"Zeballos Mining District and Vicinity, British Columbia" by M. F. Bancroft

Geological Survey Memoir 204
"Gold-bearing Deposits on the West Coast of Vancouver Island between Esperanza Inlet and Alberni Canal" by M. F. Bancroft

Geological Survey - Summary Report, 1932, Part AII, Page 29
"Zeballos River Area, Vancouver Island, B. C." by H. C. Gunning

Mines & Geology Branch, Bureau of Mines
"Investigations in Ore Dressing and Metallurgy, January to June, 1938"