Mineralization and Rock Alteration in the Nederland District, Colorado.

by Robert M. Rigg

Rock Alteration, Nederland district.

30TL26 30TL27 30TL29	6th level, Coldspring mine.
30TL38 30TL40 30TL41 30TL43	5th level, Coldspring mine.
30TL65 to 30TL69	Clyde mine.

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ILLUSTRATIONS

Mineralization and Rock Alteration in the Nederland District, Colorado.

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Abstract

The gneissic quartz monzonite (Boulder Creek granite) wall rock of the ferberite veins of the Nederland district, Colorado, was beidellitized, propylitized, sericitized, and somewhat silicified and carbonatized. Sericitization is the dominant mode of alteration. Subsequent silicification by quartz veinlets made the wall rock competent and megascopically appear unaltered at the vein and wall rock contact. The alteration of the wall rock was primarily of pre-ore occurrence, for quartz veinlets which heralded ferberite mineralization are post-sericite. There is some evidence of post-vein quartz sericitization. Wall rock alteration and ferberite mineralization are believed to have occurred primarily in an alkaline environment.

The mineralogical association, drusy cavities, and unfilled openings in the ferberite veins suggest that mineralization occurred in the upper part of the mesothermal or in the lower part of the epithermal zone.

Acknowledgement

The author wishes to thank Dr. T. S. Lovering of the University of Michigan under whose supervision this paper was written. He kindly furnished the specimens which were studied and his numerous helpful suggestions greatly facilitated the completion of this paper.

Introduction

Location

The Nederland district lies in the southeastern quarter of Boulder County, Colorado. It is covered by the northern six miles of the Black Hawk, the southern two miles of the Boulder, and the northeastern corner of the Central City topographic maps of the United States Geological Survey [1].

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[1] George, R. D., The main tungsten area of Boulder County: Colo. Geol. Survey, First Ann. Report, p. 9, 1908.

General Geology

The area is part of a broad, eastward-sloping upland belt extending from the ridges of the upturned sedimentary rocks at the western border of the Great Plains, westward to the steeper slopes of the Front Range [1].

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[1] George, R. D., The main tungsten area of Boulder County: Colo. Geol. Survey, First Report, p. 15, 1908.

The ore deposits of the Nederland district occupy a narrow easterly trending belt which extends from Nederlandto within a few miles of Boulder. The ore occurs in veins trending east to northeast and are chiefly in gneissic quartz monzonite (Boulder Creek granite). The veins follow faults of comparatively small throw along which repeated movement has taken place. Dikes of early Eocene porphyry, chiefly hornblende andesite and quartz monzonite, are common [1].

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[1] Lovering, T. S., XVI International Geol. Congress, Guidebook 19, Excursion C-1, pp. 140-141.

The deposits are fissure fillings and consist essentially of quartz and ferberite containing less than one percent of manganese. In the western part of the tungsten district, much of the ferberite is coarsely crystalline, but in the veins further east, it is much finer grained. The ore occurs as brecciated fragments cemented by later opaline or chalcedonic quartz, or as a matrix containing fragments of finely crystalline vein quartz. Drusy openings lined with beautiful crystals of ferberite are common. There is a noticeable concentration of the ore deposits close to the northwestward-trending Hurricane hill reef, an iron-stained sheer zone marked locally by silicification _/.

_/ Lovering, T. S., Preliminary map showing the relations of ore deposits in Boulder County, Colo.

Most of the ore bodies in the district are less than 100 feet long and two feet wide, and have been bottomed at depths of less than 200 feet from the surface _/.

_/ Ore deposits of the western U. S., Lindgren Volume, pp. 668-671.

Tungsten deposits are erratic and any general change in values with depth is difficult to interpret.

The ore deposits are later than dikes of early Eocene age and appear to be earlier than the erosion surface developed during the latter part of the Eocene. The presence of drusy cavities in the ore and large unfilled openings in many of the veins, and the presence of chalcedonic quartz indicate veins formed at low pressures close to the surface [1].

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[1] Ore deposits of the western United States, Lindgren Volume, pp. 668-671.

Lindgren corraborates this view by remarking that in Boulder County, Colorado, the tungsten and telluride veins distinctly resemble the deposits formed at slight depths below the surface [1].

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[1] Lindgren, Waldemar, Mineral deposits, 3rd edition, p. 678

Production

The Nederland district has been one of the most productive tungsten districts in the United States, and it has produced slightly more than one million units of tungsten trioxide valued at approximately $19,000,000.[1]

[1] Ore deposits of the western United States, Lindgren Volume, pp. 668-671.

Shipments of tungsten concentrates from Colorado in 1935 amounted to 519 short tons, all of which was ferberite[1].

[1] Minerals Yearbook, 1936, p. 449.

Fresh Boulder Creek Granite

The unaltered Boulder Creek granite is a dark gray, gneissic biotite quartz monzonite showing a slightly porphryritic habit. In the hand specimen, the rock consists essentially of quartz, orthoclase, plagioclase, and biotite. The grains of feldspar are 6 millimeters in length; those of quartz are about 3 millimeters in diameter. The rock shows well-defined platy and linear structure.

Locally, the normal biotite granite gives way to a hornblende granite through a transition zone of hornblende and biotite. The hornblende facies is probably due to assimilation of hornblende schists and only differs from the normal Boulder Creek granite in the presence of hornblende instead of biotite [1].

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[1] Lovering, T. S., U. S. Geol. Survey manuscript report.

Under the microscope, the typical Boulder Creek granite contains about 35 percent oligoclase, 25 percent quartz, 15 percent biotite, and a few grains of orthoclase. The texture is hypidiomorphic. Undulose extinction of the quartz grains, bent plagioclase twinning lamellae, some evidences of peripheral granulation of the of the grains, and minute fractures running across several crystals are criteria suggesting deformation at shallow depths [1].

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[1] Grout, F. F., Petrography and petrology, p. 376, McGraw-Hill Book Co., Inc., 1932.

The common accessory minerals are apatite, zircon, ilmenite, magnetite, rutile, and titanite. Myrmekitic intergrowths are present.

Altered Boulder Creek Granite

Introduction

Megascopic examination of the wall rock of the 5th level of the Cold Spring mine and of the Clyde mine showed an apparently anomalous condition. It was noted that the wall rock became increasingly altered as the veins were neared, apparently a maximum of alteration and incompetency being reached at distances of a few feet from the veins. Frm these weak zones to the veins, the wall rock appeared less altered and more competent.

The explanation to this condition was obvious when the wall rock was examined in thin-section. Propylitization and sericitization were the dominant forms of alteration in the zones of greatest incompetency. Silicification became the dominant mode of alteration from these zones towards the veins. The increase in the silicification of the wall rock is responsible for the unexpected competency of the wall rock next to the veins.

Oligoclase and biotite show progressive alteration as the vein is neared. Microcline, orthoclase, and quartz are relatively free of alteration. The absence of alteration of microcline and orthoclase may indicate that the solutions which altered the rock were high in potash. Ilmenite is altered to leucoxene. Beidellite alters to sericite and quartz as the vein is approached. Magnetite shows slight alteration to limonite in many places.

The three alteration series which were examined were alike in many respects. Beidellitization in the wall rock decreased and disappeared as the veins were approached. Sericitization increased as the veins were approached in the Cold Spring mine, but in the Clyde mine sericitization decreased as the vein was approached and is only 2 to 3 percent of the rock at the vein and wall rock contact. Propylitization progressively increased as the veins were neared. Silicification by quartz veinlets increased greatly as the veins were neared, generally being the dominant mode of alteration at the vein and wall rock contact. Carbonatization was relatively uniform and constant throughout the alteration series, totalling about 5 percent of the wall rock.

Beidellitization

The plagioclase of the Boulder Creek granite probably first underwent beidellitization. The Boulder Creek granite, which was formed in an alkaline environment like all granitic melts, became out of equilibrium with beidellitizing solutions. It is believed that beidellitization was then at a maximum at the vein and wall rock contact. The silica content of the wall rock was then at a minimum, and the water of hydration and alumina were at a maximum. Soda and lime were probably at a minimum. The absence of alteration of the microcline and the orthoclase suggests that potash remained nearly constant throughout beidellitization. This suggests that the plagioclase feldspars were out of equilibrium and that the orthoclase feldspars were in equilibrium with the percolating solutions. These solutions, which were probably high in alumina, leached silica, soda, and lime from the wall rock.

A change in the character of the mineralizing solutions allowed sericite and quartz to replace the beidellitized rock. The wall rock was freshened by the alkaline solutions which caused sercitization and silicification. This suggests that beidellitzation occurred in an acid environment.

Sericitization -- early

Sericitization proceeded subsequent to the beidellitization of the wall rock. Sericitization accompanied by some silicification occurred at the expense of beidellite. It is very likely that some sericite and the accompanying silicification also occurred as an alteration product of oligoclase. In the development of sericite from plagioclase the presence of potassium-bearing solutions, which exchange alkalies with the sodium compounds, must be assumed -/. Recent work by

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-/ Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 770, p. 605, 5th ed., 1924.

Norton suggests that soda plagioclase will alter to paragonite in hot carbonic acid solutions at temperatures under 300 degrees Centigrade -/. The possibility of

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-/ Norton, F. H., Accelerated weathering of feldspars: Am. Mineralogist, vol. 22, p. 12, January 1937.

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what is called sericite in this paper in reality being paragonite is doubtful because of the progressive decrease in soda veinwards (diag, 2, A). It is considered likely that sericitization and the accompanying slight silicification occurred in alkaline solutions -/ which were high in potash.

-/ Grout, F. F., Petrography and petrology, p. 219, McGraw-Hill Book Co., Inc., 1932.

Propylitization

Ransome remarks that propylitization results chiefly from carbon dioxide in solution, and that it may be the result of the cooler and weaker phases of hypogene solutions or it may be supergene [7]. The close

[7] Ransome, F. L., The geology and ore deposits of the Breckenridge district, Colorado: U. S. Geol. Survey Prof. Paper 75, pp. 94-102, 1911.

association of the propylitization with the veins is strong evidence that the propylitization is of hypogene origin. The paragenesis of the propylitization is doubtful.

Silicification

Intense silicification by small quartz veinlets occurred after sericitization and its small amount of accompanying silicification. Quartz veinlets may be observed cutting through felted masses of sericite and quartz, the quartz veinlets greatly increasing in quantity as the vein is neared. Following the silicification of the wall rock by these small quartz veinlets, it is likely that the chemical composition was similar to that now present. Silica was at a maximum, and the water of hydration and the water present in the pores of the rock were at a minimum at the vein and wall rock contact.

Carbonatization

Silicification was accompanied by slight carbonatization, the carbonate being in the quartz veinlets in many instances. Carbonatization, however, seems to have traveled farther from the main channelways of mineralization than did the quartz veinlets. It seems likely that carbonatization both preceded and was associated with the silicification by quartz veinlets, and this view is born out by a study of the gangue in polished sections.

The quartz veinlets heralded ferberite mineralization. These veinlets may be traced into the early quartz gangue of the ferberite veins. Thus, rock alteration preceded ore deposition.

Sercitization -- late

In a few places it may be observed that shreds of sericite replace the quartz veinlets. This suggests slight post-quartz veinlet sericitization and a maintainence of the alkaline conditions which favors sericitization. It could not be determined whether this late sericitization was pre- or post-ferberite, but it is interesting to note that Gannett found that ferrous tungstate is not precipitated in acid solutions, but is nearly completely precipitated in slightly alkaline solutions [1]. This strongly suggests that the alteration

[1] Gannett, R. W., Experiments relating to the enrichment of tungsten ores: Econ. Geol., vol. 14, pp. 68-78, 1919.

of the wall rock and the deposition of the ferberite in the brecciated veins occurred in alkaline solutions which contained appreciable quantities of silica and potash, and carbon dioxide.

Alunitization (?)

Associated with the quartz gangue of the ferberite veins and with the quartz veinlets near the vein and wall rock contact are a few very small grains with moderatley high relief and a tendency towards square sections (pl. 7, B). The birefringence of these small grains is of the lower part of the first order. What few optical properties could be obtained suggested that this mineral was a member of the alunite series. Hess and Schaller have reported the presence of a mineral similar to this in the Eagle mine, Colorado, which they have suggested might be hamlinite, a mineral belonging to the alunite series [1].

[1] Hess, F. L., and Schaller, W. T., Colorado ferberite and the wolframite series: U. S. Geol. Survey Bull. 583, p. 14, 1914.

The soluions forming alunite (?) underwent a progressive change in nature, for they deposited abundant quartz, carbonate, alunite (?), and ferberite, probably in the order named. This suggests that alkaline solutions became neutralized, acidified, and then alkaline again. Alunite (?) was deposited when the solutions were acid. These acid solutions contained sulphuric acid [1]. That sulphates are

[1] Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah; U. S. Geol. Survey Bull. 511, p. 23, 1912.

Ransome, F. L., The geology and ore deposits of Goldfield, Nevada: U. S. Geol. Survey Prof. Paper 66, pp. 189-195, 1909.

present in the vein-forming solutions of the district is indicated by the fact that barite is rather abundant in the Clyde mine.

Gannett's experiments concerning the precipitation of ferberite in slightly alkaline solutions[1]

[1] Ibid.

suggests that the alunitizing acid solutions contained ferrous tungstate in solution. These acid solutions upon becoming alkaline again precipitated ferberite from solution.

Alteration Series

Cold Spring Mine, 5th Level

35 feet from the vein

A fresh specimen of the Boulder Creek granite showed in the thin-section less than 1 percent alteration. The rock has a fairly uniform hypidiomorphic texture. Quartz shows undulose extinction, however remaining uniaxial. Some evidences of slight granulation of the margins of the grains may be observed.

The rock is composed of subhedral grains of oligoclase of the composition Ab75 An25; anhedral grains of microcline, orthoclase, and quartz; and biotite. The oligoclase grains are a maximum of 6 millimeters in length; the microcline grains are a maximum of 4 millimeters in length.

The essential mineral composition is estimated to be:

Oligoclase	35%
Quartz	30
Microcline	20
Biotite	10
Orthoclase	5

The quartz grains contain numerous hair-like inclusions of rutile. The brownish-green biotite contains several small lenses of titanite aligned along the biotite's cleavage planes. Other accessories are magnetite, zircon, apatite, and ilmenite showing incipient alteration to leucoxene. A few grains of myrmekite encroach upon the microcline. A very few inclusions of hornblende in quartz were noted. There are a few grains of microcline perthite.

The alteration products total less than 1 percent. The sericitization of the oligoclase appears to have been more active along one of the twins in the Albite-twinned oligoclase (pl. 1, A). Some kaolinization is suggested by the presence of a dust-like alteration product of low birefringence upon the myrmekite. There is a slight limonitic stain on the magnetite. A few irregular fractures in the thin-section are filled with a greenish material suggesting chlorite.

<u>10 feet from the vein</u>

Under the microscope, a sample shows a total alteration of 25 percent. An estimation of the alteration products gave the following percentages of these minerals in the wall rock:

Beidellite	20%
Sericite	4
Quartz	1
Epidote	
Carbonate	
Leucoxene	

There is a suggestion of a minute fracture pattern in the rock in which the solutions causing beidellitization entered. Some of these roughly parallel fractures are tight and contain no mineral matter. The irregular veinlets of beidellite in quartz appear to weakly replace the quartz. Oligoclase shows alteration to beidellite (pl. 1, B). There are a few small veinlets of beidellite crossing the microcline grains. Neighboring grains of quartz show sutured margins.

Sericitization appears to have occurred at the expense of beidellite. Veinlets of sericite in quartz cross-cut and replace beidellite veinlets. A felt-like mass of sericite and secondary quartz was noted to be replacing beidellite. Fractures through which the sericitizing-silicifying solutions have entered have in some places been preserved (pl. 2, B).

Biotite shows some alteration to epidote, carbonate, and chlorite (pl. 2 A). There is a small veinlet of epidote crossing the thin-section that was examined.

<u>3 feet from the vein</u>

The rock at this point showed about 30 percent alteration. An estimation of the alteration products gave the following percentages of these minerals in the wall rock:

Propylite	15%
Sericite	10
Beidellite	5
Limonite	
Leucoxene	
Quartz	

Sericite increases at the expense of beidellite and oligoclase. Oligoclase is completely altered; microcline is fresh (pl. 3 A).

Biotite is 50 percent propylitized to chlorite, epidote, and carbonate. A few grains of biotite in the thin-section showed leaching and some alteration to carbonate.

<u>Next to the vein</u>

Under the microscope, the rock at this point was found to be 40 percent altered. The percentages of the alteration minerals are:

Sericite	25%
Quartz	10
Propylite	
Titanite	
Magnetite	
Leucoxene	
Carbonate	

Oligoclase is completely altered to sericite and quartz; ; microcline and orthoclase remain fresh. Sericite and secondary quartz occur in a fine felt-like mass which is cut by quartz veinlets. Larger shreds of sericite replace the sericite and quartz, and quartz veinlets, suggesting early and late sericitization (pl. 3, B).

Apatite shows slight sericitization along fractures.

Biotite is 75 percent propylitized. Some secondary titanite from biotite was noted.

Introduced material composes about 20 percent of the wall rock. The majority of this introduced material is quartz veinlets. These quartz veinlets cut sericite. Small rhombs and irregular grains of carbonate are introduced. A few very small rhombs of alunite(?) are associated with the introduced quartz veinlets.

Analyses of the Alteration Series of the 5th level, Cold Spring mine [1]

[1] Analyses by Mr. J. G. Fairchild of the U. S. Geol. Survey.

	A	B	C	D
SiO_2	65.67	63.34	66.61	68.71
Al_2O_3	16.52	18.21	15.13	14.93
Fe_2O_3	1.21	0.79	1.40	1.02
FeO	2.53	2.44	2.26	2.07
MgO	1.00	1.08	1.45	1.50
CaO	0.08	0.40	1.23	2.01
Na_2O	0.81	0.41	1.20	2.85
K_2O	6.70	6.11	5.02	5.14
H_2O -	0.94	0.71	1.45	0.14
H_2O	2.34	4.07	2.08	0.56
TiO_2	0.33	0.75	0.54	0.62
CO_2	1.70	1.16	1.09	0.46
P_2O_5	0.22	0.24	0.19	0.16
S (total)	0.02	0.04	0.02	trace?
	100.07	99.75	99.67	100.17

A: next to the vein.

B: 3 feet from the vein.

C: 10 feet from the vein.

D: 35 feet from the vein.

Molecular percentages

The molecular percentages of the Cold Spring mine, 5th level, alteration series are plotted in diagrams 2 and 3. The curves illustrate the superposition of one type of alteration upon another.

If the silica and combined water curves were to be continued such that they would reach a minimum at the vein and wall rock contact, they would probably illustrate the amount of silica and combined water present in the wall rock immediately after beidellitization. The soda and lime curves, if continued in the same manner, would reach a minimum at the vein and wall rock contact. Magnesia had probably reached a minimum and alumina a maximum at the vein wall immediately following beidellitization.

The alteration of the wall rock subsequent to beidellitization was responsible for the increase in silica, potash, and slight increase in soda at the vein and wall rock contact. Combined water decreased in quantity. The pseudo-fresh appearance of the Boulder Creek granite at the vein wall may be attributed to the increase in silica and decrease in combined water.

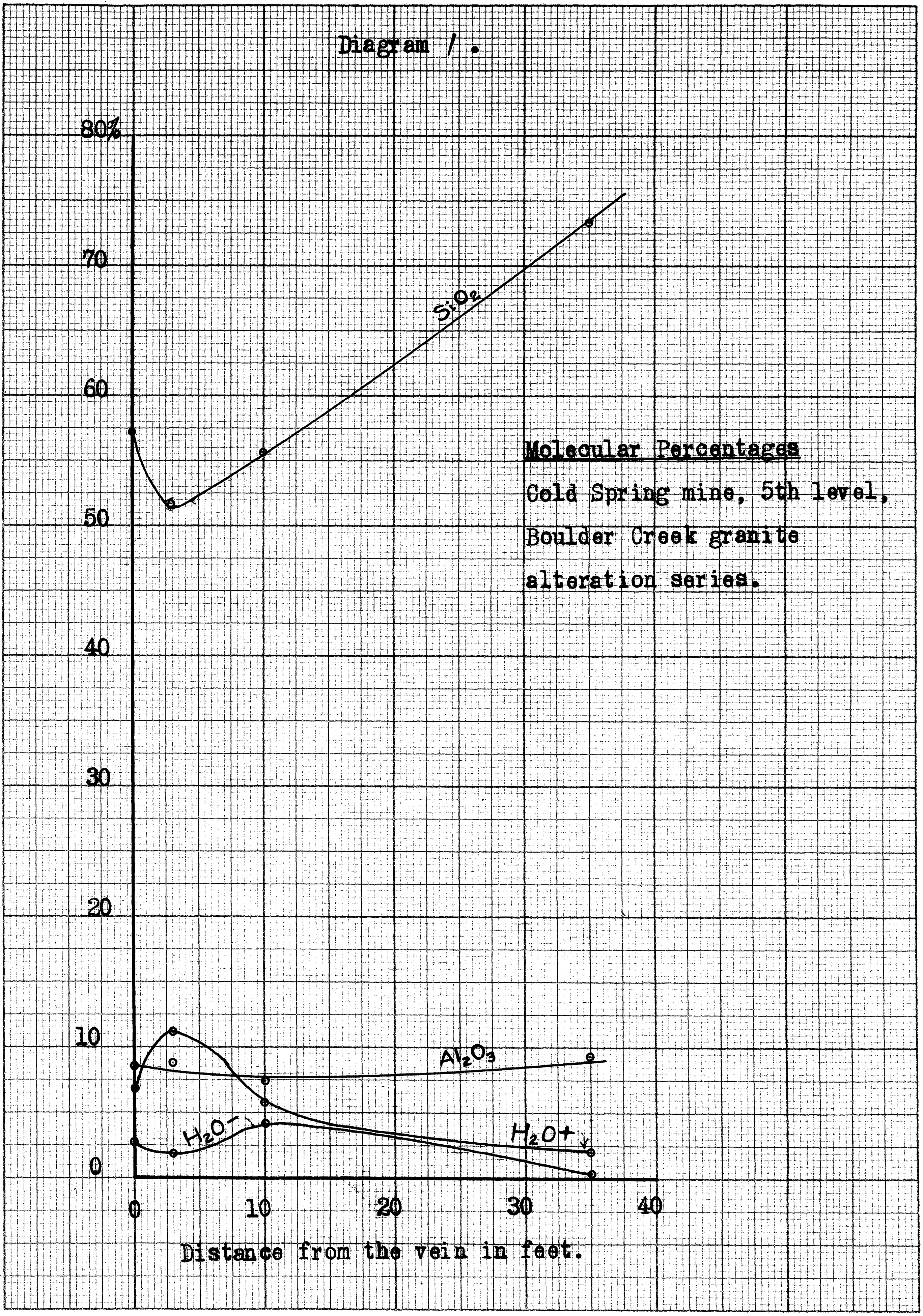


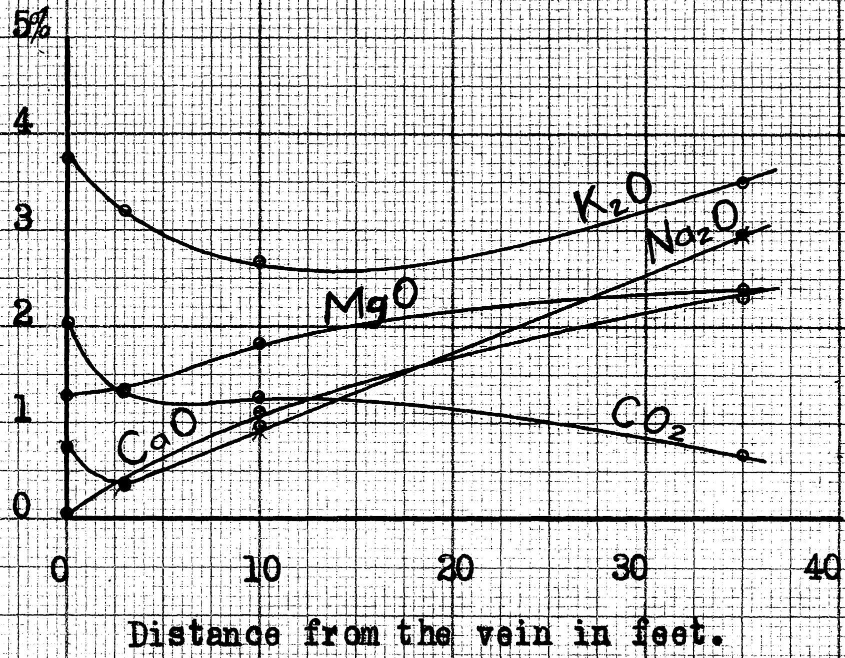
Diagram 1.
80%
70
60
50
40
30
20
10
0
SiO2
Molecular Percentages
Cold Spring mine, 5th level,
Boulder Creek granite
alteration series.
Al2O3
H2O-
H2O+
0
10
20
30
40
Distance from the vein in feet.

Diagram 2.

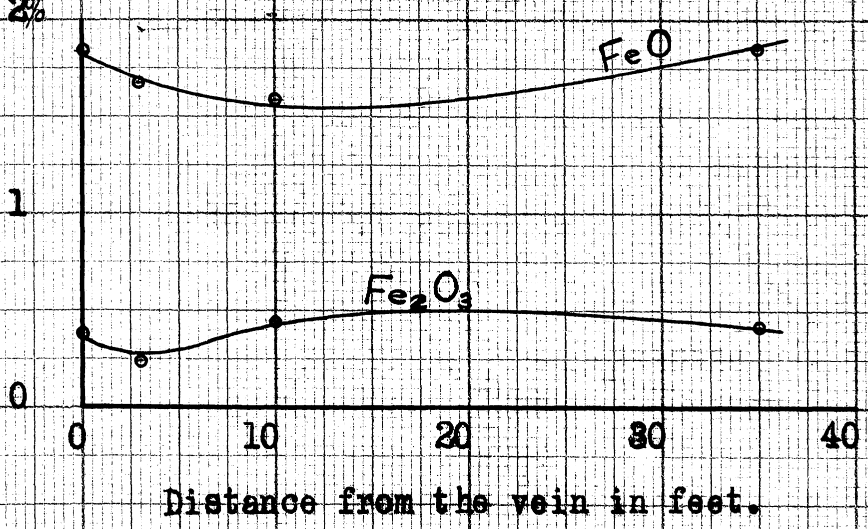
Molecular Percentages

Cold Spring mine, 5th level,

Boulder Creek granite alteration series



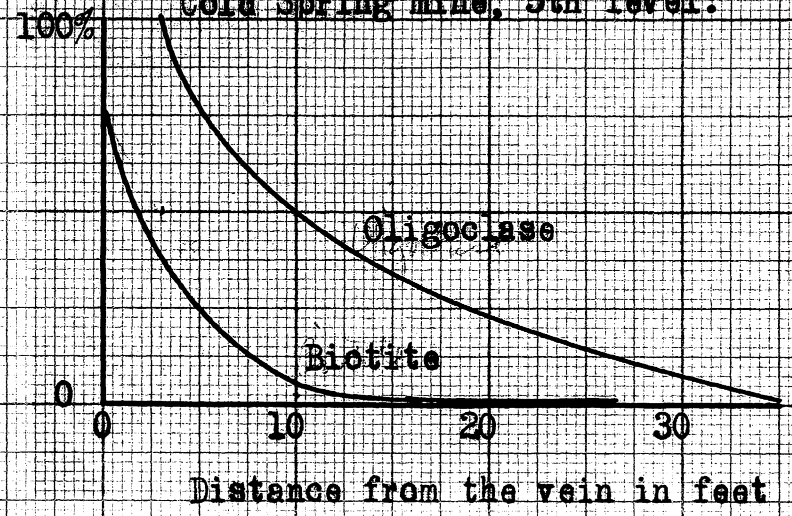
A.



B.

Diagram 3.

A. Alteration of Oligoclase and Biotite
Cold Spring mine, 5th level.



B. Percentages of the Alteration Minerals
in the Cold Spring Mine, 5th level, Alteration Series.

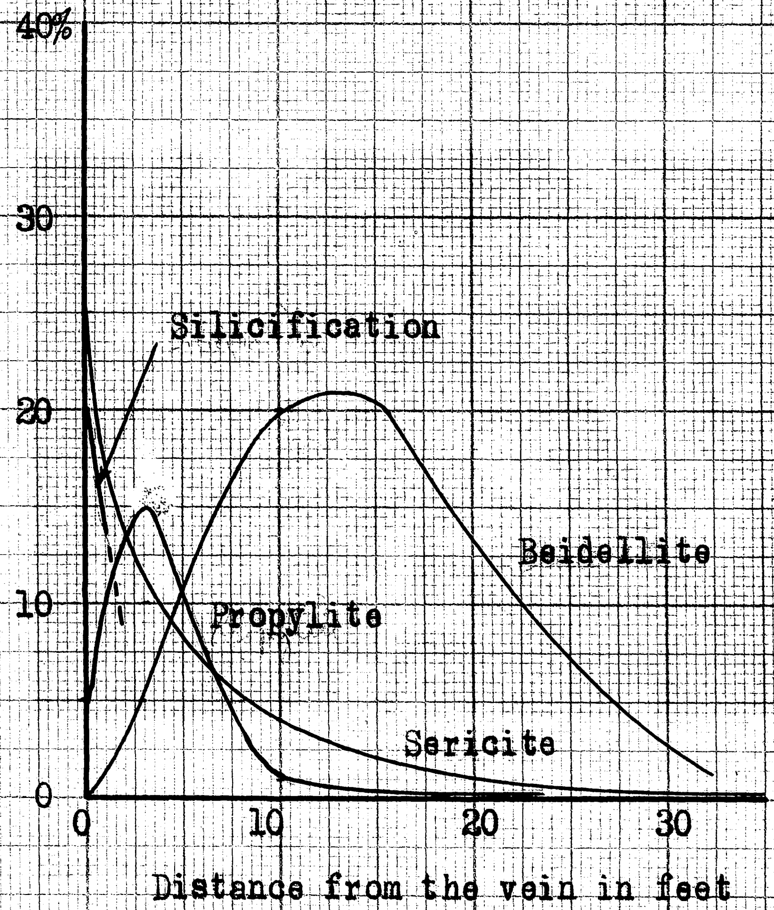
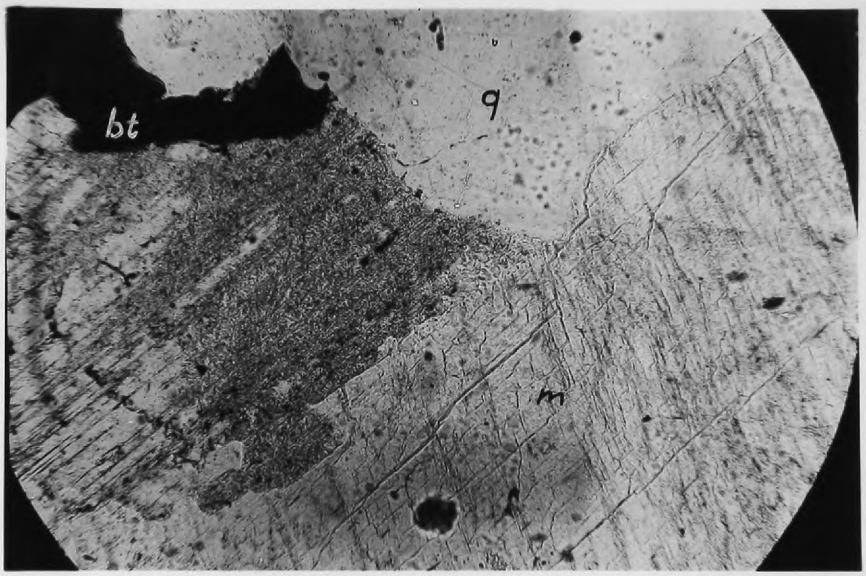
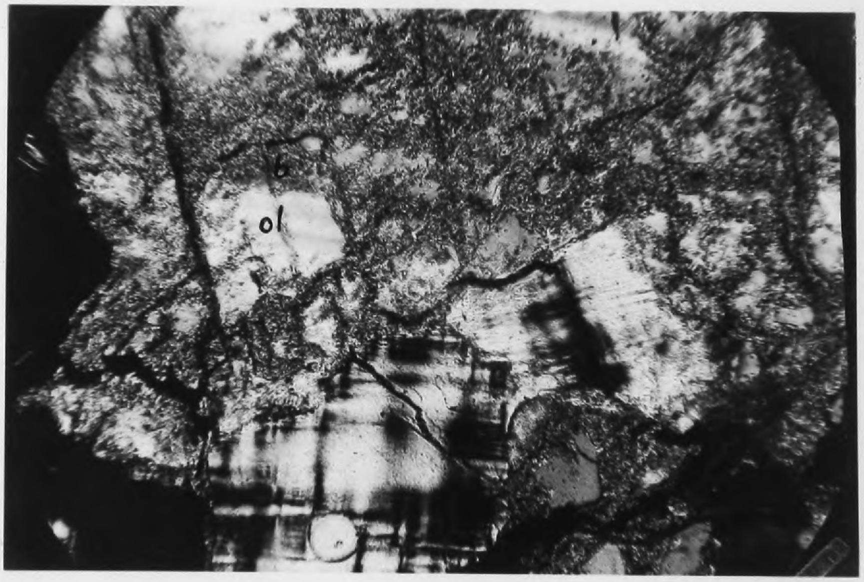


Plate / .



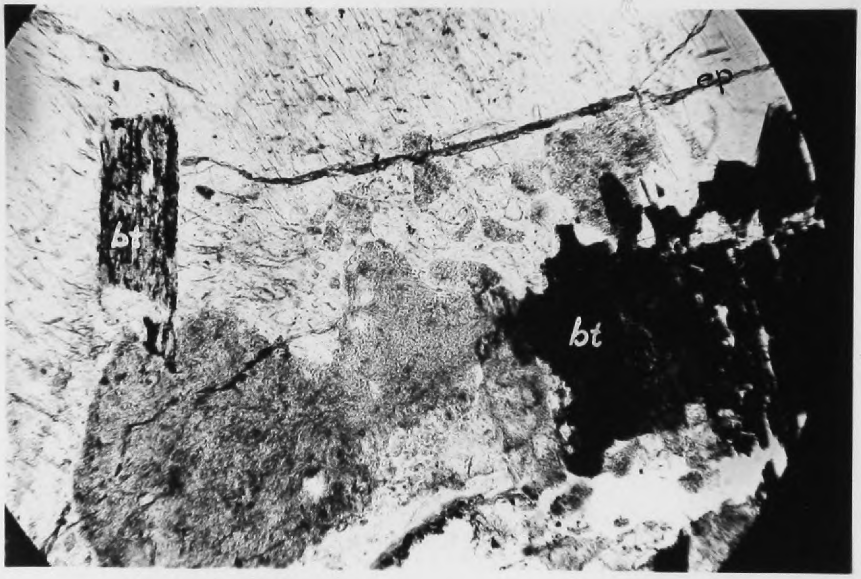
A. Boulder Creek granite 35 feet from the vein, Cold Spring mine, new shaft, 5th level. Parallel nicols. X65.

Oligoclase is being sericitized parallel to its twinning lamellae. Microcline (m), quartz (q), and biotite (bt) are fresh.



B. Boulder Creek granite 10 feet from the vein, Cold Spring mine, new shaft, 5th level. Nicols crossed. X65.

Oilgoclase is undergoing beidellitization along replacement veinlets. Microcline is unaltered.

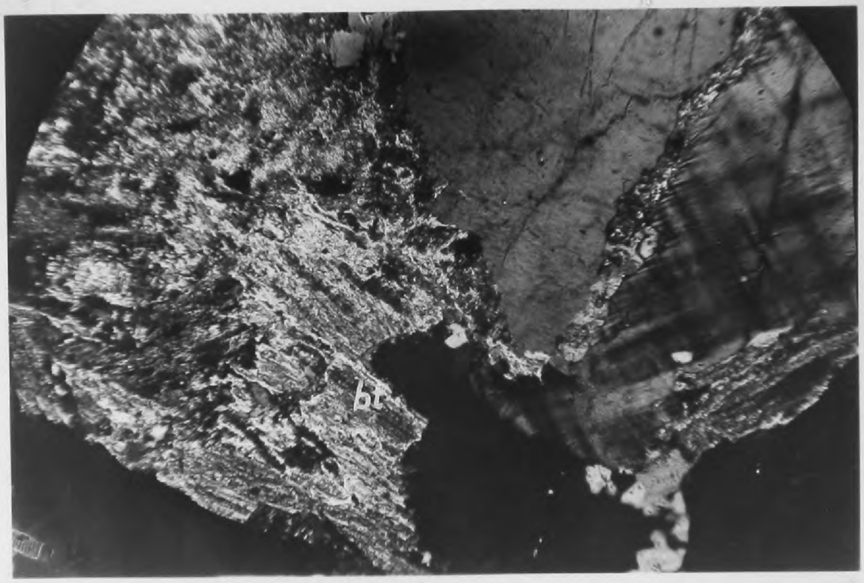


A. Boulder Creek granite 10 feet from the vein, Cold Spring mine, new shaft, 5th level. Parallel nicols. X65.

Propylitized and unaltered biotite (bt). The circular area is sericite. The epidote (ep) veinlet cuts microcline.

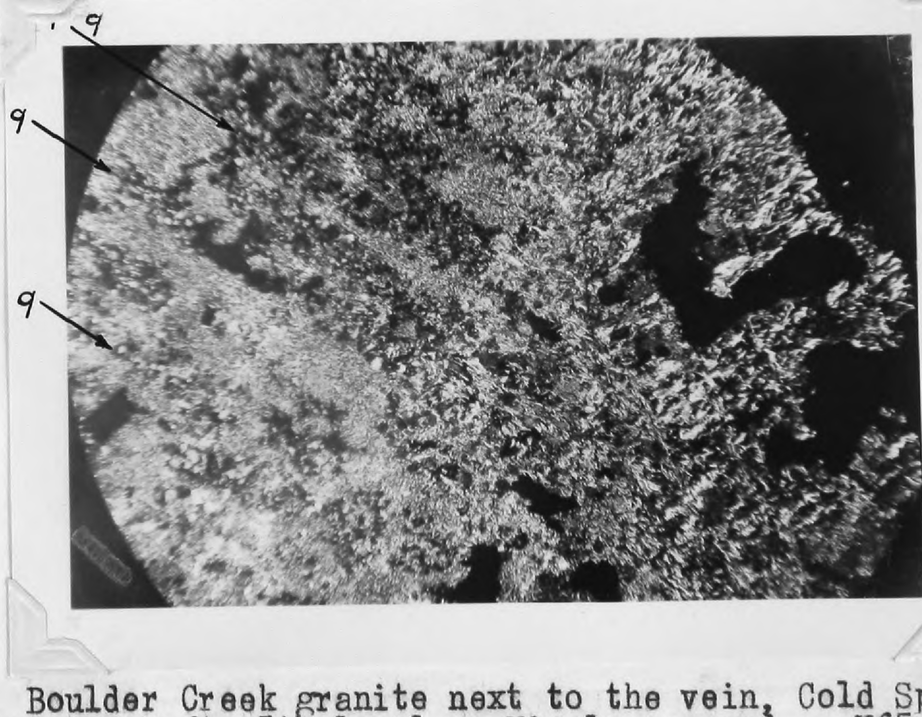
B. Boulder Creek granite 10 feet from the vein, Cold Spring mine, new shaft, 5th level. Parallel nicols. X65.

The felted mass of sericite and quartz is replacing beidellite. The fracture through which sericitizing solutions have entered has been preserved. Biotite (bt) is unaltered.



A. Boulder Creek granite 3 feet from the vein, Cold Spring mine, new shaft, 5th level. Nicols crossed. X 65.

Oligoclase is completelty altered to sericite and some quartz. Biotite (bt) is propylitized. Microcline and quartz are unaltered.



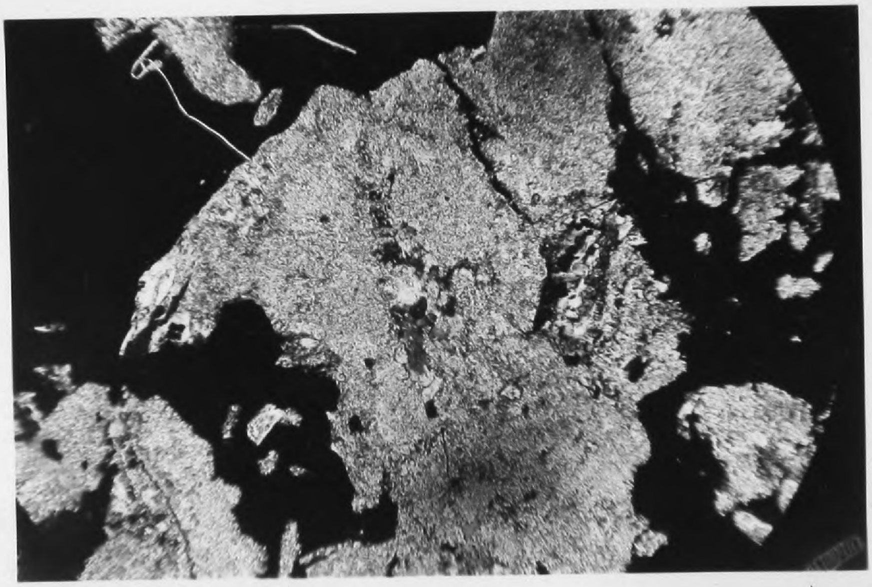
B. Boulder Creek granite next to the vein, Cold Spring mine, new shaft, 5th level. Nicols crossed. X65.

A felted mass of sericite and quartz is cut by quartz veinlets (q). The larger shreds of sericite are post-quartz veinlet.

Plate 4 .

A. Boulder Creek granite next to the vein, Cold Spring mine, new shaft, 5th level. Nicols crossed. X65.

Apatite (ap) is undergoing incipient alteration to sericite. The ground mass is a mass of sericite, quartz, and carbonate.



B. Boulder Creek granite next to the vein, Cold Spring mine, southernmost vein of the 6th level. Nicols crossed. X65.

Quartz veinlets cut felted masses of sericite and quartz.

Cold Spring mine, east breast, southernmost vein of the 6th level.

Fresh rock

Under the microscope, a fresh sample of Boulder Creek granite was less than 1 percent altered. This specimen primarily differs from that obtained from the 5th level in that it contains 5 percent green hornblende (pl. 5, A). In addition to the evidences of stress obtained from the previously described alteration series, the oligoclase, which is twinned according to the Albite and Pericline laws, shows slightly bent twinning lamellae.

It is estimated that the mineralogical composition of the essential minerals in the rock is:

Oligoclase	30%
Microcline	30
Quartz	20
Orthoclase	10
Biotite	5
Hornblende	5

Accessory minerals are rutile inclusions in quartz, magnetite, zircon, apatite, ilmenite, and considerable titanite. The zircon inclusions in quartz have pleochroic haloes. Myrmekite appears to be deuterically replacing oligoclase (pl. 5, B).

There are a few irregular fractures filled with sericite in the oligoclase. Biotite shows incipient propylitization. Hornblende is fresh.

The rock contains about 1 percent of introduced substances. A veinlet of rhombehedral grains of carbonate contains beidellite in addition. There is a small veinlet of metallic ores.

4 inchs from the vein

A sample taken 4 inchs from a vein 3 inchs thick is altered to about 45 percent. An estimation of the alteration minerals in the wall rock gave the following results:

Sericite	40%
Propylite	1
Carbonate	
Leucoxene	
Magnetite	
Limonite	
Quartz	

Oligoclase is completely sericitized, carbonatized, and perhaps somewhat silicified. The carbonate occurring as an alteration product of the oligoclase exists as small rhombs and irregular masses.

Biotite is 15 percent propylitized to chlorite, carbonate, and epidote. There is some alteration to magnetite. No hornblende was observed in the thin-section.

Introduced carbonate is aligned along cleavage planes in biotite, and also occurs as small veinlets in a few quartz grains.

The primary quartz grains in the Boulder Creek granite, contain in addition to the hair-like inclusions of rutile, numerous inclusions of microlites.

Next to the vein

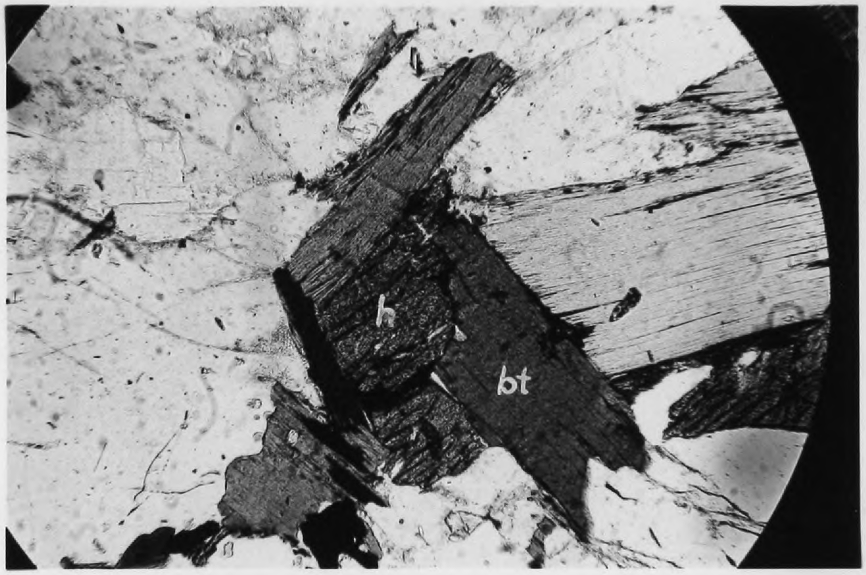
Boulder Creek granite taken next to a vein which is 3 inchs thick is 45 percent altered. An estimation of the alteration minerals in the wall rock gave these results:

Sericite	40%
Propylite	5
Magnetite	
Leucoxene	

Oligoclase has completelty altered to sericite. Veinlets of quartz cut sericite (pl. ,B). but, in addition, there a few sericite shreds covering the quartz veinlets in places.

Biotite is completely propylitized. There is no evidence of hornblende.

Plate 5 .



A. Fresh Boulder Creek granite, hornblende and biotite facies, Cold Spring mine, 6th level. Nicols crossed. X65.

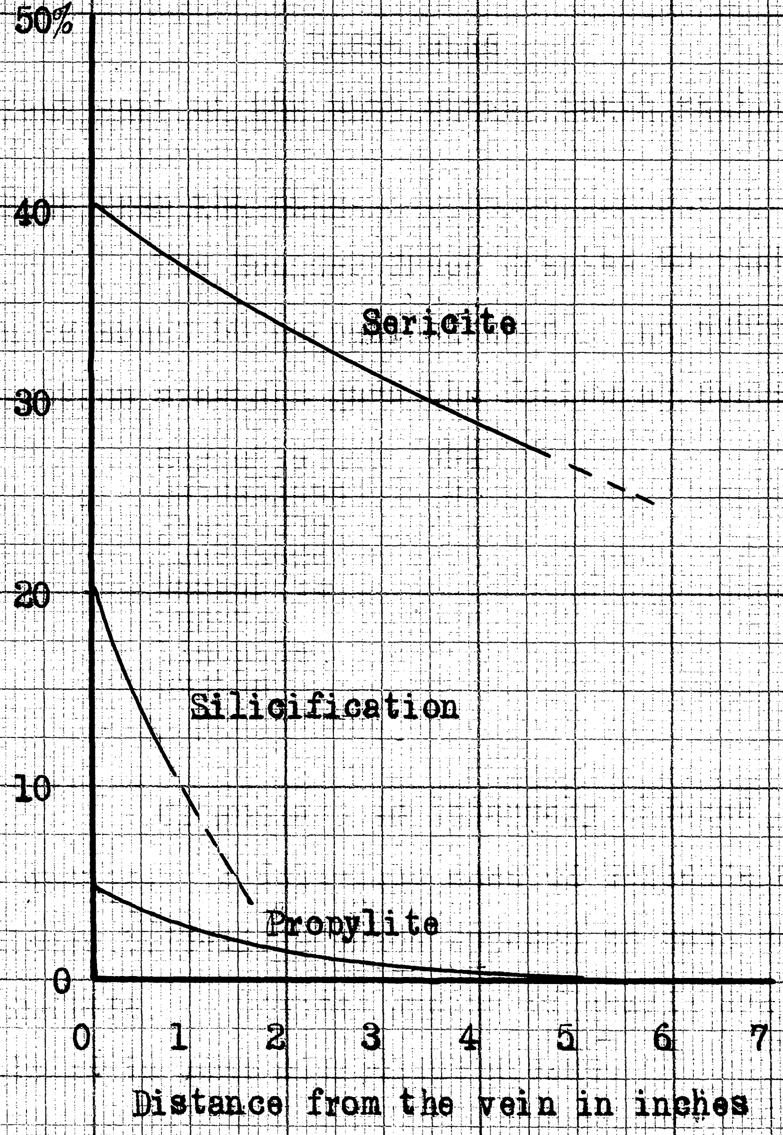
Green hornblende grains (h) are partially surrounded by brown biotite grains (bt).

B. Fresh Boulder Creek granite, hornblende and biotite facies, Cold Spring mine, 6th level. Parallel nicols. X65.

Myrmekite is deuterically replacing oligoclase. Quartz grains are poikilitically included in the oligoclase. The fracture is filled with carbonate.

Diagram 4.

Percentages of the Alteration Minerals
in the Cold Spring mine, 6th level, Alteration Series.



Quartz veinlets containing some associated carbonate compose 20 percent of the rock. Associated with the quartz veinlets are a few minute rhombs of alunite (?). There is a small veinlet of metallic ore minerals.

Clyde mine

65 feet west of the east winze, north wall, tunnel level.

50 feet from the vein.

The Boulder Creek granite 50 feet from the vein is about 60 percent altered. An estimation of the alteration minerals gave the following percentages:

Sericite	55%
Beidellite	5
Propylite	
Leucoxene	
Magnetite	
Quartz	
Limonite	
Rutile	

Oligoclase is intensely altered to sericite and quartz. A felt-like mass of sericite and quartz replaces beidellite which appears to have replaced oligoclase. Rounded grains of quartz are poikilitically included in some microcline grains.

Biotite is 95 percent propylitized. Rutile and magnetite also are alteration products of biotite.

Some of the biotite grains are leached.

Quartz veinlets cut the sericite and quartz alteration products, but are in turn covered with a few larger shreds of sericite. Carbonate veinlets and carbonate masses compose 5 percent of the rock.

40 feet from the vein

The Boulder Creek granite 40 feet from the vein is about 50 percent altered. An estimation of the percentages of the alteration minerals gave the following results:

Sericite	50%
Leucoxene	
Rutile	

Oligoclase has completely altered to sericite; microcline and orthoclase are fresh. The secondary rutile is an alteration product of what appears to have been biotite. Leached biotite composes 5 percent of the rock.

Quartz veinlets compose 5 percent of the rock; introduced carbonate is 5 percent of the rock.

30 feet from the vein

The Boulder Creek granite 30 feet from the Clyde vein is 50 percent altered, the alteration products being sericite, leucoxene, and leached biotite. There are needles of an opaque white substance in the leached biotite which resemble rutile needles that have altered to leucoxene.

Carbonate veinlets comprise 5 percent of the rock, the carbonate occurring as rhombs and as irregular masses. Quartz veinlets compose 5 percent of the wall rock. The quartz veinlets cut sericite, but are in turn altered to shreds of sericite.

16 feet from the vein

The Boulder Creek granite at this point is about 35 percent altered. The percentages of the alteration products in the rock are:

Sericite	35%
Propylite	
Limonite	
Leucoxene	
Rutile ?	

Oligoclase is completely altered to sericite; microcline and orthoclase remain fresh. Biotite is completely proplytized and leached. Secondary rutile is thought to be an alteration product of biotite. The leached biotite has an opaque needle-like white substance aligned along its cleavage planes which suggests leucoxene.

A very little of the magnetite is altered to limonite. Ilmenite is completely altered to leucoxene.

Quartz veinlets compose 25 percent of the wall rock. The veinlets cut sericitized masses and are in turn replaced in places with later sericite. Carbonate occurs as small rhombs and irregular masses, much of it occurring in the quartz veinlets.

Next to the vein

The Boulder Creek granite next to the Clyde vein is about 2 percent altered to sericite. Some leucoxene is present. No oligoclase was found in the thin-section; microcline is fresh.

The introduced substances total about 90 percent of the wall rock, having the following percentages:

Quartz vein	80%
Quartz veinlet	5
Carbonate	
Alunite (?)	

The introduced quartz shows two epochs of mineralization. The quartz vein whose grains have an average diameter of 0.2 millimeters is cut by a veinlet whose grains are microcrystalline.

Carbonate occurs as small rhombs and irregular masses. It is associated with the quartz vein, being evenly distributed throughout it. A few minute rhombs of alunite (?) are associated with the introduced quartz.

Summary of the Clyde mine alteration series

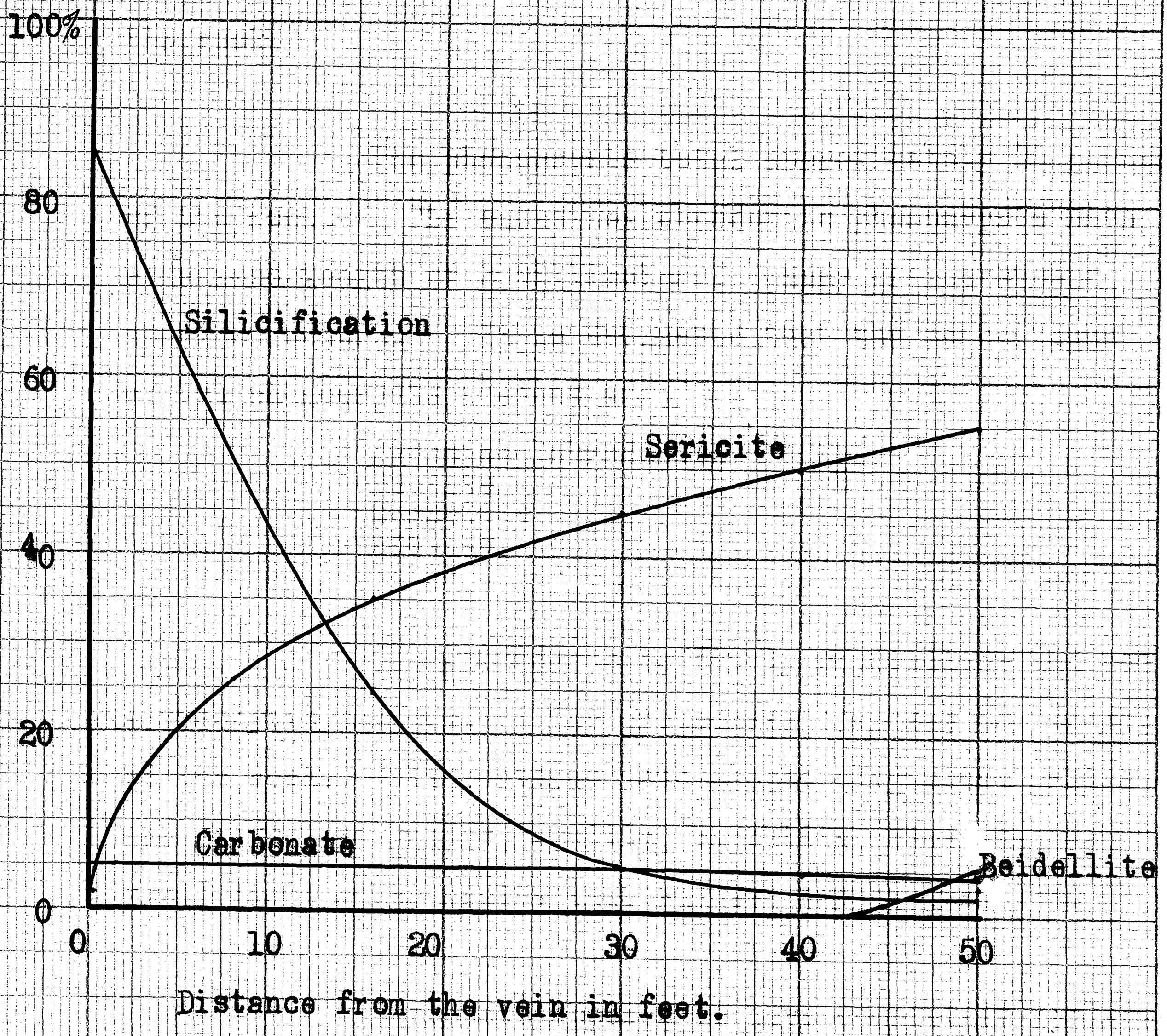
The data furnished by the Clyde mine alteration series suggests that quartz veinlet mineralization occurred at the expense of sericite. Quartz veinlets traverse sericitized masses, but are turn replaced in places by late sericite, suggesting pre- and post-quartz sericitization, the pre-quartz sericitization being the more intense, having reached a maximum at the vein and wall rock contact. Two epochs of vein quartz mineralization occur.

Beidellite is of minor importance in the alteration series, occuring only in small quantity in one section. Propylitization reached a maximum of intensity 40 to 50 feet from the vein, biotite being completely altered from this zone towards the vein.

Carbonatization was relatively uniform throughout the series. Near the main channelways of mineralization, the carbonate was closely associated with the introduced quartz.

Diagram 5.

Percentages of the Alteration Minerals in the Clyde mine.



Biotite andesite porphyry dike

A sample of a bioitite andesite porphyry dike taken from the end of the Frigid tunnel is about 3 percent altered. The rock is porphyritic with a trachytic groundmass. There are a few carbonate veinlets in the rock.

The phenocrysts total approximately 30 percent of the rock. The andesine-labradorite phenocrysts have a maximum length of 2 millimeters. Many grains show a zonal structure. It is estimated that the percentages of the phenocrysts present are:

Andesine-labradorite	25%
Biotite	5
Magnetite	
Apatite	

The groundmass is finely crystalline and has a trachytic texture. The groundmass composes 65 percent of the rock. It contains lath-shaped oligoclase grains and orthoclase grains, apatite, magnetite, ilmenite, and small light green grains that suggest augite granules.

Carbonate appears to have completely replaced the plagioclase phenocrysts in a few instances, the carbonate occurring as rhombs. Other alteration products are leucoxene, sericite, and perhaps some kaolonite.

Introduced substances total about 4 percent of the rock. Veinlets traversing the thin-section contain rhombs of carbonate and brownish irregular masses suggesting beidellite (pl. 6, A).

A. Biotite andesite porphyry dike, Frigid tunnel. Crossed nicols. X65.

The rock is cut by small veinlets containing rhombehedral grains of carbonate (c) and beidellite (bd). The fractured phenocryst is andesine-labradorite.

B. Ore from the Clyde tunnel, Clyde mine. Nicols crossed. X65.

Unaltered fragments of microcline and quartz (q) in the vein.

Ore mineralization

General features

Ferberite is associated with sphalerite, galena, pyrite, chalcopyrite, barite, fluorite, alunite (?), quartz, and carbonate. Ferberite is undoubtely primary _/. Barite

_/ Emmons, W. H., The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, p. 428, 1917.

and fluorite are quite likely of primary origin and suggest deposition in the epithermal or mesothermal zones. Emmons states that observations of the occurrences of fluorite as a secondary mineral in mines containing sulphide ores are few _/.

_/ Idem, p. 503.

Alunite (?) is associated with the early quartz gangue, and it is not known to have formed under high temperatures and great pressure _/. Alunite may be formed by hydrothermal

_/ Idem, p.478.

solutions acting on aluminous and potassic rocks at moderate temperatures _/.

_/ Lindgren, Waldemar, Mineral deposits, 4th ed., p. 398, McGraw-Hill Book Co., Inc., 1933.

The zoning of the wall rock alteration from quartzose at the vein wall to sericite and propylite suggests mesothermal deposition. Open vugs lined with crystals of ferberite and the brecciated veins suggest epithermal deposition. This evidence suggests that mineralization occurred in the upper part of the mesothermal zone or in the lower part of the epithermal zone.

Ferberite may be observed pseudomorphously altering to limonite in the zone of oxidation. Gannett has observed that sulphuric acid solutions derived from the sulphides present in the vein would remove some tungsten and decompose some to tungstite. Hydrochloric acid has the same effect. After tungsten is dissolved, however, it is easily precipitated by ferric salts, but this precipitate is colloidal and difficult to filter, and secondary enrichments may be absent. If secondary enrichment does occur, it is difficult to interpret, for the secondary minerals are the same as the primary minerals. In general, secondary tungsten ores are huebnerite or wolframite [1].

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[1] Gannett, R. W., Experiments relating to the enrichment of tungsten ores: Econ. Geol., vol. 14, pp. 68-78, 1919.

Samples taken from the tunnel dump of the Primos mill and from prospects on a vein on the north side of Hurricane hill contained barite, sphalerite, bornite, galena, chaclcopyrite, cubanite (?), pearcite, covellite, pyrite, and quartz. Chalcocite has been reported from these locations, but none coulde be observed in the polished sections. Barite, sphalerite, bornite, galena, and chalcopyrite suggest deposition in the mesothermal zone. Pearcite is of secondary origin. Covellite replaces a brown mineral resembling cubanite (?), and is secondary.

There were repeated movements along the veins throughout mineralization, and each period of vein reopening was generally followed by quartz mineralization. In diagram , which illustrates the regional paragenesis of the minerals in the district, periods when the veins were reopened are indicated by dashed lines, such as - - -. Diagram was split into two columns, for the paragenesis of the minerals of the two columns to one another is in some instances doubtful. The right hand column was compiled from data obtained from polished sections of ore from the Primos mill and from prospects in a vein striking northwest located on the north side of Hurricane hill. The left hand column was obtained from studies of the ore of the Cold Spring, Clyde, Quaker City, Cross, Frigid tunnel, Lucky no. 2, Lucky no. 3, and the Beddig mines.

Diagram 6.

Regional paragenesis of the Nederland district, Colorado.

Beidellite
Sericite and quartz
Propylite *
Quartz, carbonate, and alunite (?)
- - - - - -
Quartz
Sericite *
Pyrite

Ferberite
Sphalerite
Galena
Chalcopyrite
- - - - - -
Quartz
Pyrite
Barite
- - - - - -
Quartz
- - - - - -
Fluorite
- - - - - - - (?)
Limonite and carbonate

Barite
Sphalerite
Bornite
Galena
Chalcopyrite
Cubanite (?)
Pearcite
Covellite
Quartz

* paragenesis doubtful.

Mineralographic descriptions

Cold Spring mine

Specimens from the 70 foot level of the Cold Spring mine no. 3 show ferberite undergoing pseudomorphous replacement by limonite. The paragenesis is quartz, ferberite, and limonite.

A specimen taken from the Cold Spring ore shoot had the paragenesis : quartz, ferberite, quartz, pyrite, and quartz. Post-pyrite fracturing is healed by the last quartz to be deposited. Ferberite is characteristically bladed.

The pre-ore gangue in the Cold Spring ore was found to have the paragenesis: carbonate, carbonate, carbonate, quartz, and ferberite. Vugs in the gangue contain well-developed crystals of carbonate on their walls.

Clyde mine

Ore from the east breast, tunnel level has the paragenesis quartz, pyrite, ferberite, quartz, pyrite, and quartz. The introduction of quartz followed reopening of the veins. The lath-shaped grains of ferberite are much larger in size near the contact of the last, cross-cutting quartz vein. The quartz of the different mineralizing epochs is lithologically indistinguishable. Some slight pyritization of the wall rock is suggested by the presence of a few pyrite grains in the altered wall rock.

A specimen taken at the top of the ore shoot near an open vug, the vein being 300 feet south of the portal of the Clyde tunnel, contained medium-sized, lath-shaped grains of ferberite in a quartz vein containing brecciated fragments of altered wall rock. The paragenesis is: quartz, pyrite, ferberite, galena, chalcopyrite, quartz, and barite. A few ferberite grains partly envelop euhedral pyrite grains. A grain of galena was found to have enwrapped ferberite. Galena shows slight evidence of centripetal replacement by chalcopyrite. Spindle-shaped grains of barite are normal to the early and late quartz contact.

A thin-section of this vein shows the brecciated, altered wall rock healed by vein material. Brecciated fragments of quartz and microcline compose about 15 percent of the vein, their sizes being 0.8 millimeter in greatest diameter (pl. 6 . B) The quartz fragments show undulose extinction, however remaining uniaxial, and contain a few hair-like inclusions of rutile. Other primary accessory minerals in the vein are zircon and apatite. Vein quartz composes about 60 percent of the thin-section, ferberite 15 percent, carbonate 5 percent, and barite less than 5 percent. Less than 1 percent of sericite is present, and perhaps some chlorite. The ferberite grains average 1 millimeter in length, and the spindle-shaped barite grains average the same size. Carbonate occurs as rhombs and as small irregular masses. Minute rhombs of alunite (?) are present, associated with the vein quartz (pl. 7, B).

Quaker City dump

An ore sample from the Quaker City dump containing fluorite was examined with the reflecting and binocular microscopes. A quartz ferberite veinlet is cut by a later veinlet of quartz. Subsequent fracturing allowed fluorite to conclude the mineralization.

Cross mine

Ore taken from the Cross mine dump shows ferberite undergoing pseudomorphous alteration to limonite. The paragenesis is quartz, ferberite, and limonite.

Frigid tunnel

Ore taken from the Tungsten stope of the Frigid tunnel showed that the blades of ferberite are noticeably larger in the middle of the vein than they are along the walls of the vein. Sphalerite in a few places enwraps ferberite grains. The vein shows evidence of reopening. The paragenesis is: carbonate, quartz, pyrite, ferberite, sphalerite, quartz, and pyrite.

Lucky no. 2 mine

Ferberite and pyrite are undergoing pseudomorphous replacement by limonite. A brown horn quartz contains the ferberite. The paragenesis is quartz, pyrite, ferberite, and limonite.

Lucky no. 3 mine

Carbonate replaces quartz, the ferberite being unattacked (pl. 8). The carbonate may be of supergene origin. The paragenesis is quartz, pyrite, ferberite, and carbonate.

Beddig mine

Ore from the 5th level of the Beddig mine has late pyrite enveloping ferberite (pl. 9, B). Though marcasite has been reported from the Beddig mine, none was to be found in the polished sections which were examined.

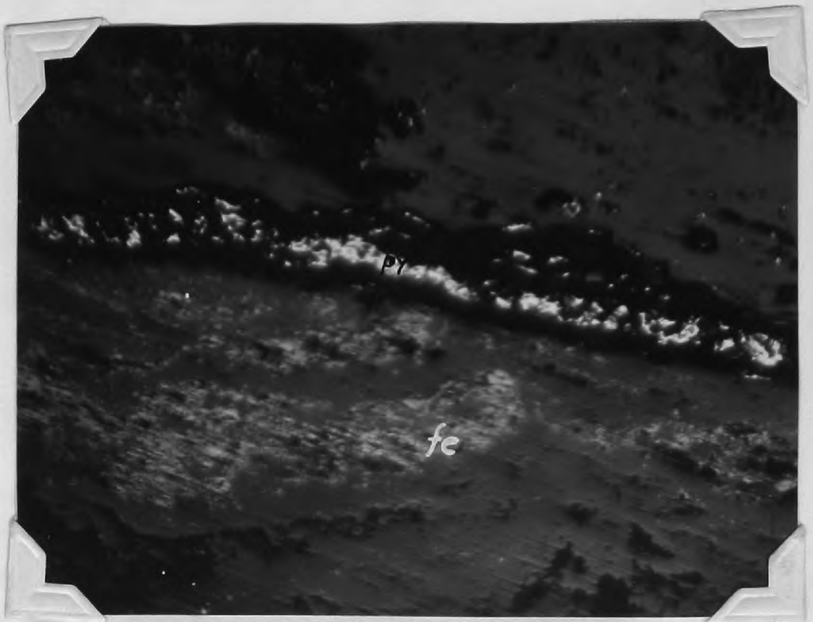
Primos mill

A peculiar brown mineral resembling cubanite in optical and microchemical tests was found as small veinlets in chalcopyrite. The mineral appeared to be replacing chalcopyrite. The paragenesis of the ore is: quartz, pyrite, barite, sphalerite, galena, chalcopyrite, cubanite (?), covellite, and quartz.

Prospects on the north side of Hurricane hill

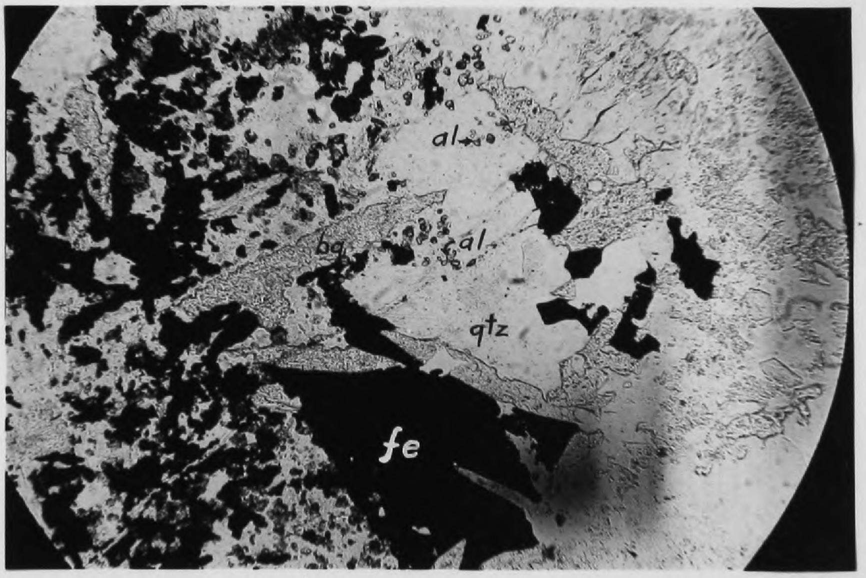
Samples were obtained from a vein striking northwest on the north side of Hurricane hill at an elevation of 8450 feet. The paragenesis is: quartz, barite, bornite, galena, chalcopyrite, pearcite, and covellite (pl. 9 , A).

Plate 7.



A. Ore from the east breast of the Clyde vein, tunnel level. X140.

Ferberite (fe) is cut by a veinlet of late pyrite (py) and quartz.



B. Ore from the Clyde tunnel, Clyde mine. Parallel nicols. X65.

Spindle-shaped grains of barite (ba) in a ground mass of vein quartz and ferberite (fe). The minute grains of moderately high relief are alunite (?).

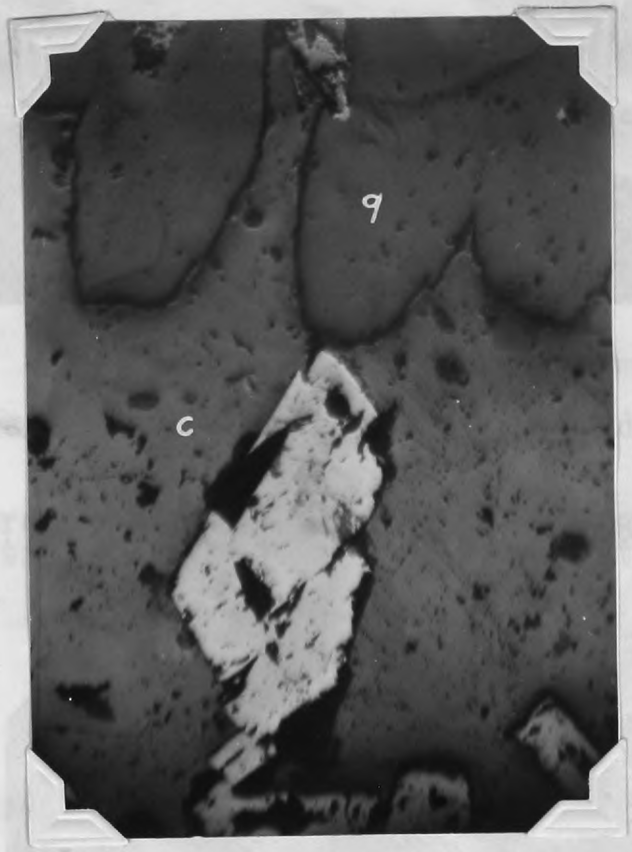
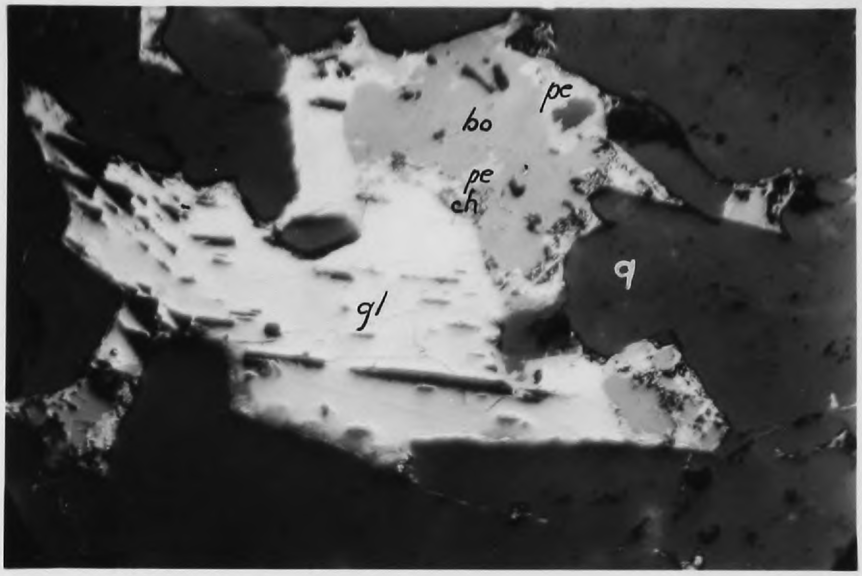


Plate 8 .

Ore from the Lucky no. 3 mine.   X140.

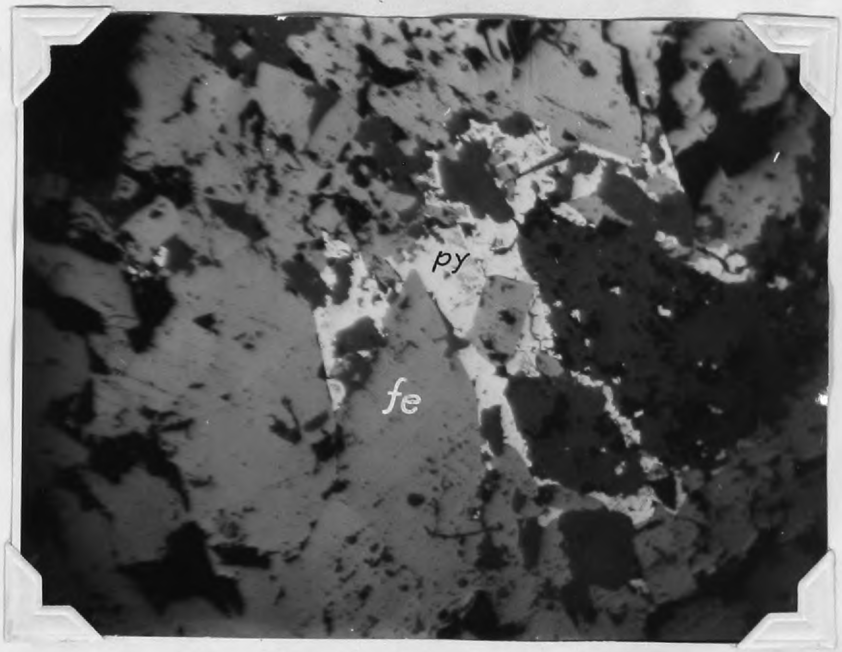
Carbonate (c) is replacing quartz (q); ferberite is unattacked.

Plate 9.



A. Ore from prospects on the north side of Hurricane hill. X140.

Bornite (bo) is being replaced by galena (gl) and pearcite (pe). Veinlets of chalcopyrite (ch) cut bornite.



B. Ore from the Beddig mine, 5th level. X140.

Late pyrite (py) envelopes ferberite (fe).

Plate 10 .

Ore from the Primos mill. X90.

Pyrite (py) is being replaced by chalcopyrite (ch). Pyrite and sphalerite (sp) envelope barite (b).