SILVER MINERALIZATION AT THE DOLLY VARDEN MINE.

C.E.Gordon Brown.

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The Dolly Varden Mine is situated in the Kitsault River valley, eighteen miles from the head of Alice Arm, in the Naas River mining division of British Columbia. During the years 1919-21, it was operated by the Taylor Engineering Co Ltd., Who produced 1,300,000 oz. of silver from about 36,000 tons of ore. The ore was transported by narrow gauge railway to Alice Arm, and shipped to Anyox smelter for treatment. During recent years, a small quantity of high grade ore has been extracted by leasers and shipped to the Tacoma smelter.

The mine presents an interesting example of bonanza type of ore deposit, combined with some supergene enrichment.

General Geology.

The mine is located near the south end of the "Kitsault Igneous Body". The latter is composed of a group of extrusive and fragmental igneous rocks, which are surrounded by sedimentary rocks, principally argillites, of the Bear River series. The Kitsault igneous body is about eight miles long and one mile wide; it runs almost north and south and has it's axis slightly to the west of the Kitsault River. The Bear River series has been correlated with the Hazleton series of Lower Jurassic age.# At a distance of five miles to the west is the contact of the Coast Range batholith with the overlying sediments. The

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Hansen, Can. Geol. Survey. Mem. #175

immediate relation of the batholith to the ore deposits of the Kitsault area is obscure, since there are no outcrops of plutonic rocks in the valley.

The ore deposit is a vein, which follows a fault fracture in tuff. In the productive part of it's length, the vein follows a contact between red-purple tuff and green tuff: in other places it is wholly in the green tuff. Diabase dikes cut the vein in a number of places.

Structural Geology.

The vein is a replacement of the green rocks which form the footwall of the fracture: it is up to 25 feet wide, has an average strike of N 55E , and a dip to the north west of between 45 and 60 degrees. The topography at the mine is fairly steep hillside with longitudinal gullies, following fault outcrops. Below the main level portal, the hillside falls away very steeply to the Kitsault River, 700 feet below.

Faulting is a conspicuous feature of the developed portion of the vein. The structural features may be roughly divided into four separate groups.

(1) Faulting in the plane of the vein along the hanging wall. This was probably a continuation of the faulting which first afforded a passage for hydrothermal solutions, and may be responsible for later hypogene deposition.

(2) A series of reverse faults having very little vertical displacement. These strike approximately north and south and have displacements up to

130 feet. They divide the vein up into a number of short segments. (See Fig 1)

(3) Fracturing and intrusion of diabase dikes. One dyke, only, is important as it is useful as a plane of reference: it is 10 to 16 feet wide. Other dykes are small.

(4) A normal fault, the 205 fault (see fig. 1 and 2), cuts all the earlier faults and the dyke. It affords a channel for free circulation of meteoric water.

Fig. 1 is a plan of the vein segments at different elevations. Fig. 2 is a projection on a vertical plane of the various segments. The only fault which, on the drawing, shows vertical movement, is the 205 fault . This appears displaced by the earlier faults, when the vein is drawn in the unfaulted position.

Economic Geology.

The values in the vein were found to decrease rapidly with depth. Commercial ore appears to bottom a short distance below 400 level. Three types of commercial ore were found:

(1) Native silver, in veinlets and masses, was found close to the surface and near the 205 fault.

(2) Black quartz, with no silver minerals visible to the naked eye, occurred near the hanging wall throughout the mine.

(3) White quartz, with fine mineralization of

ruby silver, was mined, mainly from the east end of the ore shoot.

Referring to fig. 2, the following was the tonnage and grade of ore mined during the year 1920 from the various stopes.

Summary of Ore Shipments, 1920.

Stope	Tons.	Average Assay.
252	358	23.2 oz.
351	5707	16.4
452A	3747	27.4
452B	829	36.0
453	255	37.9
454	314	12.6
455A	2516	26.4
455B	1961	17.6
455C	433	36.7
456	690	29.5
457	570	25.5
	17380	

Figures for #1 Glory Hole (151 stope) are only available for one month (Sept.) when 330 tons averaging 55 oz. were shipped. The above figures do not include high-grade, which was sacked and shipped separately to Tacoma: sacked ore ran 500 oz or better.

The metallic minerals present in the vein are Pyrite, Chalcopyrite, Tetrahedrite, Galena, Argentite, Pyrargyrite, Sphalerite and Native Silver. The gangue mineral was mainly quartz, with small amounts of Barite, Calcite and Jasper.

The origin of the ore was a debated point during the time that the mine was under development and operation. It was then considered that the high grade silver minerals were due to supergene enrichment of low grade argentiferous galena and tetrahedrite protore.*

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* Hanson G. C.I.M.M. Trans. Vol.25 p. 212-224. 1922

Study of polished sections of ore under the modern metallographic microscope, with a technique much improved since that time, shows supergene enrichment, superficially imposed upon a high grade primary mineralization of a low temperature type.

Hypogene Mineralization.

The following minerals are considered to be of hypogene origin:

Metallic Minerals.	Gangue Minerals.
Pyrite	Quartz
Sphalerite	Barite
Tetrahedrite	Calcite
Galena	Jasper
Chalcopyrite	
Argentite #	
Pyrargyrite #	

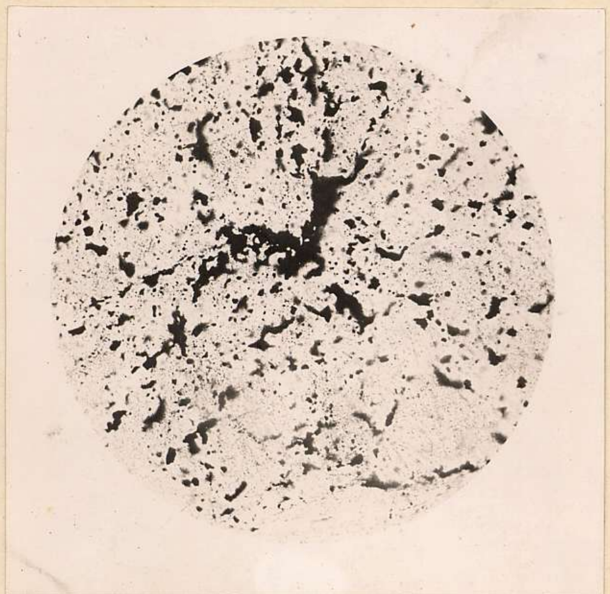
May possibly be supergene in some cases.

The mode of occurrance and probable origin of these minerals is treated individually below.

Pyrite occurs abundantly throughout the vein. It was probably the earliest of the metallic minerals and in low grade portions of the vein is almost the only mineral present, other than quartz. There is very little silver associated with the pyrite as determined by assay of picked mineral. In a large portion of the stoped area, a band of massive fine grained pyrite, up to 10 feet thick and barren of silver, occurs on the footwall at a distance of 15-20 feet from the hanging wall. To what extent pyrite has been replaced by later minerals is not evident in the sections studied; it is probable that some replacement of pyrite by argentite and ruby silver has occurred especially in the part of the vein about 10 feet from the hanging wall, where silver minerals are particularly plentiful. Newhouse says," Study indicates that replacement of one sulphide by a later one plays a considerable part in massive sulphide ore bodies. In fact, successive partial replacement of earlier sulphides by later ones seems to be the rule.........It is also true that, as replacement proceeds, it destroys its own footprints, and so it is only on its frontier that evidence is found."# Some evidence of possible replacement of pyrite will be described below.

<u>Argentite</u> is an important hypogene source of silver; it occurs in three ways:

(1) As an interstitial mineral, filling the spaces
spaces between grains of brecciated quartz. Fig. 3



X90

Fig.3 Argentite grains in brecciated quartz
Thin section

is a thin section of quartz with argentite showing as

#Newhouse W.H."The Microscopic criteria of Replacement in the Opaque Ore Minerals". Fairbanks.

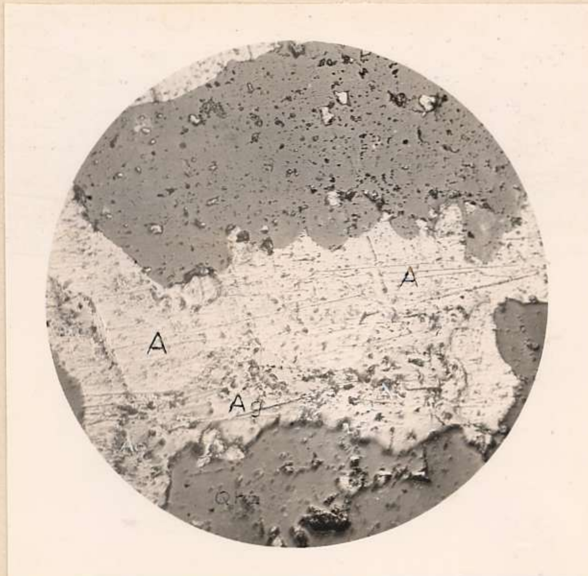
irregular dark patches. This gives the ore a characteristic blueish black color. With a view to comparing the silver content of the black quartz at different levels, two samples were selected, one from immediately beneath the outcrop, and the other from 452A stope, 100 feet below. There is no direct vein continuity between these two places, since the vein is displaced between them by a flat fault having an offset of 40 feet or more. The two specimens appeared identical to the naked eye, except that there were some areas of supergene native silver in the specimen from the higher elevation. The material was crushed and picked, under the low power binoculars, as free as possible of minerals other than black quartz. Assay values are as follows:

Black quartz from 252 stope,	el. 1809	576.62	oz/ton
" " " 452A "	el. 1693	295.15	"

Allowing for contamination of the upper sample by secondary native silver, these figures show about the diminution of values to be expected in the low temperature type of deposit. Microchemical tests on this material showed iron and silver present but failed to indicate arsenic or antimony or copper: thus it would appear that there is no stephanite, polybasite, pearcite or tetrahedrite associated with the argentite in the black quartz.

(2) Argentite also occurs in veinlets, associated with tetrahedrite and pyrargyrite. The fact that this type of occurrence is more common in the upper part of the vein certainly suggests secondary origin, but

intermineral relationships and other factors, to be described below, appear to disprove this contention. Immediately below the oxidized capping, the argentite has been altered to native silver. Fig 4 is a veinlet of argentite with spots of native silver round the edges.



X 30

Fig 4. Argentite (A) with native silver (Ag.).

(3) A further mode of occurrence of argentite is as a filling of vugs, associated with calcite and barite. The minerals usually have crystal faces and in many cases have not filled the vug completely.

It would seem that there were two different periods of argentite deposition. The first was when the black quartz was formed and the second when the veinlets,which cut across the black quartz, were filled. The vug filling may have been connected with either of these periods.

Argentite has an inversion point at a temperature of about 175 degrees Cent (175, Bowen: 179,Sch - neiderhohn:).# At this temperature,it inverts to a lower degree of symmetryand becomes anisotropic. All argentite specimens examined proved to be isotropic. This fact, while perhaps not conclusive, suggests a temperature of formation corresponding to epithermal type of deposit,rather than to enrichment by supergene solutions.

Tetrahedrite is not common but occurs in veinlets and in irregular patches. In veinlets, it seems

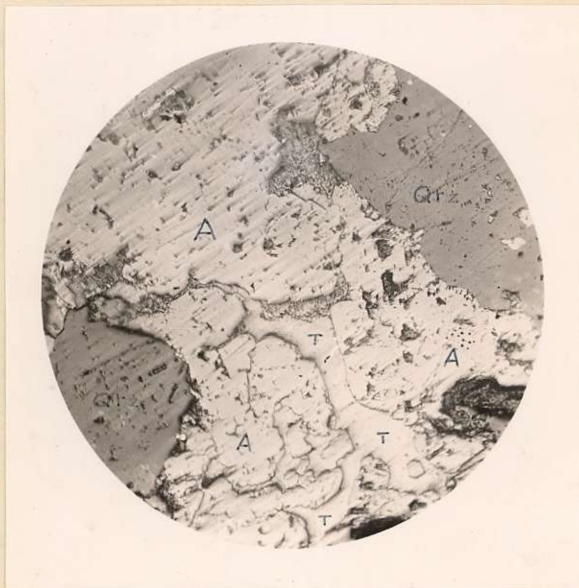


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Fig.5 Tetrahedrite (T) and Argentite (A) in veinlet.

to be contemporaneous with galena, and overlapping, but in general later than argentite. (Fig 5). When occurring as irregular patches, it appears to be similar in occurrence to the argentite in the black quartz, except that it has a different appearance in hand specimens.

#Bowen N.L. "Geologic Thermometry". Fairbanks.
Schneiderhohn H. Amer.Mineral. Vol 12 1927.

Fig. 6 is a specimen of irregular patches of tetrahedrite. See also Fig. 10.

x 90

Fig. 6 Patches of tetrahedrite in quartz.

A shipment of 120 tons of ore ran 0.19% Cu: neglecting chalcopyrite, which is quite uncommon, this corresponds to a content of about 1% of tetrahedrite in the ore. It would seem that, if the ore deposit is due to secondary enrichment, this amount of tetrahedrite would give rise to alteration minerals such as covellite: this mineral has not been observed, a fact which suggests that the ore below the capping is of unaltered hypogene origin.

Pyrargyrite is found throughout the oreshoot. It's mode of occurrence is similar to argentite, namely dissemminated through brecciated quartz and in veinlets. The dissemminated mineral gives the ore a red color, known locally as "ruby stain", in the absence of argentite. Fig. 8 shows veinlets of pyrargyrite crossing the quartz breccia: the latter carries innumerable small patches of the same mineral. The

X90

Fig.7 Veinlets of pyrargyrite (dark) in quartz.

pyrargyrite is thought to be later than the earlier generation of argentite and probably contemporaneous with the second injection of argentite in veinlets. This fact could not be determined with certainty.

Replacement of pyrite by pyrargyrite is suggested by figs. 8 and 9.(see next page). Fig. 8 appears to be residual pyrite in pyrargyrite. Cusps and transecting veinlets of the latter mineral are seen in the patch of pyrite. Fig. 9 shows what may be an instance of "centrifugal" replacement, i.e. replacement starting from the center;# at least, it is difficult to account for the islands of pyrargyrite in the center of an apparantly euhedral pyrite crystal.

#Lindgren,W. "Mineral Deposits" P185.

X90

Fig 8 Residuals(?) of pyrite (Py) in pyrargyrite (Pyr)

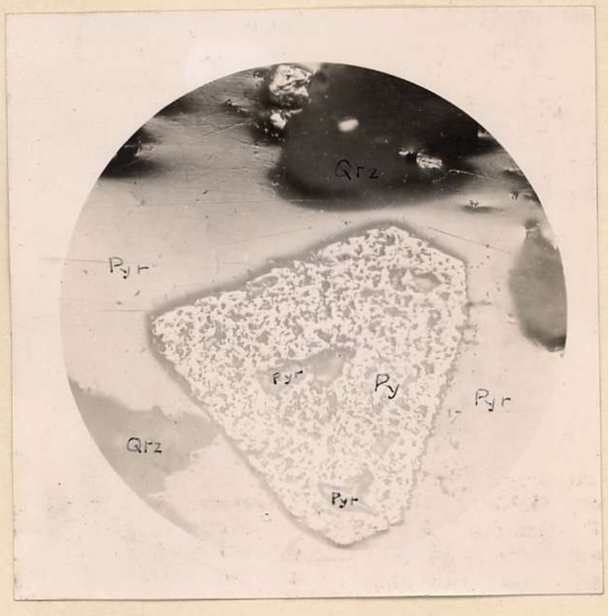

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Fig.9 Centrifugal replacement (?) of pyrite (Py) by pyrargyrite (Pyr)

Galena occurs sparsely in the oreshoot as veinlets and bunches. It is apparently contemporaneous with tetrahedrite as seen by fig. 10 (next page). It also appears to be later than, but overlapping, argentite. The late deposition of galena is usual according to

Guild.[#] Fig 11 is argentite and galena, the latter being of later deposition.

x 30

Fig. 10 Galena (G), Tetrahedrite (T) and native silver (Ag) in a veinlet.

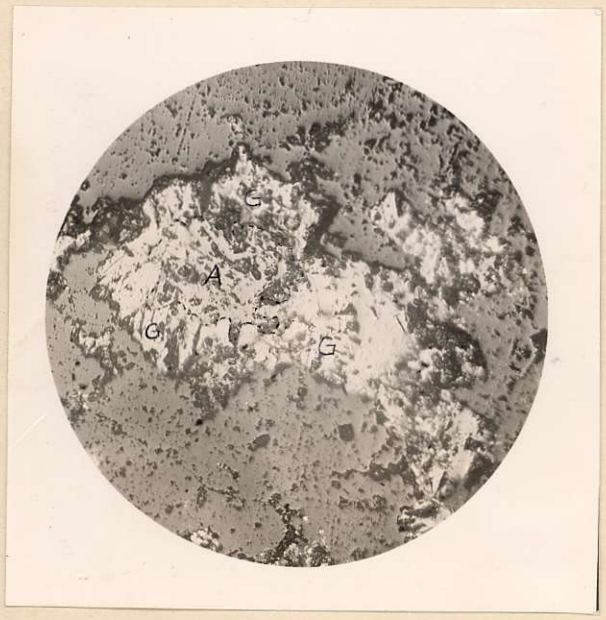

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Fig. 11 Galena (G) later than Argentite (A) in a veinlet.

Galena is not important as an ore mineral; picked specimens seldom run more than 10 oz/ton Ag. In the low grade segment of the vein east of the 304 fault,

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[#] Guild F.N. "The Enrichment of Silver Ores". Fairbanks.

galena, associated with sphalerite is common. Values are, however, extremely low.

Sphalerite constitutes less than 2% of the deposit in the productive part of the vein. It is one of the early minerals, probably contemporaneous with quartz and pyrite. The texture is fine grained and the mineral is light straw colored in the upper part of the ore shoot. In 457 stope it is dark colored, coarse grained and massive.

Chalcopyrite is comparatively rare. It's age relations to other minerals could not be determined since only one small grain was visible in the sections.

Gangue Minerals.

Quartz is the most abundant gangue mineral; it forms 70-85% of the vein. No banding structure is visible and the quartz is hard and glassy. Probably two or more generations are present but this could not be determined for certain; however, the earlier brecciated quartz seems to have recrystallized in addition to being impregnated with argentite. In places, notably in 455 stope, the quartz is dark gray, but does not carry values, indicating that brecciation was succeeded in places by a second generation of quartz without argentite.

Barite is present in small quantities throughout the vein. It appears as a coating on fracture planes and may have been contemporaneous with formation of argentite and pyrargyrite in veinlets. Increase or decrease of the quantity of barite with depth, could not be determined. Hanson states that barite is more common in the deeper parts of the vein.

<u>Calcite</u> occurs as crystals in vugs, probably contemporary with argentite.

<u>Jasper</u> is uncommon; it is usually found in irregular patches.

~~Mineral~~ <u>Succession of Hypogene Minerals</u>.

The following is considered to be the sequence of events after the formation of the original fracture, which served as a channel for ore solutions.

(1) Deposition of quartz, pyrite and sphalerite. The ore solutions ascended in channels along the fracture plane, causing metasomatic replacement, silicification and sericitization of the green tuffs on the footwall side. The hanging wall, by reason of its having less permeability or because it was protected by a layer of fault gouge, was not involved in this replacement. It is noticeable that, in the part of the vein whichdoes not follow the contact and which has green rocks for both hanging and footwalls,replacement has occurred in both walls.

(2) Movement followed, along the hanging wall. This is evident from the presence of silicified fault gouge next to the hanging wall in every segment of the vein. This movement was accompanied by fracturing and brecciation of the vein filling. A feature, which may have an important significance in the formation of the ore shoot,is that the layer of silicified gouge and quartz stringers on the hanging wall is widest in the productive area. This may mean that fracturing was m

most intense in the oreshoot, thus providing a free passage for the solutions.

(3) Solutions containing argentite (and tetrahedrite ?) were next injected along the channels. This process resulted in the formation of the black quartz. Quartz probably accompanied this phase of the mineralization. Vugs were filled with argentite.

(4) Further movement, forming fractures, was followed by injections of, first, argentite and pyrargyrite and afterwards galena,tetrahedrite and barite. These minerals were thus deposited as veinlets in the earlier ore minerals.

The relation of calcite,barite and jasper to the other minerals could not always be ascertained.

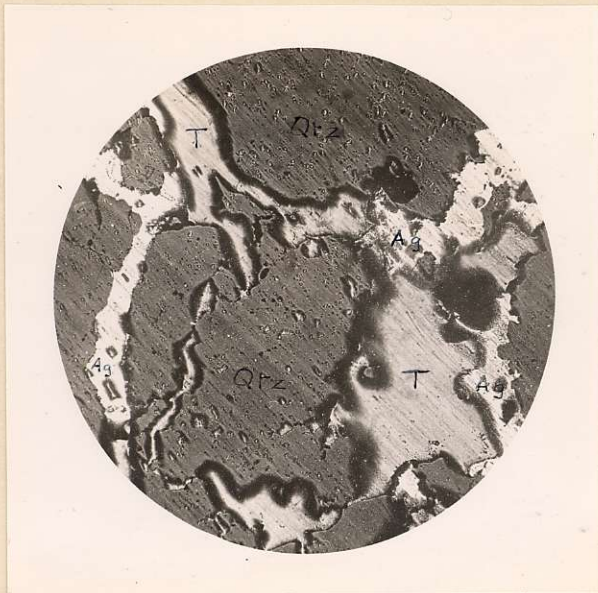
Faulting Subsequent to Hypogene Deposition.

Subsequent to hypogene ore formation, stresses connected with mountain building, caused faulting of the vein. The faults run approximately north and southand have displacements up to 130 feet. The faults belonging to this series are remarkably clean cut; they also have little vertical displacement. The oreshoot was thus cut up into small segments,widely separated from one another. The intervening country rock has no appreciable silver content, a fact which precludes the possibility of any widespread secondary enrichment.

Subsequent to the horizontal movement, diabase dykes were intruded in fractures which do not displace the vein. The vein matter adjacent to the large dyke near the center of the oreshoot, appears to be slightly lower in grade. Following the intrusion of the dyke, a younger series of faults, notably the 205 fault, displaces both dyke and ore segments.

Supergene Mineralization.

The outcrop of the vein consists of a barren, oxidized capping 8-12 feet thick. At the base of the capping, there is an abrupt change to unoxidized vein matter. Native silver, which is the only supergene mineral of importance, occurs in large plate-like



x 30

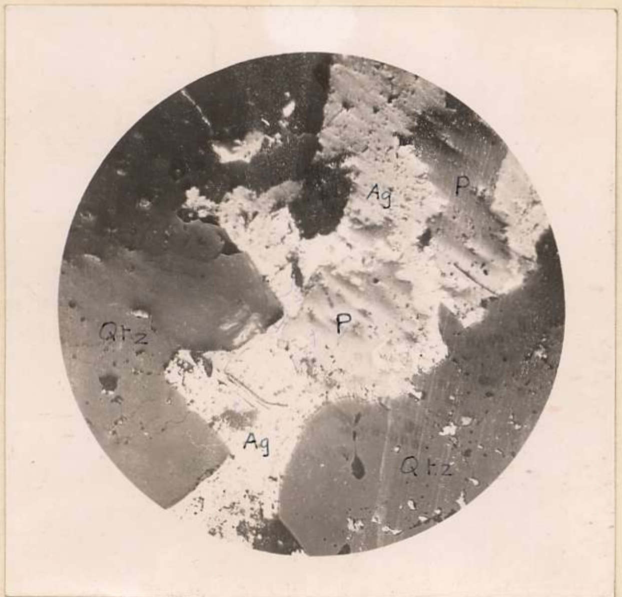
Fig. 12. Native Silver (Ag) occupying the same fracture as Tetrahedrite (T).

masses and scales immediately below the capping. The silver has been taken into solution in the eroded portion of the vein and then redeposited below the zone of oxidation, in fractures formed by faulting. Silver is readily deposited from sulphate solutions by ferrous Sulphate.# The latter would be plentiful in ground water

#Emmons W.H. "The Enrichment of Sulphide Ores". p119. U.S.G.S. Bul. 529. 1913.

due to partial oxidation of pyrite, and accounts for the alteration of the silver minerals to native silver. Fig. 13 represents a veinlet of ruby silver in process of reduction to native silver.

In the examination of polished sections, it was often noted that native silver occurred in the same fracture as tetrahedrite, galena, argentite and ruby silver (figs.4,10, 12), with an abrupt boundary between them. It is, however, more than probable that this is the result of reopening of fissures, filled during hypogene mineralization, by subsequent faulting, rather than the result of simultaneous deposition.



X 90

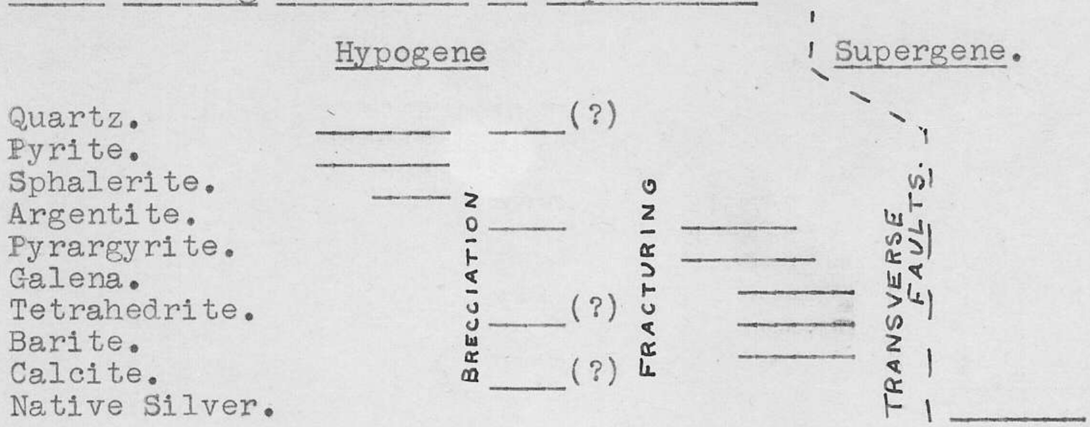
Fig. 13. Pyrargyrite (P) altering to Native Silver (Ag) in veinlet.

The quantity of native silver rapidly diminishes with depth, until, at 60 feet below the outcrop, it occurs only adjacent to a favorable channel for supergene water such as the 205 fault. The earlier series of faults (203,417,304 see fig. 1,2;), are tight and dry;

they are evidently unfavorable for the circulation of meteoric water, and consequently, the ore adjacent to them is not appreciably enriched. Native silver was important economically: it is probable that 40% or more of the silver produced occurred in this form.

Mention has already been made of the absence of covellite, or other alteration products of tetrahedrite; alteration products of galena, such as cerrussite or anglesite, are also absent in the deposit.

Table showing Succession of Deposition.



Origin of the Ore.

The orebody cannot be correlated with any specific intrusion of plutonic rocks. It can only be conjectured that an unexposed part of the batholith was the source of the ore solutions. The same magma may have produced the dykes: the latter, however, do not seem to have been connected with the oreforming process as they were intruded later, after the vein had been faulted.

The depth of formation of the vein can be inferred from the surrounding topography. The highest summits in the batholith, in the vicinity of the mine, are approximately 2500 feet higher than the outcrops. Making an allowance for erosion, we are brought to the conclusion that the depth of formation was not much more than 3000 feet: at the same time, it could not have been less than 800 feet, having regard to the topography of Dolly Varden Mountain. Again, from the fact that argentite at the Dolly Varden is isometric, we infer that the temperature of formation was at least 175 degrees cent: also that conditions of cooling were such as to prevent it reverting to the anisotropic form.

Neglecting the supergene native silver, reasons to account for the impoverishment of the ore at the comparatively slight depth of 250-300 feet are not evident. It seems probable that the present deposit represents the lower part of a shallow ore shoot of the bonanza type, and that physical conditions at the time of formation were such as to cause precipitation of ore minerals only over a comparatively limited vertical range. The possibility that the oreshoot pitches to the west must also be considered: in this event, ore may be found considerably below the lowest known elevation, as at present determined by diamond drilling.

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