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A Mineralographic Investigation on
Ore from the Little Gem Mine.

Geology 9

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TABLE OF CONTENTS

	<u>Page</u>
Introduction	1
Location	1
Geology	1
Ore Occurrence	2
Mineralography	2
Sections	2
Reagents	3
Table of Etch Reactions	4
Observations	4
Etch tests	6
Microchemical Tests	6
Assays	7
Section B	9
Section D	19
Section E	19
Section F -1	9
Section F -2	9
Conclusions	11
Mineralogy	10
Paragenesis	11

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Introduction

Location

The Little Gem mining property consists of 11 claims located on Roxey Creek, a tributary of Gun Creek, in the Lillooet Mining District of British Columbia. The mine is on the top of a ridge that slopes down to Roxey Creek.

Beside trenching work, two tunnels have been driven on the property. One tunnel at an elevation of 6400 feet follows high-grade ore for most of its total length of 200 feet. The other tunnel at 6350 feet elevation is about 500 feet long and follows the ore for about 60 feet.

Geology

The local rock formation is a biotite-quartz-diorite. This diorite is in the form of a tongue 2000 feet wide and $2\frac{1}{2}$ miles long extending from a larger body of diorite that covers Gun Creek valley. A massive dark green serpentine borders ~~bordered~~ the diorite to the north west and shows a banded structure along the contacts where it is badly sheared and broken. Numerous Aplitic dikes traverse the diorite and follow closelely a brown weathered dike of ferruginous carbonate composition. There are numerous small diabase dikes. In a few places, small sections of greenstone are included in the diorite.

Ore Occurrences

The ore bodies appear to be lenticular and vary in width from a few inches to several feet. Two veins which are thought to be part of the same ore body, are being developed at present. The foot-wall vein dips at 90 degrees and strikes easterly-westerly. It is exposed for 50 feet on the surface. It varies in width from a few inches at the lower end to about six feet at the upper end and is covered by an altered diorite cap-rock. The hanging-wall vein is parallel to the foot-wall vein 17 feet to the south. This vein appears wider and longer than the foot-wall vein and averages six feet in width over 90 feet of length.

Throughout the ore bodies are numerous masses of quartz and feldspar. Very little alteration appears at the borders of the veins.

A shear, 6 to 12 feet wide, striking easterly-westerly was traced for 200 feet on the surface. The shear cross-section assays from 0.22% to 0.40% cobalt. Where small dikes cut the shear, arsenopyrite and cobalt bloom are found. These occurrences may indicate higher values below. #

Mineralography

Sections

Sections were cut in triplicate, one for the author, and two which were superpolished by Mr. J. Donnan for Dr. H.V. Warren. The author's sections were mounted with Damar Gum in brass molds. A section for assaying was cut between those of the author and those of Dr. Warren.

The sections were made up from the following samples:

- "A" -1 Channel Sample 47 feet from portal of Upper Tunnel, 5.5 feet wide. Most of the massive sulphide pieces were removed from this sample. Taken 2 feet from floor across face of tunnel by R. Taylor, Aug. 2/38.
- "A" -2 Channel sample 54 feet from portal of Upper Tunnel, 5.7 feet wide. Most of massive sulphide pieces were removed from this sample. Sample taken 2 feet from floor across face by R. Taylor, Aug. 3/38.
- "A" -3 Channel sample 54 feet from portal of Upper Tunnel, 5.7 feet wide. Most of massive sulphide pieces have been removed from this sample. Sample taken 2 feet from floor across face by R. Taylor, Aug. 4/38.
- "B" Channel sample 90 feet from portal of Upper Tunnel, 4.4 feet wide. Taken in roof of tunnel by J.M. Taylor, Oct. 1941.
- "C" Channel sample 30 feet from face of Upper Tunnel, 4.7 feet wide. Taken in roof of tunnel by J.M. Taylor, Oct. 1941.
- "D" Channel sample 10 feet from face of Upper Tunnel, 4.5 feet wide. Taken along broken hanging-wall face breast high by J.M. Taylor, Oct. 1941.
- "E" Channel sample 5 feet wide from Lower Tunnel. Sample taken on south wall of main showing. Channel extended from 4 feet to 9 feet above Tunnel floor. Taken by J.M. Taylor, Oct. 1941.
- "F" Lumps of massive sulphide taken in the region of samples "B" and "C" in the Upper Tunnel. Taken by J.M. Taylor, Oct. 1941.

Three sections were taken from sample "F" and marked "F" -1, "F" -2, and "F" -3.

Reagents

Beside the ordinary reagents, the following were made up as indicated in Mr. Ellis Thompson's paper: "A Qualitative and Quantitative Determination of Ores of Cobalt, Ont." Economic Geology, Vol. 25. No. 5, 1930.

- (1). Conc. HNO_3 .
- (2). 3:10 HNO_3 .
- (3). Saturated KMnO_4 .
- (4). Saturated FeCl_3 .
- (5). Aqua Regia / Arsenopyrite. This reagent was made by saturating the aqua regia with arsenopyrite. The solution was taken to dryness overnight to get all the sulphur into solution.
- (6). Aqua Regia / 1.82 gm. Co
1.82 gm. Ni
2.25 gm. As
1.00 gm. S

The above elements were taken to dryness in a large volume of aqua regia overnight. The residue was taken up with 20 c.c. of aqua regia and filtered.

Table of Etch Reactions

The following table is taken from Ellis Thompson's report.

Mineral	Conc. HNO_3	1:1 HNO_3	3:10 HNO_3	Sat. FeCl_3	A.R. / CoNiAsS	A.R. / FeAsS
Arsenopyrite	Dk. grey	Irrid. dk bn rem.	-	-	-	Ft. bn rubs clean
Cobaltite	-	-	-	-	-	-
Rammels- bergite.	Dk grey rem.	Dk grey bk rem.	lt. bn rem.	Dk bn rem.	-	L t dk bn rem.
Loellingite	Grey diff rem.	Grey diff rem.	-	Ft bn diff. rem or neg.	-	-
Safflorite	Dk grey rem.	Dk grey rem.	Ft bn rem.	-	Lt bn diff rem.	-

Observations

Because sections "A" -1, "A" -2, and "A" -3 contained very little sulphide, and because of lack of time, these sections were not examined

Under the microscope all sections appeared to consist of three constituents - metallic-lustred groundmass, metallic-lustred inclusions and gangue.

The following table gives a list of general observations made on the sections.

Section	% inclusions in groundmass	Gangue	Remarks
B	15 - 20	Nearly all carbonate.	Some soft black gangue veining the carbonates.
C	25 - 30	A little carbonate, rest Qtz.	Tree-like intergrowth of gangue and sulphides.
D	20 - 25	Grey quartz, much carbonate.	Inclusions shot with gangue.
E	80 - 90	Quartz and a little white carbonate.	Tree-like intergrowth of gangue and sulphides. Two generations of quartz. Gold seen in safflorite near gangue.
F -1	30	Grey quartz, very little carbonate.	Eutectic -like mixture of both sulphides. Intimate mixture of sulphides and gangue.
F -2	85 - 90	Grey quartz, very little carb.	Two generations of quartz. Gold seen between sulphides and gangue.
F -3	85 - 90	Grey quartz, much carbonate.	Two generations of quartz. Some soft green gangue. (serpentine?)

The following table gives the physical properties of the groundmass and inclusions as noted by the author under the microscope and under polarized light. All sulphides were Anisotropic.

Component	Colour	Hardness	S.G.	Polish	Polarization colours
Groundmass	tin-white	F/ (5.5-6.5)	5.9-6.2	High polish and lustre.	Purple, pink, brown, Green-yellow, shows diamond-shaped prisms.
Inclusions	Pale-cream.	F/ (5.5-6)	6.9-7.2	Not so good as that of groundmass.	Not so strong as those of groundmass, more subdued. Yellow-brown, steel-blue.

Etch Tests: Etch tests were run on the sections to determine a method for identifying the inclusions. The special reagents were tested on pure samples of Danaite, Safflorite and Loellingite provided by Dr.

H.V. Warren

The following table gives the etch reactions observed:

Reagent	Groundmass	Inclusions
1:1 HNO ₃	Iridescent differential etch. Shows prismatic structure.	Lt. bn to grey. Sometimes shows fibrous structure. (slight effervescence?)
3:10 HNO ₃	Neg.	Neg.
Conc. HNO ₃	Dark grey, rough surface.	Light brown differential to dark grey.
1:1 HCl	Neg.	Neg.
Aqua Regia.	Neg.	Neg.
KCN	Neg.	Neg.
KOH	Neg.	Neg.
HgCl ₂	Neg.	Neg.
Sat. FeCl ₃	Neg.	Faint brown to neg. diff.
Sat. KMnO ₄	Neg.	Neg.
A.R. / FeAsS	Neg.	Neg.
A.R. / CoNiAsS	Neg. to brown	Neg. occasionally lt. bn. diff.

Microchemical Tests: Microchemical tests were run on samples of the groundmass and inclusions drilled as clean as possible for cobalt, iron, and arsenic. The following tables gives the results of these tests:

Element	Groundmass	Inclusions
Cobalt	Always positive	Always positive, some sections showed more than others.
Iron	Positive	Positive. Some showed less than others.
Arsenic	Positive.	Positive.
Nickel	A little sometimes	?

From the results of these etch tests and microchemical tests it was found that the inclusions etched light brown to dark grey with concentrated HNO_3 . The etched appeared to be darker, the greater the amount of cobalt present in the inclusion. Concentrated and 1:1 HNO_3 were found to be the best reagents to distinguish between the groundmass and inclusions when in doubt.

The groundmass gave all reactions for arsenopyrite, while the inclusions varied in their reactions between those of safflorite and loellingite as indicated in the table from Ellis Thompson's report. It was found that the inclusions, in most cases, gave much stronger cobalt tests than the groundmass.

Assays

The assay sections of samples "B", "C", "D", "E", "F" -1, and "F" -2 were assayed in spare time for Cobalt, Iron, Arsenic, and Sulphur. The following table gives the results.

Section	Au in oz./T.	Co %	Fe %	As %	S %	Insol %	Total
B	0.44	3.43	15.6	25.5	9.2	1.8	55.53
C	2.64	4.66	26.3	55.8	13.9	5.28	105.99
D	2.72	1.42	24.6	21.4	7.2	14.4	68.95
E	4.48	4.43	19.2	49.5	2.79	14.0	89.88
F -1	0.36	6.25	26.3	46.9	17.5	1.6	98.53
F -2	0.96	5.93	20.7	65.7	1.57	2.6	96.5

The high result for the total in section "C" is probably due to the sulphur assay being in error.

The low results for the totals in the other sections is due to the presence of carbonate and other soluble gangue in the sections. The assays were corrected for insol and the difference from 100%. The corrected assays are recorded in the following table together with

the estimate of the percentage of inclusions in the groundmass as previously recorded on page 5.

Section	Co %	Fe %	As %	S %	Total %	% inclusions to groundmass
B	6.39	29.0	47.5	17.11	100.00	15 - 20
D	2.6	45.1	39.2	13.1	100.00	20 - 25
E	5.84	25.3	65.3	3.68	99.12	80 - 90
F -1	6.45	27.1	48.4	18.05	100.00	30
F -2	6.32	22.0	70.0	1.67	100.00	85 - 90

Section C was left out because the assays did not add up to 100%. Assuming that all the sulphur is in the arsenopyrite, the arsenic equivalent to the sulphur was calculated. The results are as follows:

	B	D	E	F -1	F -2
As equiv to S	40	30.6	8.6	42.1	2.72
As left over for saff-loell.	7.5	14.5	56.7	6.3	67.28

The arsenic equivalent to the cobalt was then calculated assuming that the cobalt was all in pure safflorite.

	B	D	E	F -1	F -2
Cobalt equiv. to As	16.2	6.6	14.8	16.4	16.1

The iron equivalent to the sulphur was then calculate assuming that it was all present as arsenopyrite.

	B	D	E	F -1	F -2
Iron equiv. to S	30	22.9	6.4	31.6	2.9
Corrected iron assay for com- parison.	29	45.1	25.3	27.1	22.0

From the comparison of the above calculations with the corrected assays the following points were noted.

Section B: The iron equivalent to sulphur in FeAsS is just enough to satisfy the corrected assay. The arsenic left over after allowing for FeAsS is insufficient for the cobalt, hence the inclusions may be quite pure safflorite. The remaining cobalt must be in the arsenopyrite. This fact was borne out by the inclusions giving very strong cobalt tests.

Section D: In this section there is far more iron than can be accounted for by the FeAsS, also more arsenic than can be accounted for by the cobalt, hence iron must be replacing cobalt in the safflorite in this section. The inclusions gave strong tests for iron and very weak tests for cobalt in this section thus bearing out the observations.

Section E: The iron equivalent to the FeAsS is much smaller than the total amount indicated by the assays. The arsenic is more than enough to account for the FeAsS and the Cobalt, hence much iron must be in the inclusions. This fact was borne out by microchemical tests.

Section F -1: In this section there is not enough iron indicated by the assay to account for all the sulphur and not enough arsenic left after subtracting its equivalent to sulphur to account for all the cobalt, hence the inclusions must be high in cobalt and some cobalt must replace iron in the groundmass. Microchemical tests indicated high cobalt in the inclusions and higher than usual cobalt in the groundmass.

Section F -2: In this section, the iron equivalent to the sulphur is very low leaving much for the inclusions. The arsenic equivalent to cobalt is much less than that left after accounting for its equivalent to sulphur. These facts indicate that the inclusions must be rich in iron and low in cobalt. This fact was borne out in microchemical tests.

The following analyses are from "A System of Mineralogy"

by Dana:

<u>Danaite:</u>	<u>As</u>	<u>S</u>	<u>Fe</u>	<u>Co</u>	<u>Similar to</u>
	47.45	17.78	30.91	4.75	B
	41.44	17.84	32.94	6.56	F -1
Safflorite-					
Loellingite	70.59	1.65	28.67	6.1	F -2
	63.66	3.66	21.22	6.44	E

The similarity between the above assays and those of the sections should be noted. It should be noted also that sections B and F -1 showed a small number of inclusions, while F -2 and E showed little groundmass.

Conclusions

Mineralogy

The mineralogical composition of this ore appears to be a mixture of two metallic-lustred minerals:- Cobaltiferous arsenopyrite (groundmass) sometimes called Danaite and a mineral which may be called Safflorite-Loellingite. Safflorite-Loellingite, according to textbooks, is a diarsenide of iron and cobalt in which the cobalt is replacing the iron. From the results of the assays and calculations, and the etch and microchemical tests, the composition of this mineral appears to vary between pure Safflorite (CoAs_2) and pure Loellingite (FeAs_2). Intermediate compositions being formed by the replacement of iron by cobalt in the Loellingite. The inclusions showed great variation in their iron and cobalt content as calculated from assays and as noted in microchemical tests. The inclusions also gave etch reactions

varying between safflorite and loellingite, depending on their cobalt content.

The groundmass gave all reactions for arsenopyrite plus microchemical tests for cobalt and sometimes a slight test for nickel. This mineral was thought to be Danaite or arsenopyrite in which cobalt is replacing the iron.

Comparison of the corrected assays with the assays for Danaite and cobaltiferous Loellingite given in "A System of Mineralogy" by Dana indicate that some of the sections were practically pure Danaite or Safflorite-Loellingite. This fact was also borne out by observation on these sections.

Paragenesis

As most of the time available was used for work on the two sulphide minerals, - including assaying, etch and microchemical tests, little time was left to work out the paragenesis of the ore deposit. However, the following points were noted.

- (1). The danaite groundmass appeared to be the earliest in mineralization.
- (2). The safflorite-loellingite appeared to have been deposited contemporaneously with or later than the danaite. In some sections it appeared to be veining the danaite.
- (3). All the gangue was veining the sulphides and in some places showed replacement of the danaite. Two generations of quartz was observed in some sections.
- (4). A carbonate gangue was noted in some sections but it was not definitely determined whether the calcite was earlier or later than

the quartz, although in some sections it appeared to be veining both generations of quartz.

(4). Only two specks of gold were seen by the author and these occurred at the boundary between sulphides and siliceous gangue possibly indicating that the gold came in late with the quartz. There is no apparent relation between the gold and the cobalt as indicated by the assays, although a rough relation may be seen between the gold and insol assays, however it is not very definite.

The following photographs show some of the above mentioned points.

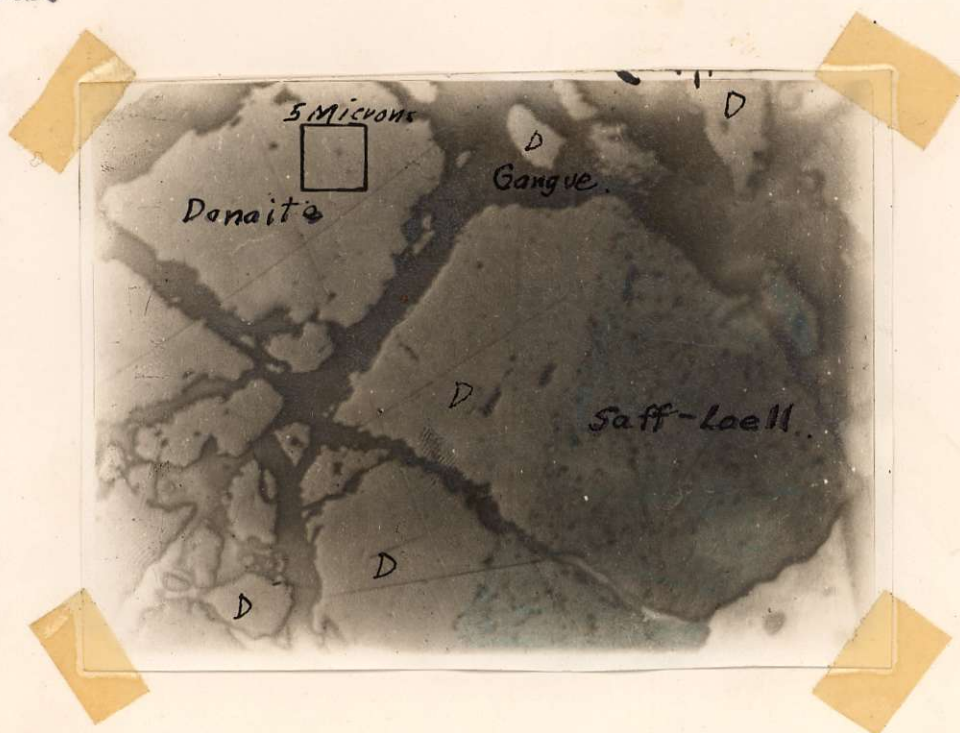


Figure 1: Section E, showing Danaite and Safflorite-Leollingite both fractured and replaced by gangue.



Figure 2: Section E, showing Danaite and Safflorite-loellingite replaced by one generation of quartz. Another generation of quartz is seen veining the first generation.



Figure 3: Section F -2, showing danaite projecting into into Safflorite-Loellingite with some unattached remnants of danaite.
(Danaite etched).

The following table is a summary of the paragenesis of the ore deposit:

- (1). Danaite (and possibly some safflorite-loellingite).
- (2). Safflorite-Loellingite.
- (3). Siliceous gangue No. 1.
- (4). Siliceous gangue No. 2 Possibly gold came in with one of these.
- (5). Calcite.

~~Corrosion~~ Assays.

Section	B	C	D	E	F ₁	F ₂
AU. 02/T.	0.44	2.64	2.72	4.48	0.36	0.96
Co %	3.43	4.66	1.42	4.43	6.25	5.93
Fe %	15.6	26.3	24.6	19.2	26.3	20.7
As %	25.5	55.8	21.4	49.5	46.9	65.7
S %	9.2	^{136.2} 73.95	7.14	2.79	17.5	1.57
Insol. %	1.8	5.28	14.39	13.96	1.58	2.60
Total %	55.53	^{100.00} 105.99	68.95	89.88	98.53	96.50
Total of Fe, As, Co & S.	53.73	^{100.00} 105.99	54.56	75.92	96.95	93.9
Corrected Co	6.39		2.6	5.84	6.45	6.32
" Fe	29.0		45.1	25.3	27.15	22.05
" AS	47.5		39.2	65.3	48.4	70.00
" S	17.11		13.1	3.68	18.05	1.67
Total	100.00		100.0	100.12	100.05	100.04
As equivalent to S in FeAsS based on S assay						
	40		30.6	8.6	42.1	2.72
As left.	7.5		14.5	56.7	6.3	7.28
Fe equivalent to S in FeAsS based on S assay						
	29.8		22.8	6.4	31.4	2.91
As equiv to Co in CoAs ₂ based on Co assay						
	16.2		6.6	14.82	16.38	16.05
As Equiv to Fe in FeAs ₂ based on Fe left after taking account of FeAs S.						
			58	51.0		51.0