ROCK ALTERATION AND VEIN MINERALIZATION
AT THE BUFFALO MINE,
GRANT COUNTY, OREGON

by

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ROCK ALTERATION AND VEIN MINERALIZATION
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INTRODUCTION

PURPOSE OF STUDY

The veins at the Buffalo Mine and the rock alteration associated with the veins were studied to determine the processes of vein formation and to gain information concerning processes related to vein formation.

To accomplish these purposes the mineralogy and mineral relationships in the altered rock were determined and were compared with those in the altered rocks at other mining districts, the occurrence of the altered rock in relation to the mineralization in the veins was observed, and the mineralogy, structure, and methods of emplacement of the veins was studied.

FINDINGS AND CONCLUSIONS

The alteration produced in the tonalite adjacent to the veins at the Buffalo Mine is characterized by zones, each of which has different alteration minerals. These alteration minerals have a definite zonal arrangement in relation to the veins. In the most intensely altered tonalite sulphur, carbonate, and potassium have been introduced and sodium and magnesium have been leached. The zonal alteration pattern and the chemical gains and losses in the altered tonalite are similar to those described at many other mining districts.

The alteration occurs along northeast-striking faults and fissures. It is associated with barren fault zones and fissures as well as with the veins. The intensity of alteration is not related to the amount of mineralization in the veins. At least some of the alteration was produced after the deposition of the ore minerals. Some alteration may also have preceded the ore. In fact, the solutions producing the wall rock alteration were possibly unrelated to the ore-bearing solutions. For these reasons the wall rock alteration cannot be used as a definite guide to ore. The alteration does, however, indicate fissures in which mineralization may have occurred.

The veins at the Buffalo Mine have a fairly simple mineralogy. Textural relationships indicate that some of the sulphides were brecciated and then were cemented and partly replaced by later minerals. Most of the gold and all of the silver are in solid solution with sulphides of other metals.

The veins are controlled by faults and shear zones. The veins vary from simple filled fissures to complex vein zones. Brecciated fragments of wall rock are abundant in certain parts of the veins. Some of these fragments have been partly replaced by vein minerals. Banding and ribbon structures are common. Some of the veins contain comb quartz, vuggy quartz, and mineral crustifications. The author concludes that open space filling and replacement were both involved in the vein emplacement. Open space filling, however, was the dominant process. The veins are best developed where the faults form well-defined fissures.

The veins at the Buffalo Mine, like most of the gold lode deposits in northeast Oregon, occur in the vicinity of the contacts between intrusive rocks and older sedimentary rocks, and are probably genetically related to these igneous rocks.

METHODS OF WORK

During the early summer of 1957 the author, while employed by the Oregon Department of Geology and Mineral Industries, assisted Dr. Koch in mapping the geology of the Buffalo Mine. In the later part of the summer, after terminating employment with the Department of Geology, the author spent approximately five weeks at the mine collecting samples for vein and alteration study and making detailed maps of the mine. The adits which cut the veins at nearly right-angles on two levels presented a good opportunity for sampling and study of alteration zones. Continuous or close-spaced samples were collected throughout the length of both adits and some were also collected from drifts and stopes.

Laboratory work was done between November, 1957 and March, 1958. Eighty-five thin sections of the altered rock were studied. Fourteen polished sections and many samples of vein material were also examined. Seventeen samples of vein material and wall rock were collected for gold and silver assay. Differential thermal analyses were used on eight samples for determination of clay content. A spectrographic analysis was used to help identify one mineral.

Refractive index measurements were made in white light using the oil immersion method. Even-numbered, three-place index oils were

used. These were checked on a Fisher refractometer after each measurement. The probable accuracy of these measurements is ± 0.004. Optic angles were estimated visually.

BUFFALO MINE

Location

The Buffalo Mine is in northeast Oregon approximately 30 miles west of Baker (Plate 1). The mine is located within the Granite Mining District which is in the northern part of the Sumpter quadrangle. The mine is 5 miles north of Granite in Sec. 14, T. 8 S., R. 35 1/2 E., on the southwest slope of the divide between Granite Creek and Crane Creek. These are both tributaries of the North Fork of the John Day River.

The best route to the mine is through Baker, Sumpter, and Granite. Highway 220 connects Sumpter with Highway 7 from Baker at a point about 9 miles south of Baker. About 8 miles of Highway 220 are paved from this intersection. The remaining section of road to Sumpter, a distance of 11 miles, is wide and graveled. Granite is 13 miles northwest of Sumpter, and the road to it and farther north to the mine is narrow and graveled only in places. During the winter months snow on the route from Baker to the mine is plowed only as far as Sumpter.

The mine can also be reached from a point to the south on Highway 26 between Prairie City and Unity, from Dale to the west, and from La Grande to the north. These three routes are poor and are not well marked.
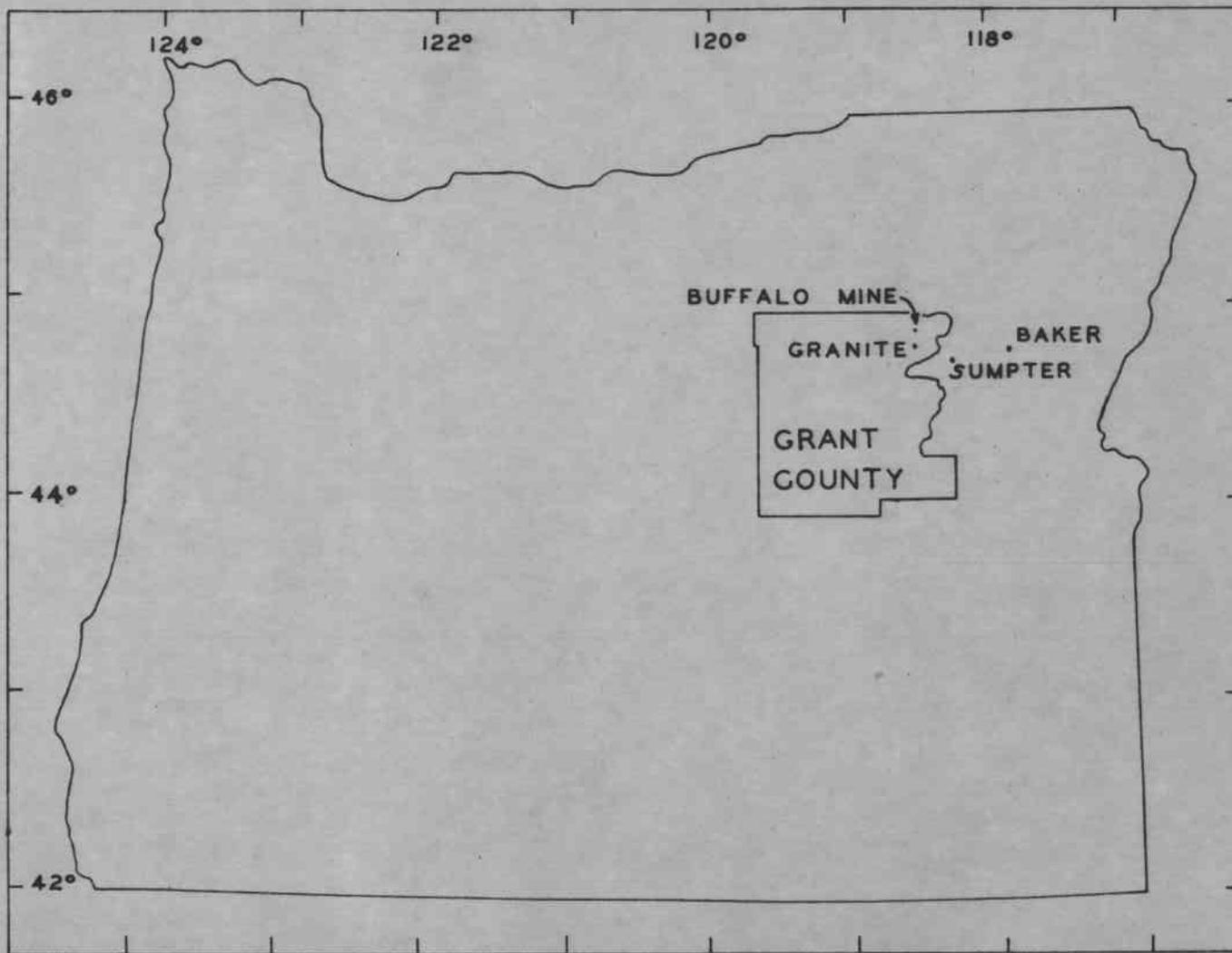
PLATE 1. Index Map of Oregon Showing Location of the Buffalo Mine.

History and Production

The Buffalo Mine has produced gold and silver since it was first located in the late 1870's. Since that time the mine has been operated sporadically by many different owners. The total recorded production, 28,994.30 ounces of gold and 212,107 ounces of silver (Table 1), has a gross value of roughly $900,000 (gold $35 an ounce). The grade of the ore since 1950 averages about 1 ounce of gold and 8 ounces of silver per ton. At present metal prices the average tonnage value of this ore as mined is about $43 per ton. This average increased to over $50 a ton in 1956 and 1957. Monthly production during 1957 was between 150 and 200 tons.

Other mines in the Granite District include the Cougar-Independence, Ajax, Magnolia, New York, Monumental, La Bellevue, and Continental. The total recorded production from these mines is about $1,290,000 (gold $35 an ounce).

Development

The Buffalo Mine is shown on two geologic maps (Plates 2 and 3), a composite level map, and a cross section (Plate 4). The geology has been plotted on a map based partly on a transit survey by Philo Anderson and partly on a compass and tape survey by Dr. Koch and the author.

The mine is developed on two levels which are about 200 feet apart. At present the 400 level is the main working level. A combined total of over 4000 feet of workings is open on both levels.

Table 1. Production from the Buffalo Mine
(As reported to the U.S. Bureau of Mines)

Year	Tons	Gold(ounces)	Silver(ounces)
1903	10	24.19	
1904	50	48.38	69
1906	134	362.81	567
1907	230	498.74	7,703
1908	400	870.75	15,094
1909	10	61.87	300
1919	325	1,378.69	6,473
1921	800	347.19	1,011
1922	50	379.09	1,293
1923	102	617.90	2,866
1924	553	701.80	3,974
1925	1,082	1,450.05	6,896
1926	2,487	2,399.56	15,392
1927	4,310	1,959.79	10,963
1928	2,233	900.54	10,159
1929	3,035	1,449.00	20,037
1930	981	602.89	4,803
1931	212	284.36	3,869
1932	104	243.14	1,385
1933	75	30.20	493
1934	242	93.94	652
1935	1,000	304.18	3,890
1936	50	9.24	104
1938	250	63.00	2,123
1939	862	1,006.00	3,798
1940	1,483	1,013.00	4,335
1941	3,072	2,261.00	11,695
1942	540	315.00	1,795
1944	23	110.00	900
1946	31	259.00	82
1947	622	332.00	1,976
1948	1,634	1,396.00	10,302
1949	749	626.00	3,703
1950	574	599.00	4,221
1951	360	270.00	2,565
1952	286	428.00	2,568
1953	1,034	1,032.00	10,242
1954	2,004	1,002.00	12,814
1955	1,824	1,117.00	8,583
1956	1,390	2,147.00	12,412
Totals	35,213	28,994.30	212,107

This is over 50 percent of the total workings. An adit on each level joins the northeast-striking veins at nearly right angles. There are drifts north and south of the adits along all the main veins on each level. Five veins have been worked on the 400 level. From west to east these are the Monitor Vein, Number One Vein, Number Two Vein, Number Three Vein, and the Constitution Vein. All the veins except the Monitor have also been worked on the 200 level. Most of the production has come from the Number Two Vein and the Constitution Vein. All recent work has been done on the Constitution Vein. In September 1957, drifts had extended approximately 585 feet north and 270 feet south of the adit on the 400 level of the Constitution Vein. Ore has been stoped up to the 200 level over much of this distance.

Mining is mostly cut and fill. The ore and waste are easily separated in the stopes.

When the veins were mined near the surface, the ore contained much free gold, and the gold was processed into bricks at the mine. Now the ore is taken from deeper levels where most of the gold is in solid solution with sulphides. This ore is run through a bulk sulphide flotation process. The concentrate is shipped to the Tacoma Smelter. Some free gold is caught in the ball mill and is recovered during cleanup.

GEOLOGIC MAP
OF THE
BUFFALO MINE

200 LEVEL

SCALE: 0   50   100 FEET

1957

EXPLANATION

ARGILLITE   TONALITE   VEINS

FAULTS   BEDDING   DIKES

TIMBER AND CHUTES

TRUE NORTH   MAGNETIC NORTH   20°

N-11,250

N-11,000

N-10,750

N-10,500

VEIN NO 1

VEIN NO. 2

VEIN NO. 3

CONSTITUTION VEIN

CAVED

CAVED

33°   45°   73°   68°   55°   90°   65°
90°   90°
63°   77°
73°   80°
90°   73°
89°   57°
75°   80°
80°   70°

E-9,750   E-10,000   E-10,250   E-10,500   E-10,750

MONITOR VEIN

VEIN NO. I

VEIN NO. 2

VEIN NO 3

CONSTITUTION VEIN

CAVED
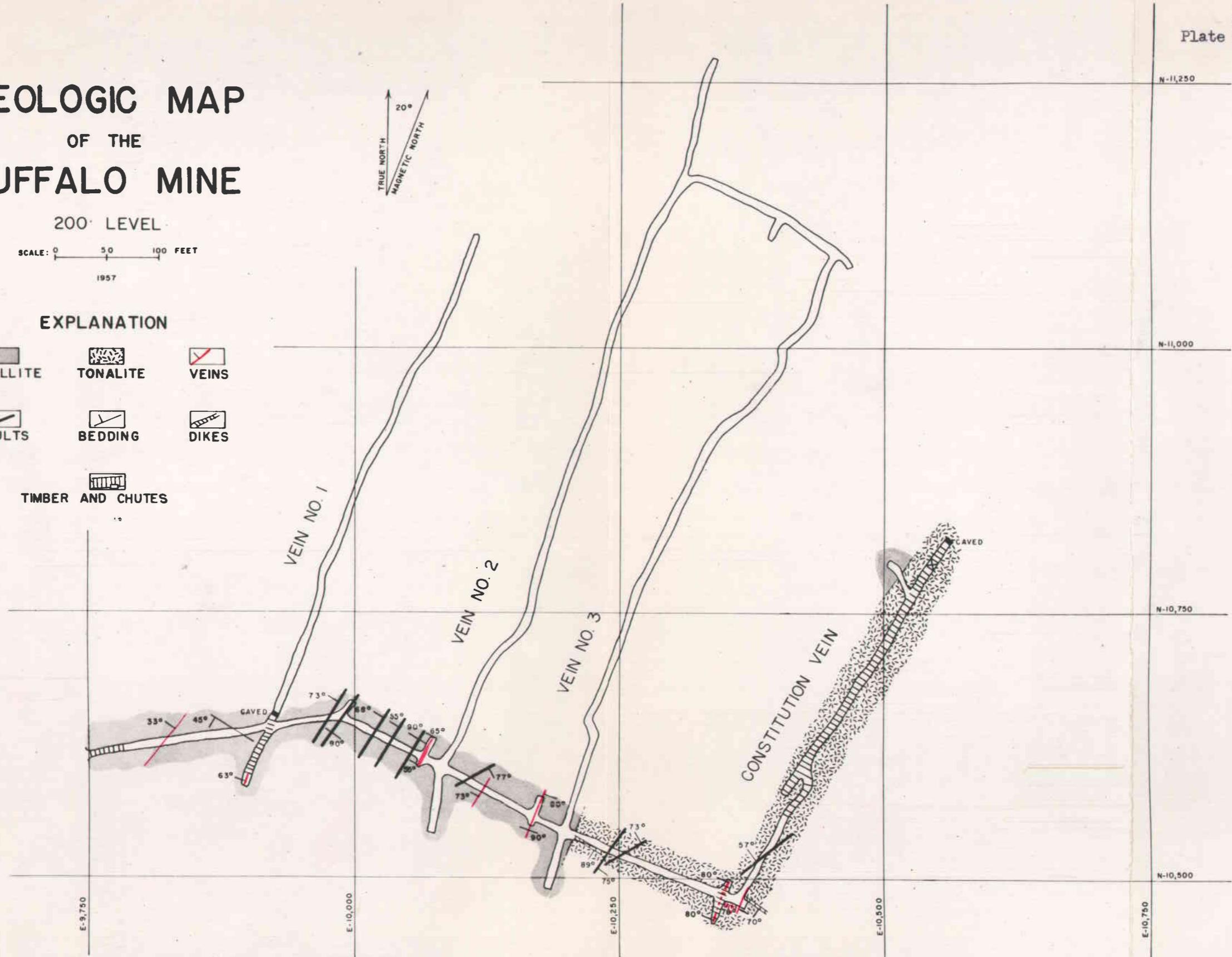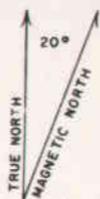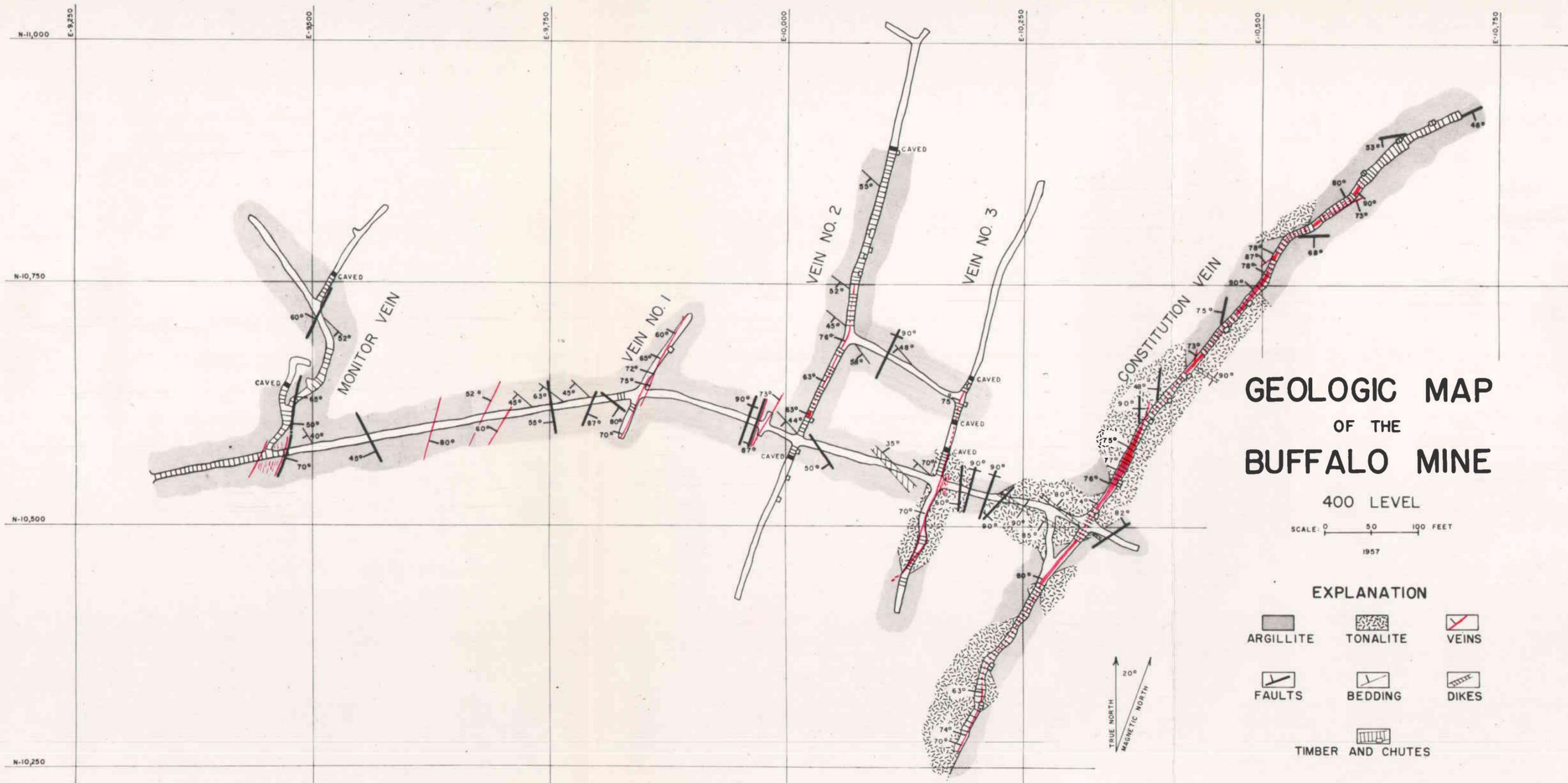
GEOLOGIC MAP
OF THE
BUFFALO MINE

400 LEVEL

SCALE: 0   50   100 FEET

1957

EXPLANATION

ARGILLITE	TONALITE	VEINS
FAULTS	BEDDING	DIKES

TIMBER AND CHUTES

TRUE NORTH
MAGNETIC NORTH
20°

N-11,000
N-10,750
N-10,500
N-10,250

E-9,250
E-9,500
E-9,750
E-10,000
E-10,250
E-10,500
E-10,750

PLATE 4.

400 LEVEL
200 LEVEL
PITS AND STOPES OPEN AT SURFACE

SCALE
0   200   400 FEET
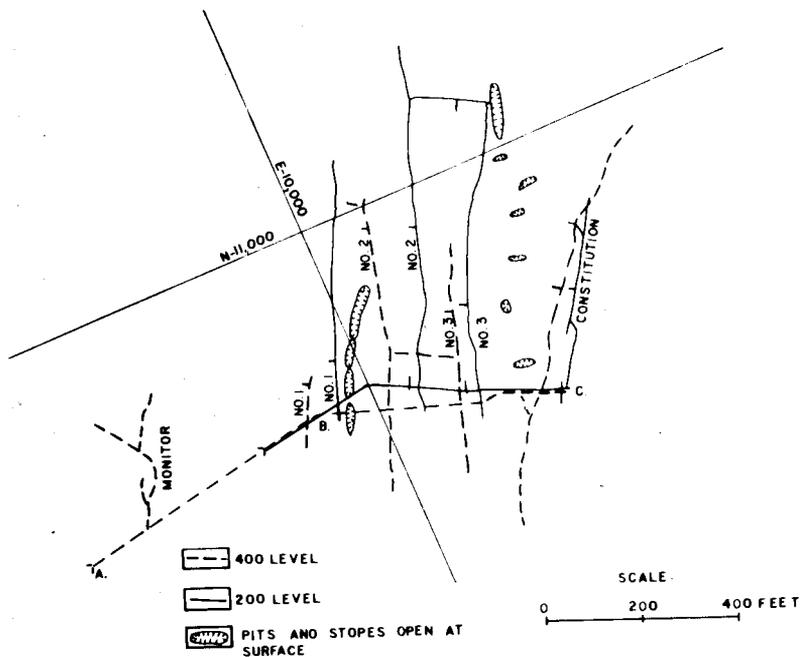
Composite level map of the Buffalo Mine.

TONALITE
ARGILLITE

SCALE: 0   200   400 FEET
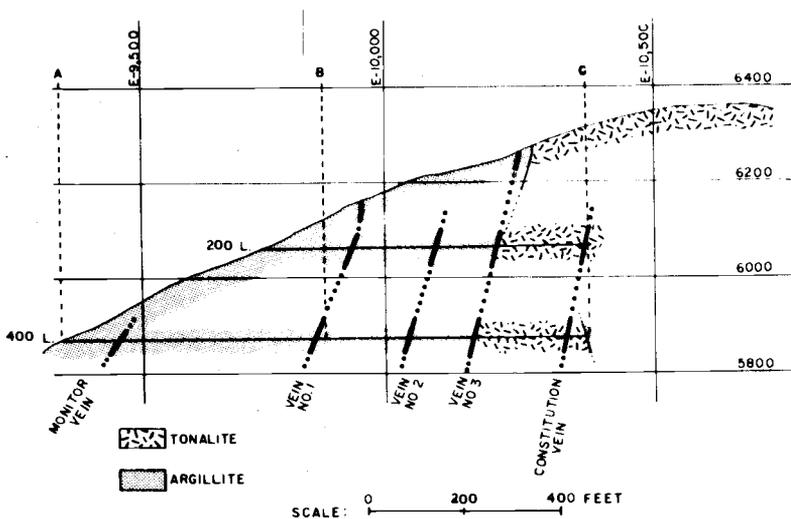
Cross section along line A-C shown on the composite level map.

PREVIOUS WORK

The geology and ore deposits in and around the Granite District have been described in several reports. The earliest report was made by Lindgren (23, p.561-776) who in 1900 made a reconnaissance of the geology and mines throughout the entire gold belt. In 1908 Pardee (28, p.85-93) published the results of a detailed study of faulting and vein structures in the Bourne District. The geology and mineral resources of the Sumpter quadrangle were reported by Hewett and Pardee (29, p.1-128) in 1914. A detailed description of all the ore deposits of northeast Oregon was published by Swartley (43, p.1-129) in the same year. In 1916 Parks and Swartley (30, p. 1-306) made a detailed report of the mines throughout the entire state. A paper concerned with the zonal relations of the lodes of the Sumpter quadrangle was published by Hewett (14, p.305-346) in 1931. Gilluly (10, p.1-119) described the geology of the adjoining Baker quadrangle in 1937. Many of the rock units which he described in detail also occur in the Sumpter quadrangle. Taubeneck (46, p.181-238) in 1957 published a detailed report on the Bald Mountain batholith, an intrusive rock with which many of the gold veins in northeast Oregon are associated.

HISTORY AND GEOLOGY OF
THE GOLD BELT OF NORTHEAST OREGON

The following discussion on the history and geology of the gold belt of northeast Oregon has been compiled from the reports of the

previous workers in the area.

Placer gold was first discovered in northeast Oregon in 1861 at Griffin Gulch which is a few miles southwest of Baker. After this first discovery placer mining grew rapidly. By 1870 the richest placer deposits were exhausted. Underground mining of the gold veins began in the late 1860's. The mining industry in this region became well established after a railroad was built into the area in 1885.

During the next 25 years many mining districts were developed throughout the gold belt. Cornucopia, near the headwaters of Pine Creek, was the main district in the Wallowa Mountains. The Virtue and Sparta Districts were farther west near Baker. The most important districts were developed around the Elkhorn Mountains west of Baker. These districts included Bourne, Cable Cove, Rock Creek, and Granite. The Alamo and Greenhorn Districts were established in the Greenhorn Mountains southwest of Granite. The western edge of the gold belt included areas around Susanville and Canyon City.

Lode mining in the gold belt has always been sporadic. Since the Second World War the Buffalo is the only mine which has operated steadily for any length of time. This mine has been operated profitably during the period of high mining and labor costs in 1957 not only because of the good grade of the ore but because of careful planning and good management.

The gold belt of northeast Oregon is about 50 miles wide and extends west from the Snake River to the center of Grant County, a distance of about 100 miles. This area includes the Wallowa

Mountains and the many small mountain groups which are known collectively as the Blue Mountains.

The rocks which characterize the gold belt are Paleozoic and Mesozoic sediments which have been intruded by Mesozoic igneous rocks, mostly granodiorite and quartz diorite. The gold-bearing veins are associated with these Mesozoic intrusives. In this respect the gold lode deposits of northeast Oregon are similar to the Mother Lode of California and to the gold deposits associated with the Idaho batholith.

Tertiary lavas have covered large areas of the older rocks and have destroyed the drainage systems produced during a pre-Tertiary period of erosion. Some of the placer gold which has been taken from the present stream beds has been reworked from older placer deposits where the present streams have cut through channels of the pre-Tertiary streams.

The veins in the Granite, Bourne, Cable Cove, and Rock Creek Districts are controlled by faults generally striking northeast. Lindgren (23, p. 601) suggests that these faults were formed under the influence of compressive stress acting north-south. The veins vary from single filled fissures to composite vein zones consisting of many close-spaced, parallel veins. Early vein minerals are commonly brecciated and are cemented or replaced by later vein minerals.

Quartz, calcite, and dolomite are the common gangue minerals. Gold and silver occur mostly in solid solution with sulphides of other metals. Some native gold occurs in varying amounts. The common

sulphides are pyrite, arsenopyrite, sphalerite, galena, and chalco-
pyrite. Tetrahedrite, stibnite, and pyrargyrite are minor constit-
uents of the veins.

The Mother Lode vein which is in the Bourne District has been
traced over a greater distance than any other vein in the gold belt.
According to Pardee (28, p. 87) it extends about 3 miles through the
North Pole, Columbia, Galconda, and the Eureka and Excelsior Mines.
Hewett (14, p. 314) states that the Mother Lode has been worked 2500
feet below its highest outcrop.

GEOLOGY AT THE BUFFALO MINE

ROCK DESCRIPTIONS

Argillite

General Statement

Most of the veins at the Buffalo Mine are in argillite. This argillite is probably part of the Elkhorn Ridge argillite which was named by Gilluly (10, p. 14) from its exposures on Elkhorn Ridge in the eastern part of the Sumpter quadrangle. Included in this formation are siliceous argillite, tuffaceous argillite, fissile shale, chert, greenstone, and limestone. These members crop out throughout the Sumpter quadrangle (Plate 5). Argillite also occurs in the Baker quadrangle to the east and in the Desolation Butte quadrangle to the west.

Lithology

The argillite at the mine is dark gray to black and is highly siliceous. Light gray chert, layers of which vary in thickness from less than an inch to over a foot, is interbedded with the argillite (Figure 3). In the mine chert is commonly a minor part of the wall rock. In a few places, however, the wall rock consists mostly of chert beds separated by thin partings of argillite. A few thin beds of fissile shale are interbedded with the argillite and chert.

The argillite at the mine has been regionally metamorphosed and consists of the minerals quartz, biotite, muscovite, and plagioclase.
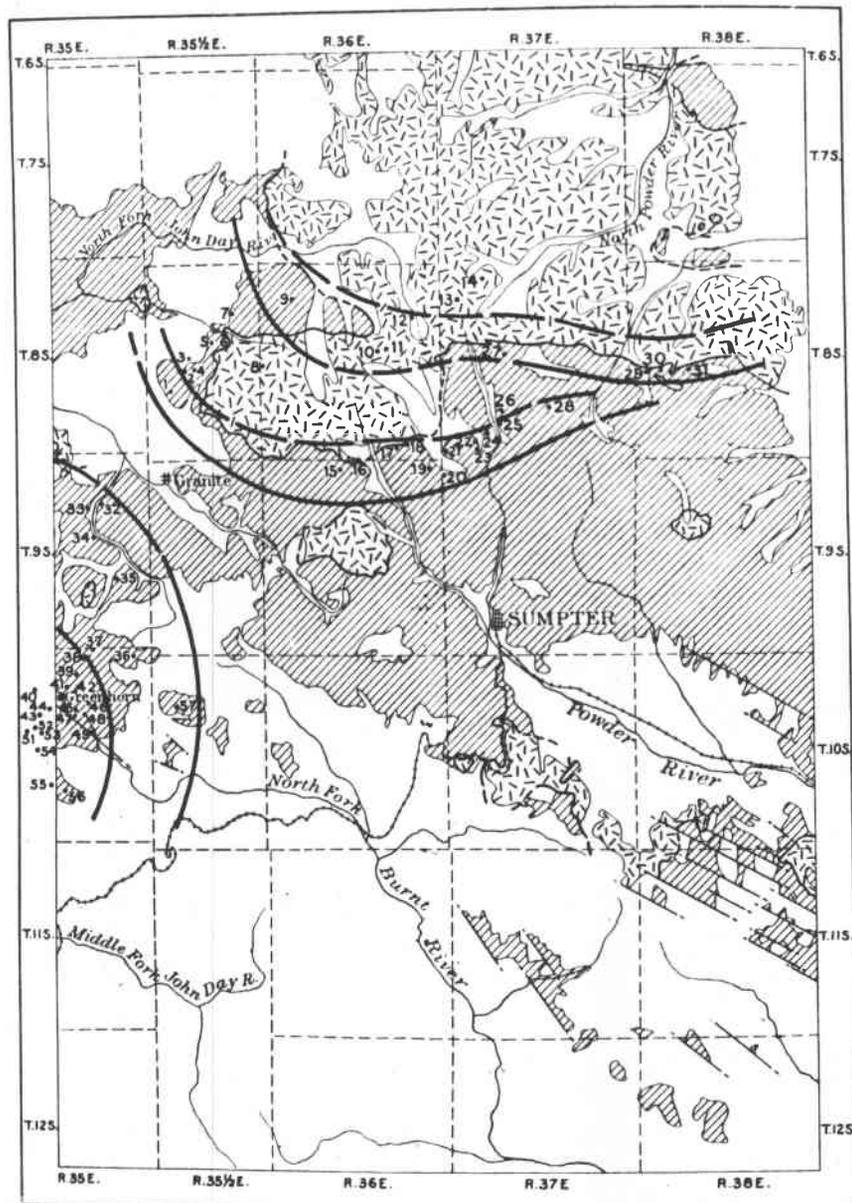
PLATE 5. Generalized geologic map of the Sumpter
Quadrangle, Oregon. (from Hewett)
        Broken lines indicate Mesozoic quartz diorite
intrusives.
        Diagonal lines indicate the argillite series
and igneous rocks older than the quartz diorite.
        Clear areas include Tertiary and Quaternary
lava flows and sediments.
        Heavy lines indicate approximate limits of
vein zones described by Hewett.
        Numbered dots indicate positions of mines.
The Buffalo Mine is number 5.

Figure 1. Outcrop of tightly folded argillite.
Flat surface is well-developed joint
system at right angles to the fold
axes.

Figure 2. Outcrop of nearly vertically
dipping argillite.

These minerals are characteristic of the biotite-chlorite subfacies of the greenschist facies.

The biotite varies from small crystals measuring less than 0.1 mm in length to large poikiloblastic crystals measuring over 1 mm in length. Muscovite is similar in form to the biotite but it is not as abundant. The micas exhibit a schistosity parallel to the bedding. They also commonly display a lineation within the schistosity produced by a parallel alignment of the crystallographic axes.

Quartz is the most abundant mineral in the argillite. It forms a mosaic of interlocking grains (Figure 4). The original grains have grown, filling all the intergranular spaces with quartz. The quartz crystals are of silt size, measuring less than 0.1 mm in diameter.

The plagioclase is a minor constituent of the argillite. It consists mostly of xenoblastic crystals which are slightly larger than the quartz crystals. A few very large porphyroblasts of the plagioclase were seen.

Fine-grained carbonaceous material is abundant throughout the argillite.

The chert has been recrystallized into mosaics of irregularly shaped quartz crystals which measure up to 0.5 mm in the longest dimension (Figure 5).

The argillite has been intruded by the Bald Mountain batholith. The contacts between the argillite and the igneous rock dip steeply in the mine, and the argillite near these contacts has been only slightly affected by the intrusive rock. Near some contacts no

Figure 3. Underground photo of a 3-inch bed of fissile shale separating thick beds of metamorphosed chert.
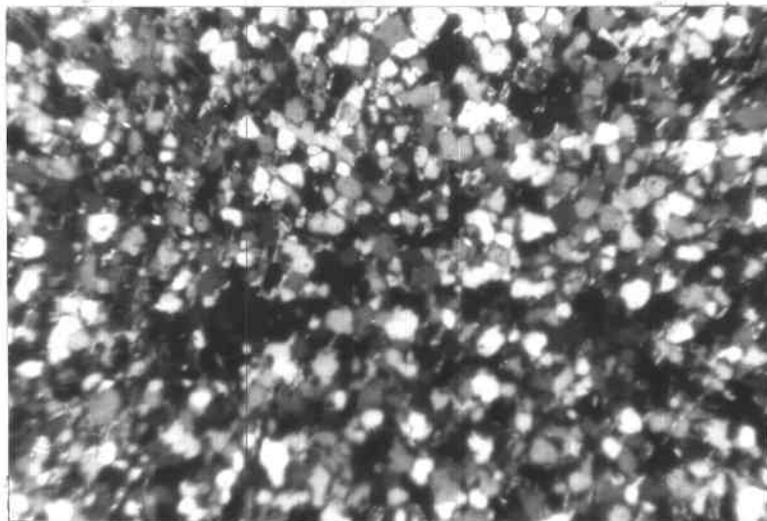
Figure 4. Fine-grained argillite consisting of angular, intergrown quartz crystals and small flakes of biotite. Width of field is 2 mm. Crossed nicols.
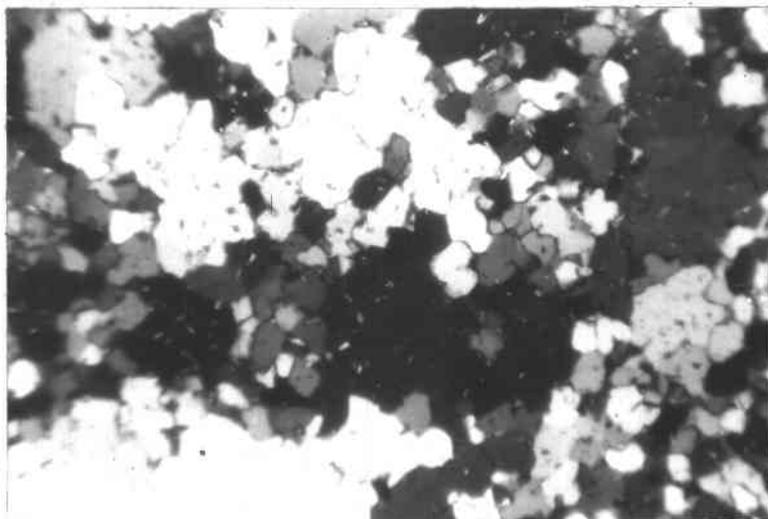
Figure 5. Metamorphosed chert consisting of ir-
regular shaped quartz crystals. Width
of field is 2 mm. Crossed nicols.
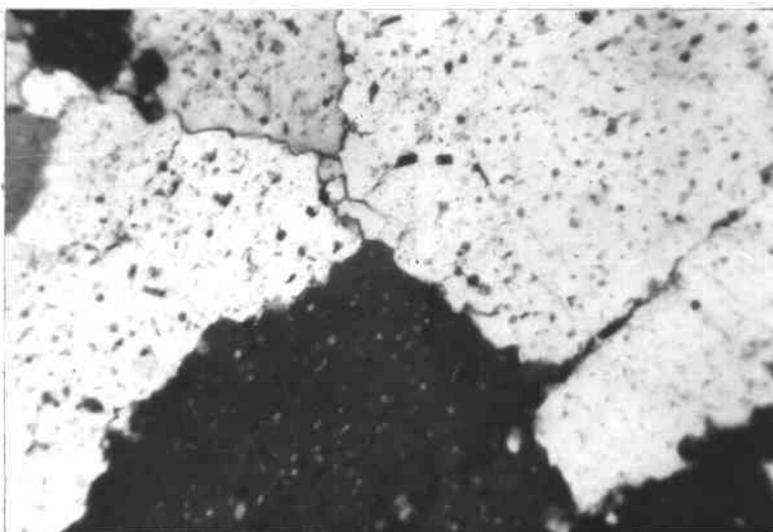
Figure 6. Altered argillite taken near a contact with
the batholith. The silt-sized quartz grains
have grown into irregular crystals measuring
over 1 mm. The rock consists entirely of these
large quartz crystals and very small, scattered
flakes of biotite. Width of field is 2 mm.
Crossed nicols.

visible changes occur, whereas near others the argillite becomes
lightered colored. In this altered argillite the former silt-sized
quartz grains have grown into irregularly shaped crystals measuring
over 1 mm in diameter (Figure 6). No carbonaceous material is pres-
ent and biotite is present in only minor amounts. The zones of this
light-colored, altered argillite vary in width from a few inches to
over 3 feet. The argillite is more intensely contact-metamorphosed
where it crops out vertically above the igneous rock. In one such
locality on the surface near the mine the altered argillite has a
well-developed schistosity and so can be classified as a schist.
In this rock the biotite forms very large crystals which display
a lineation as well as schistosity. Quartz and cordierite are the
other main constituents. The cordierite forms large poikiloblastic
crystals which enclose small quartz and biotite crystals. These min-
erals are characteristic of the cordierite-anthophyllite subfacies of
the amphibolite facies.

Structure

The argillite is tightly folded. Near the mine the bedding
strikes approximately N. 50° W. and dips steeply to the southwest.
During the folding some of the chert beds were broken and sheared,
and they now occur as detached, elongate lenses parallel to the bed-
ding.

Faults and shear zones are common in the argillite at the mine.
Most of them strike northeast and dip steeply to the northwest.

Figure 7. Jointing in the argillite.
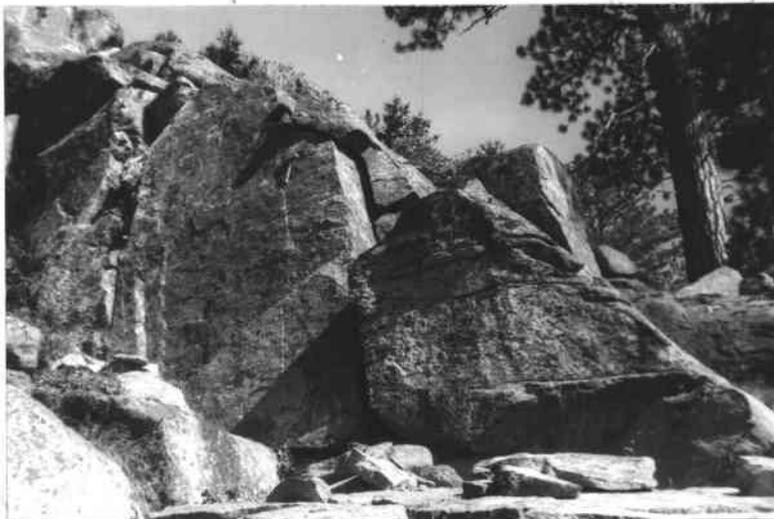
Figure 8. Outcrop of jointed tonalite.

Many of the faults are mineralized. Slickensides and dikes cut off by the faults give evidence for movement, but the amount of movement is not known. The faults are not conspicuous on the surface.

Several intersecting joint patterns are present in the argillite in the vicinity of the mine (Figure 7).

Age

Taubeneck (45, p. 98) presents evidence for a Permian age for the Elkhorn Ridge argillite. Fusulinids collected by him from a limestone lense were identified as Permian by M.L. Thompson. There is no evidence that the other rock units included in the Elkhorn Ridge argillite do not belong to the same geologic period.

Thickness

Gilluly (10, p.14) estimates the thickness of the formation to be at least 5000 feet. Exact measurements have not been made because of the complex structure and the lack of easily distinguishable key beds. A contact of the Elkhorn Ridge argillite with older rocks has not been found. The eroded upper surface of the formation is in contact with Tertiary volcanic rocks, the oldest of which is an andesite tuff-breccia which is similar to part of the Clarno formation of central Oregon (29, p. 47 and 44, p. 95).

Bald Mountain Batholith

General Statement

The Buffalo Mine is near the western edge of the southwest part of the Bald Mountain batholith (Plate 5). Hewett (14, p. 309) named this portion of the batholith the Monumental Salient. Part of the Constitution Vein and Vein Number 3 are in this igneous rock.

Lindgren (23, p. 586) first described the Bald Mountain batholith as a granodiorite intrusive. The batholith occupies over 160 square miles in the northern part of the Elkhorn Range. It was named for its outcrops around Bald Mountain, now called Mount Ireland.

Taubeneck (46, p. 191-212) has found in a recent study that the batholith is a composite intrusive composed of at least eight distinct rock types.

Lithology

The rock of the Monumental Salient is a tonalite (46, p. 197). The tonalite grades into a granodiorite in the central part of the batholith. At the Buffalo Mine the tonalite consists mostly of quartz, plagioclase, biotite, and hornblende. The plagioclase is andesine which in some specimens has narrow rims or mantles of oligoclase.

Minor accessories are potash feldspar, sphene, apatite, magnetite, ilmenite, allanite, zircon, and rutile.

Structure

The tonalite in the vicinity of the mine contains a number of northeast-striking faults which are parallel to those in the argillite. Some faults are continuous through both the tonalite and argillite. The attitudes of these faults do not change where they pass through the boundary between the two rock types. The tonalite also has several well-developed joint systems (Figure 8).

The batholith cuts across the structure of the argillite. The contact between these two rock types is well-defined but highly irregular.

Age

Taubeneck (44, p. 93-96) presents evidence for a late Jurassic or an early Cretaceous age for the main intrusive unit of the batholith. It cuts the Permian argillite and also serpentine and metagabbro which also intrude the argillite. These ultramafics are probably equivalent in age to those occurring in the Strawberry and Aldrich Mountains to the west which are thought by T.P. Thayer (45, p. 98) to be post-Permian and pre-Upper Triassic. Tertiary volcanic rocks rest unconformably on part of the batholith. The oldest of the volcanic rocks is an andesite tuff-breccia believed to be Eocene in age. The presence of thick, rotten placer gravels beneath the volcanic rocks indicates a long period of erosion after the intrusion of the batholith and before the deposition of the volcanic rocks.

Dikes

Dikes are quite common in the Buffalo Mine in both the tonalite and the argillite. Most of them follow joints which strike northwest. Some dip steeply and others are nearly horizontal. They vary from a few inches to over 3 feet in thickness.

Aplite, pegmatite, and quartz are the common types. Most of the quartz dikes are only a few inches thick. Many contain traces of pyrite and molybdenite. The aplite dikes are fine-grained and consist of quartz, potash feldspar, and plagioclase. They also contain minor muscovite and biotite. The pegmatite dikes contain the same minerals as the aplite dikes but these minerals in the pegmatites are much coarser. In the pegmatites potash feldspar and the plagioclase commonly form perthitic intergrowths. The feldspars are also intergrown with the quartz.

In one locality this same pegmatite material has penetrated along the contact between the tonalite and the argillite (Figure 9).

VEINS

General Statement

Five veins have been worked on the 400 level and four veins have been worked on the 200 level of the Buffalo Mine. Mining has been done to a maximum depth of 400 feet below the highest surface outcrops of the veins. All the veins have similar mineralogy and structure. There is no evidence of supergene sulphide enrichment in any

Figure 9.   Pegmatite filling the contact between
              the tonalite and the argillite.
              The argillite is black, the tonalite is
              medium gray, and the pegmatite is white.

of the veins. Near the surface, however, sulphides were leached so
as to leave large quantities of free gold.

Mineralogy

The following minerals are present in the Constitution Vein:

Metallic Minerals	Gangue Minerals
Arsenopyrite	Quartz
Chalcopyrite	Calcite
Galena	
Native Gold	
Pyrite	
Sphalerite	
Tetrahedrite	

Hewett (14, p. 326) mentions dolomite as the carbonate present
in the veins. Pardee and Hewett (29, p. 108) state that stibnite is
also present in the ore. These two minerals were not seen in any of
the samples studied.

The pyrite and arsenopyrite are intergrown and they have appar-
ently crystallized contemporaneously. The galena and sphalerite are
also intergrown. The grain size of these minerals varies from coarse
to fine. The largest crystals measure over 1 cm in the longest di-
mension. The pyrite and arsenopyrite crystals vary from euhedral to
anhedral. Most of the galena and sphalerite crystals are subhedral
to anhedral.

A mineral believed to be tetrahedrite occurs as small anhedral
crystals within the galena. These crystals are too small for a pos-
itive identification, but they have a color and hardness which are
typical of tetrahedrite.

Some of the chalcopyrite occurs as small rounded grains within the sphalerite crystals (Figure 11) or as rims around them and presumably is a product of unmixing from the sphalerite. In some places the rounded chalcopyrite grains are parallel to cleavage traces in the sphalerite.

The native gold is associated with the galena and sphalerite and in most places is intergrown with them. The pale yellow color of the gold is apparently the result of a large quantity of silver contained in it. The gold has an anhedral form and is in crystals measuring up to 0.5 mm in the longest dimension. Most of the gold and silver are in solid solution with the sulphides as is indicated by the fact that there are no silver minerals present in the veins except possibly a small amount of silver-bearing tetrahedrite and there is not enough native gold to account for the total amount of gold extracted from the ore.

Mineral Relationships

Most of the pyrite and arsenopyrite are fractured and brecciated. Galena with small crystals of tetrahedrite (?), sphalerite, chalcopyrite, and quartz fill these fractures and cement fragments of the earlier sulphides (Figure 10, 12, and 13). Some of the earlier sulphide fragments have rounded, embayed, outlines which indicate a partial replacement of the earlier sulphides by the later minerals.

The native gold appears to have crystallized with the later sulphides and is commonly intergrown with them and in places fills
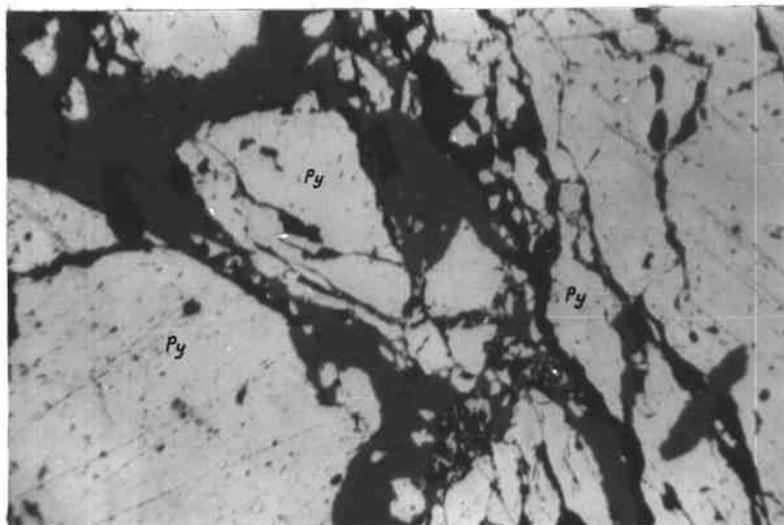
Figure 10.   Brecciated pyrite cemented by quartz.
Pyrite is white, and the quartz is
dark gray. Width of field is 1 mm.
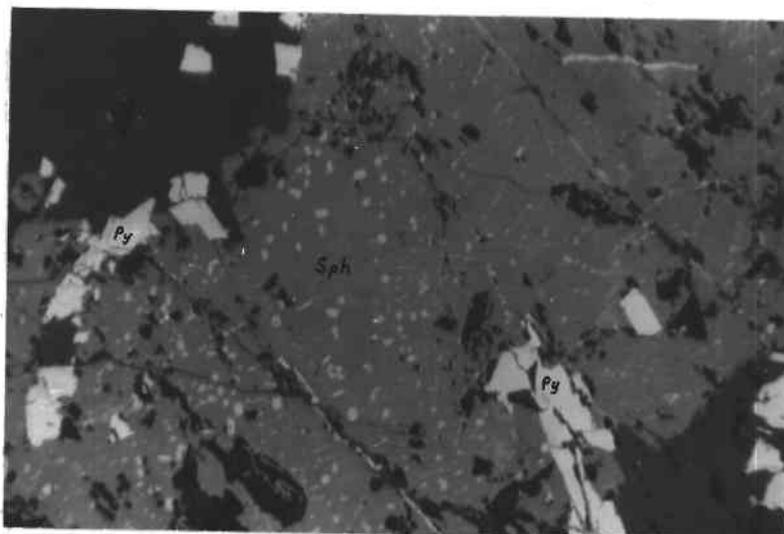
Figure 11.   Large sphalerite crystal with small
rounded crystals of unmixed chalcopyrite.
Sphalerite is medium gray, and the
chalcopyrite is light gray. The dark
gray mineral is quartz, and the white
mineral having angular outlines is
pyrite. Width of field is 1 mm.

Figure 12. Galena surrounding and replacing pyrite.
Width of field is 1 mm.
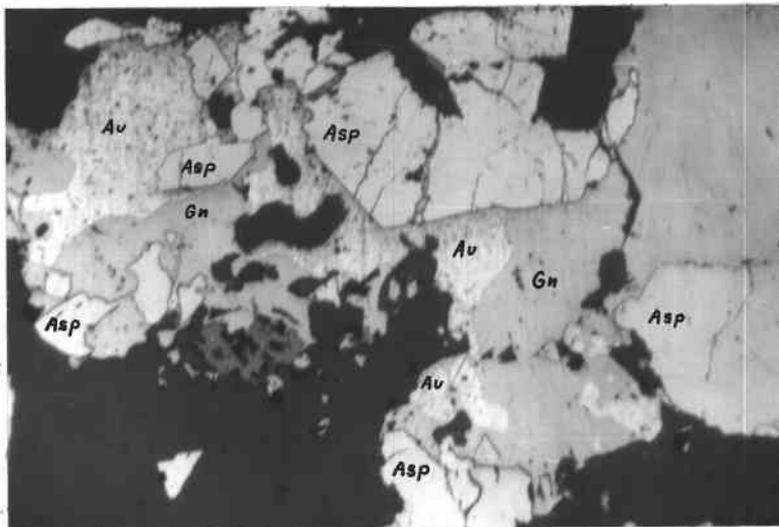
Figure 13. Galena and gold replacing and filling
cracks in arsenopyrite. The dark gray
mineral is quartz. Width of field is
1 mm.

cracks in pyrite and arsenopyrite (Figure 13). Some gold contains angular fragments of pyrite and arsenopyrite.

Calcite occurs both as brecciated fragments cemented by quartz and sulphides and as bands within the veins. Many of the calcite fragments are cut by sulphide-filled cracks. These relationships indicate that at least part of the calcite was deposited before the sulphides and quartz.

Hewett (14, p. 326) previously made a study of the vein minerals at the Buffalo Mine. The Constitution Vein was not developed at that time, and the samples Hewett studied were taken from the other veins; however, his findings are similar to those of the author who studied samples from the Constitution Vein. Hewett determined the following sequence of mineralization:

             Dolomite
          --crushing--
             Quartz
             Pyrite and Arsenopyrite
          --crushing--
             Sphalerite
             Chalcopyrite, tetrahedrite, and galena

Metal Content

Gold, silver, copper, and lead are the most valuable metals in the ore. The amounts of these metals by weight in the ore as averaged since 1950 are shown on the following list:

             Silver — 8 oz./ton
             Gold   — 1 oz./ton
             Lead   —   0.3 %
             Copper —   0.07%

The metal content by weight of the concentrates was averaged from sixteen smelter returns. These averages are as follows:

Silver	— 68 oz./ton	Copper	— 0.7 %
Gold	— 9 oz./ton	Antimony	— 0.4 %
Arsenic	— 6 %	Nickel	— trace
Zinc	— 4 %	Bismuth	— trace
		Lead	— not recorded

The results of gold and silver assays from different parts of the veins, from gouge, and from wall rock adjacent to the veins are listed in Table 2. These assays show a range in the metal content from different parts of the veins of from 1.10 ounces of silver and 0.04 ounces of gold per ton to 34.50 ounces of silver and 16.28 ounces of gold per ton. The sample assaying the highest in gold and silver content was taken across an 18-inch vein. Its value at 1958 metal prices is $600.85 per ton. The gouge and the wall rock adjacent to the veins contain some gold and silver also.

Structure and Character

The veins at the Buffalo Mine vary from simple fissure fillings to complex vein zones consisting of many closely-spaced veins. The individual veins differ considerably. Some consist entirely of massive, coarse-grained sulphides. Others are composed of banded, fine-grained sulphides mixed with much gangue (Plate 6). Some veins exhibit a combination of these features. A few of the veins consist entirely of quartz or calcite.

Mineral crustifications, comb quartz, vuggy quartz, and sharp, angular fragments of wall rock in the veins (Figure 14) give evidence

Table 2.

Gold and silver content in various vein and wall rock samples

| Silver(oz./ton)	Gold(oz./ton)	Number of samples assayed	Material Assayed
1.10	0.04	1	Vein quartz with no visible sulphides.
3.90 to 4.90	0.17 to 0.24	4	Mixed vein quartz and coarse-grained pyrite.
			Vein with outer bands of coarse-grained, massive sulphides and an inner zone of fine-grained sulphides with gangue.
0.60	0.07	1	Coarse-grained sulphides from outer bands
7.40	1.30	1	Entire vein across both the outer coarse-grained sulphides and the inner fine-grained sulphides.
34.50	16.28	1	An 18-inch vein containing both fine and coarse-grained sulphides.
0.60	0.02 to 0.08	2	Wall rock 1 foot from veins.
1.40 to 2.60	0.12 to 0.24	2	Wall rock adjacent to veins.
0.20 to 1.30	0.03 to 0.74	5	Gouge adjacent to veins.
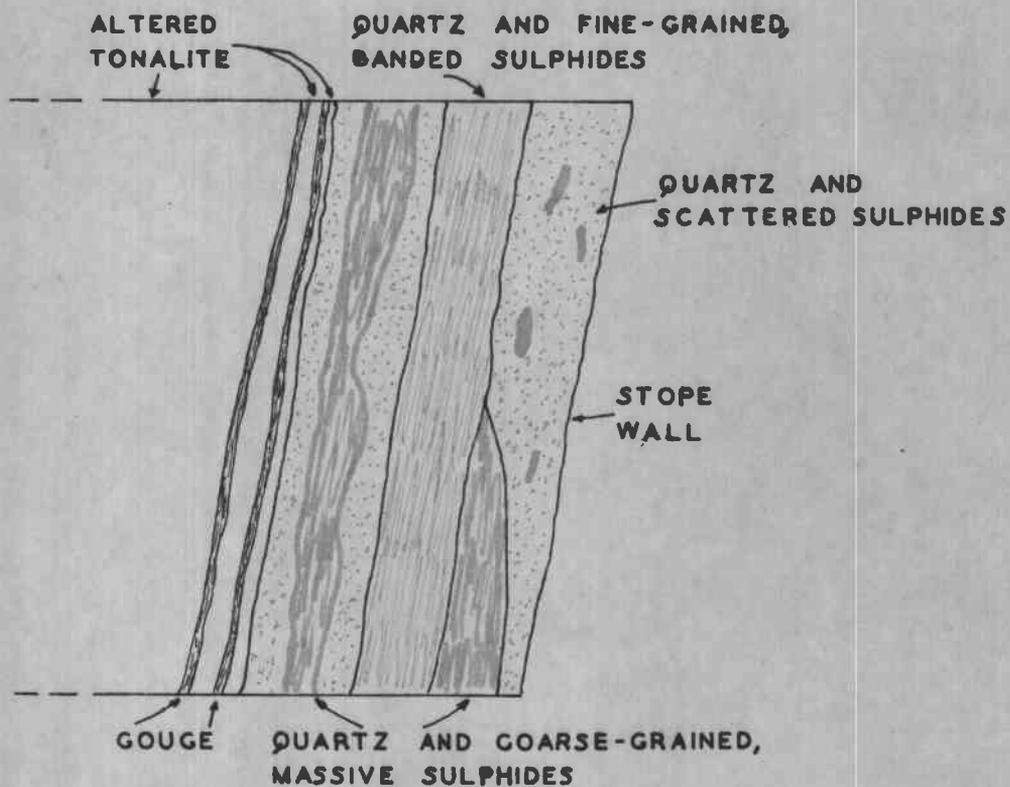
PLATE 6. Sketch map of vein structure at the end of a stope on the Constitution Vein. Scale: 1"=1'.

for vein emplacement by open space filling. Ribbon structures and breccia fragments of wall rock with hazy outlines indicate that there has also been replacement. The coarse-grained sulphides are more common in those veins showing evidence of open space filling.

At the mine the veins are controlled by faults and fractures cutting through both the tonalite and the argillite. No difference in the mineralogy or character of the veins is evident between the parts of the veins in the different country rock types. The grade of the ore, however, decreases slightly where the veins follow the contact between the tonalite and argillite. The veins strike N. 20° - 40° E. and generally dip to the northwest. The dip on the Constitution Vein, however, increases in a northeast direction on the 400 level and north of the main cross-cut becomes vertical and then easterly.

Some movement along the faults took place after the deposition of the ore. One or both of the vein walls are commonly slickensided. In some places the faults continue within the vein material, leaving the vein wall frozen to the wall rock. Gouge zones up to 6 inches thick are common along the faults. Some of this gouge is black from finely-ground sulphides.

In some places the faulting produced zones of tight fractures and breccia. In such places the country rock is usually altered but mineralization is slight or lacking. Sulphides, if present, form disseminated crystals or poorly defined veins in the altered rock.

Where the veins are best developed the wall of the faults are sharp and well defined (Figure 15). These sharp walls pinch and

Figure 14. A large argillite fragment surrounded by vein minerals. The fragment measures over a foot in length.

Figure 15. A part of the Constitution Vein having nearly a vertical dip. Vein width here is about 3 feet. Note the sharp vein walls.

swell the width of the vein from less than a foot to over 6 feet. Where the walls widen out the vein zones commonly consist of several veins separated by brecciated country rock which is riddled with intersecting veinlets (Figure 16 and Plate 7). In the places where the vein wall pinch together the vein zones may consist of several adjacent veins or of one single vein. The grade of the ore drops in these narrow mineralized zones. Evidently the rich ore was concentrated where the faulting had produced sharp, well-defined fissures which were easily penetrated by the ore-bearing solutions.

At one place on the Constitution Vein a strong fault and vein became poorly defined in a zone of highly altered and soft tonalite. This feature may indicate that pre-ore solutions altered the tonalite in certain places and that there was later movement along the fault which in the fresh tonalite produced well-defined fissures but in the soft, altered rock produced only irregular fractures which were not easily penetrated by the later ore-bearing solutions.

Age

The veins at the Buffalo Mine cut the Bald Mountain batholith which is believed to be late Jurassic or early Cretaceous in age. The veins, however, do not penetrate the overlying Tertiary volcanic rocks, the oldest of which are probably Eocene. Placer gold has been found in the old stream channels which were part of the drainage system produced during the erosion interval between the emplacement of the batholith and the deposition of the Tertiary volcanic rocks. This

Figure 16. A 6-foot wide vein zone consisting
mostly of many intersecting veinlets.

QUARTZ VEINLETS IN ARGILLITE

STOPE WALL →

← STOPE WALL

ARGILLITE FRAGMENTS

GOUGE
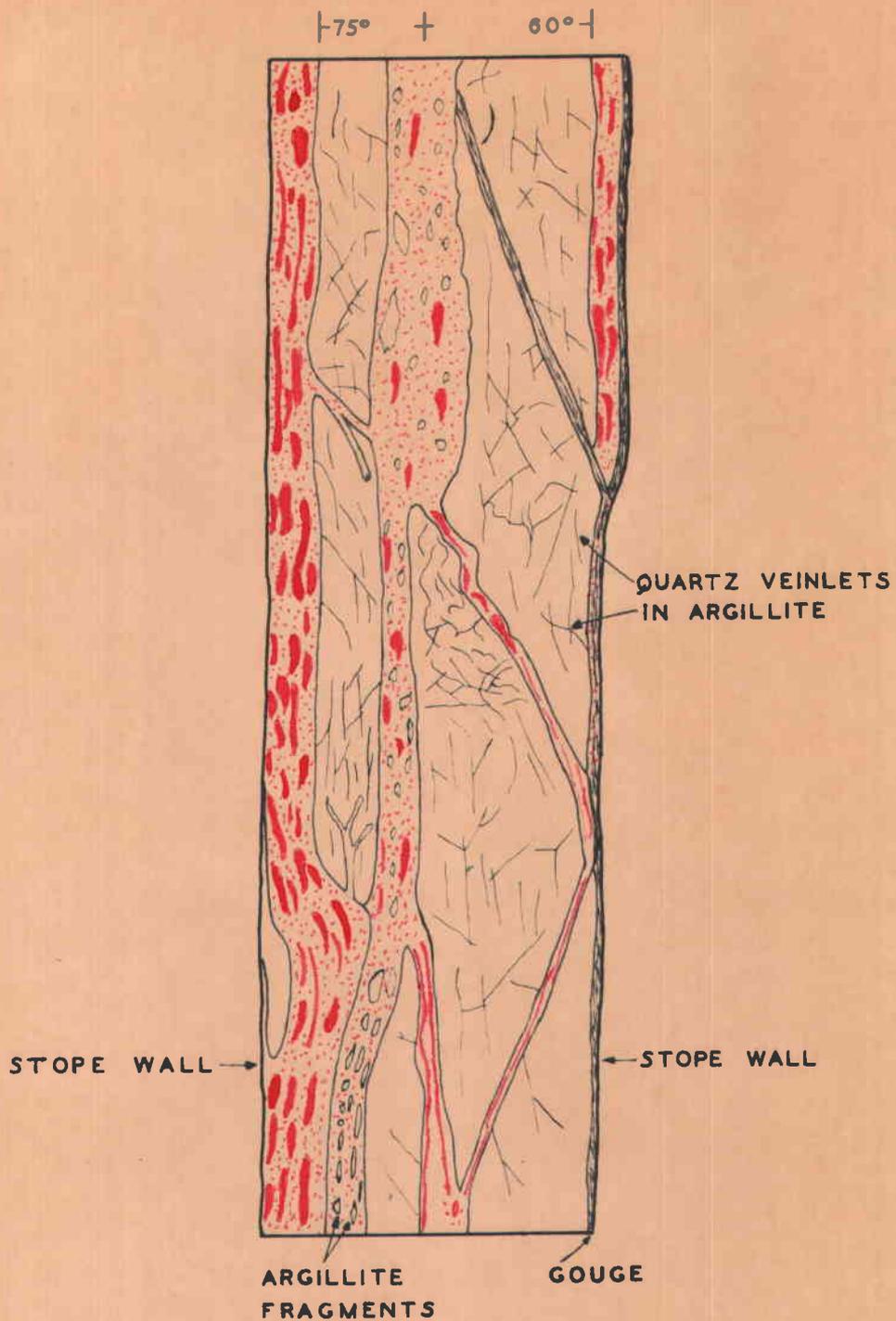
PLATE 7. Sketch map of vein structure at
the back of a stope on the Constitution Vein.
Scale: 1" = 3'.

indicates that at least part of the mineralization has occurred before the erosion began. These considerations indicate a probable early Cretaceous age for the veins.

ROCK ALTERATION

The tonalite at the Buffalo Mine exhibits two types of rock alteration. One of these is a deuteric alteration produced by a reaction between the late magmatic fluids and the earlier formed crystals. The other is a hydrothermal alteration which is associated with the veins.

DEUTERIC ALTERATION

Five samples of tonalite collected from different surface outcrops show effects of deuteric alteration. This alteration is characterized by a partial alteration of hornblende to biotite and chlorite and a partial alteration of biotite to chlorite. These alteration minerals are usually minor in amount, and in none of the sections studied were entire crystals of hornblende or biotite replaced.

The biotite which replaces the hornblende occurs as small rounded flakes or elongate laths scattered throughout the hornblende crystals.

The other deuteric mineral is a bright green chlorite. This chlorite is biaxial negative and has a 2V of 5° to 10°, an Ny between 1.620 and 1.624, and an anomalous blue interference color. According to Winchell's classification (49, p. 381-385) this chlorite is diabantite, a chlorite with nearly equal proportions of iron-magnesium and silicon-aluminum.

There are several occurrences of the diabantite. A small amount forms isolated masses of interlocking laths. This appears to have crystallized directly rather than as a replacement of previous mafic

minerals. Some of the diabantite occurs as elongate crystals penetrating large crystals of primary biotite along their cleavages. The rest of the diabantite is associated with the hornblende. Some of it replaces the small laths and rounded flakes of deuteric biotite which are present in a number of the hornblende crystals. Part of this chlorite also occurs as small areas of intergrown flakes within the hornblende and appears to be a direct alteration of it.

Sphene often occurs with the diabantite. It forms finely crystalline aggregates that are elongate parallel to the original cleavage in the biotite or forms irregular aggregates where the diabantite replaces hornblende.

The occurrences of these deuteric minerals suggest that when the biotite was crystallizing from the magma solutions already were reacting with the earlier formed hornblende, altering it to biotite. Apparently potassium was used up before the magma had completely crystallized, after which diabantite crystallized instead of biotite and the residual solutions altered part of the earlier formed hornblende and biotite to chlorite.

HYDROTHERMAL ALTERATION

General Statement

Alteration of the rocks associated with ore deposits is well known and is described in most papers dealing with ore deposits. The process whereby the rocks adjacent to veins or fissures are altered

is known as hydrothermal metamorphism or hydrothermal alteration. The names imply that hot-water solutions are a dominant factor.

In 1900 Lindgren (24, p. 578-692) wrote a lengthy article devoted entirely to replacement processes around fissure veins. During the past 50 years more-detailed work has been done on wall rock alteration to learn more about the origin of the metal-bearing solutions, the nature of these solutions, the processes resulting in the formation of metal deposits, and the value of the altered rock as a guide to ore. Hydrothermal alteration has been described from a great variety of ore deposits associated with a great variety of wall rock types. There are certain similarities in the altered types and patterns in various igneous rocks surrounding different vein deposits.

Sales and Meyer (34, p. 9-33), in a detailed investigation of the hydrothermal alteration of a quartz monzonite at Butte, Montana, described three well-defined alteration zones, each having definite minerals and relationships to the veins and to the other alteration zones. The altered rock most distant from the veins in characterized by chlorite, epidote, and a carbonate replacing primary biotite and hornblende. Some of the hornblende is also replaced by a nontronite type of clay. The feldspars have been altered to a green montmorillonite clay. Closer to the veins kaolinite rather than montmorillonite replaces the feldspars. Adjacent to the veins sericite has replaced the biotite, hornblende, and the feldspars. Quartz and pyrite are associated with the sericite.

The same general alteration pattern found at Butte has also been described by Kerr at Santa Rita, New Mexico (20, p. 275-347) and at

Silver Bell, Arizona (18, p. 451-480); by Peterson, Gilbert, and Quick at Castle Dome, Arizona (31, p. 820-840); and by Schwartz at Morenci, Arizona (35, p. 410).

Outer zones of propylitic alteration characterized by alteration of mafic minerals to chlorite, zoisite, epidote, and carbonate have been mentioned in the Bonanza Mining District of Colorado by Burbank (5, p. 79-80); in the tin-silver deposits of Oruro, Bolivia by Chace (6, p. 435-439); in the Hauraki gold fields of New Zealand by Finlayson (8, p. 633); at Cerro do Pasco, Peru by Graton and Bowditch (12, p. 655-658); at Casapalca, Peru by Noble and McKinstry (27, p. 513-515); at Victoria, Australia by Junner (17, p. 86-91); in the Goldfield District of Nevada by Ransome (32, p. 462-465); at the Comstock Lode in Nevada by Coats (7, p. 11-15); and in the copper deposit of Kyshtim, Russia by Stickney (40, p. 628-631). These are only a few of the many areas in which propylitization of the country rock has been described.

The propylitic alteration has not in all places, however, been interpreted as the product of alteration by vein-forming fluids. In some of the places mentioned the widespread propylitic alteration is believed to have been produced by deuteric or other metamorphic processes unrelated to vein formation.

Sericite is as common in alteration zones as are the propylitic alteration minerals, but it usually occurs in the more intensely altered rock close to the veins. The clay minerals which are common hydrothermal alteration products are kaolinite, illite, and members

of the montmorillonite group. Where both sericite and clay minerals are associated with the same veins, the sericite is usually closer to the veins. At Cerro de Pasco, Peru (12, p. 655) and Oruro, Bolivia (6, p. 435-439), however, the reverse is true, and the kaolinite is common adjacent to the veins.

Other alteration minerals which are commonly found in the wall rock surrounding veins are carbonates, quartz, feldspars, biotite, tourmaline, and alunite.

Alteration of the Tonalite at the Buffalo Mine

General Statement

The hydrothermal alteration in the tonalite at the Buffalo Mine forms three zones based on different alteration minerals (Table 3). The minerals have a zonal arrangement in relation to the veins. The altered tonalite which is farthest from the veins and adjacent to the fresh rock is pale green. This color is produced by chlorite, antigorite, and a green microcrystalline mineral which may be montmorillonite. These minerals have formed by alteration of biotite, hornblende, and plagioclase feldspar. The tonalite near the veins is bleached white. The alteration minerals present in this zone are sericite, muscovite, calcite, and pyrite. Quartz is the only mineral which is unaltered here.

The alteration pattern in the tonalite at the Buffalo Mine is similar to the alteration pattern occurring in a quartz monzonite at

Table 3. Alteration of the tonalite

MINERAL	ALTERATION PRODUCTS		
FRESH TONALITE	OUTER GREEN ZONE	INNER GREEN ZONE	BLEACHED ZONE
Hornblende	Antigorite Chlorite (var. Jenkinsite) Sphene? * Chrysotile? * Carbonate *	Chlorite (var. Repidolite) Chlorite (var. Diabantite) Calcite Pyrite Rutile * Quartz *	Muscovite Calcite Pyrite Rutile *
Biotite	Biotite	Chlorite (var. Repidolite) Chlorite (var. Diabantite) Calcite Pyrite Rutile Quartz *	Muscovite Calcite Pyrite Rutile
Plagioclase	Montmorillonite? *		Sericite Calcite

* Indicates mineral is present in minor amounts.

Butte, Montana; in a granodiorite porphyry at Santa Rita, New Mexico; and in a quartz monzonite at Castle Dome, Arizona. These different igneous rocks which have been hydrothermally altered have similar chemical compositions (Table 4).

Outer Green Zone

In this zone only the hornblende and plagioclase have been altered. In progressing from fresh to altered rock the first noticeable change is an alteration of the hornblende which has been converted to antigorite. The antigorite is green in plain light and greenish yellow in polarized light. It is biaxial negative with a 2V of about 30°, an Nz between 1.572 and 1.574, and an Ny between 1.568 and 1.570.

The antigorite forms coarse aggregates and in a few places anhedral crystals. Rarely it fills cracks in the minerals surrounding the altered hornblende crystals. In the beginning stages of alteration the antigorite occurs as thin seams penetrating the hornblende crystals along cleavages and cracks. Nearer the vein the antigorite has grown outward from the cracks and cleavages until only isolated remnants of unaltered hornblende remain (Figures 17 and 18). The hornblende is completely replaced near the inner margin of this zone except in places where the hydrothermal alteration occurs around small fractures and consequently is less intense.

A green chlorite occurs with the antigorite. It is distinguished from the antigorite only by its lower 2V and its higher refractive

Table 4.

Chemical analyses of unaltered igneous rocks
which have similar hydrothermal alteration features.

	1.	2.	3.	4.
SiO_2	66.81	64.03	69.60	61.26
Al_2O_3	16.58	15.58	13.99	16.22
Fe_2O_3	1.40	1.96	1.82	3.00
FeO	2.59	2.83	2.15	2.38
MgO	1.81	2.15	0.86	2.57
CaO	5.09	4.20	2.12	6.12
Na_2O	3.76	2.76	2.66	4.34
K_2O	1.19	4.11	4.56	2.61
TiO_2	0.50	0.60	0.62	0.52
MnO	0.09	0.11	0.13	0.08
P_2O_5	0.15	0.18	0.23	0.48
$H_2O +$	0.43	0.73	1.00	0.20
$H_2O -$	0.07	0.20	0.14	0.15
	99.84	99.44	99.88	99.93

1. Tonalite 3 miles east of the Buffalo Mine (46, p. 222).

2. Butte quartz monzonite (48, p. 35).

3. Quartz monzonite from Castle Dome, Arizona (31, p. 836).

4. Granodiorite porphyry from Santa Rita, New Mexico
    (20, p. 299).
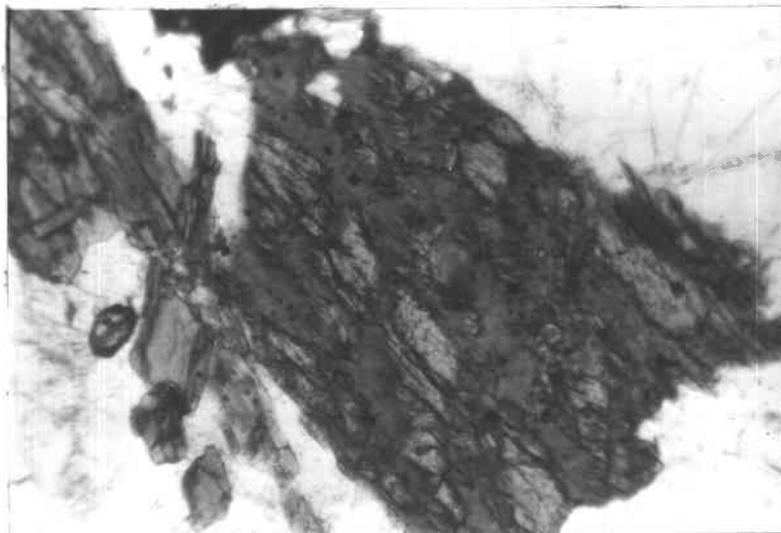
Figure 17. Hornblende in the outer green zone
partly altered to antigorite. Note
the remnants of unaltered hornblende.
The small black dots are finely crystalline
material which may be sphene. Width of
field is 2 mm. Plain light.
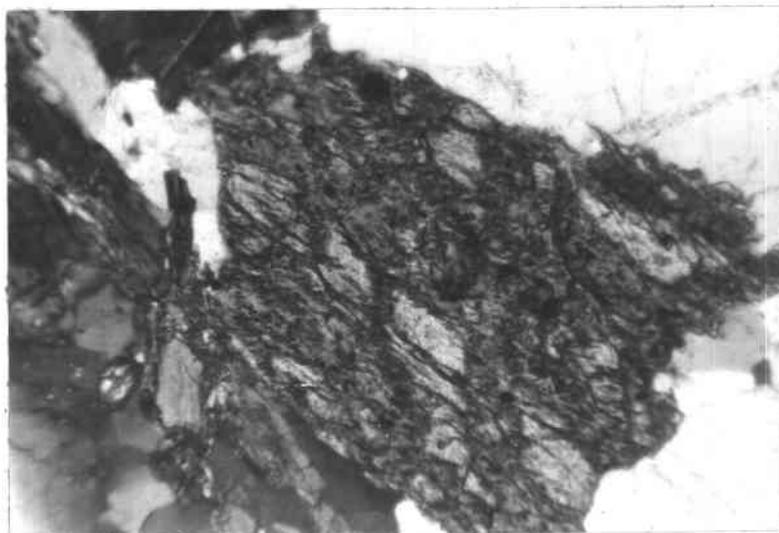
Figure 18. Hornblende in the outer green zone
partly altered to antigorite. Note
fibrous nature of the antigorite.
Width of field is 2 mm. Crossed nicols.

indices. This chlorite is biaxial negative with a 2V of about 5° and an Ny between 1.600 and 1.602. According to Winchell's classification this mineral is jenkinsite, a silicon-and magnesium-rich chlorite which is very similar in composition to antigorite.

Several minor minerals are also associated with the antigorite. Some of the antigorite contains a small amount of carbonate. There are also some long, pale green fibers which may be chrysotile. Another mineral occurs as tiny aggregates scattered uniformly throughout the antigorite (Figure 17). This mineral has a high relief and is probably sphene, but no positive identification could be made because the crystals are too small for the determination of optical properties.

In some of the large biotite crystals near altered hornblende, there seems to be an increase in development of diabantite, the deuteric chlorite previously described. This chlorite is more abundant in the tonalite of the outer green zone than in any of the samples collected for study of deuteric alteration.

The plagioclase in this zone has been partly altered to a pale green mineral which has a microcrystalline aggregate structure. No optical properties could be determined nor could the mineral be separated for analysis. It commonly occurs as thin bands and irregular patches along certain composition zones within the plagioclase (Figure 19). This mineral gives the plagioclase a greenish color when seen in hand specimens. It is similar in appearance and occurrence to the montmorillonite described by Sales and Meyer at Butte (34, p. 9-33).

Hornblende is commonly sensitive to effects of hydrothermal alteration. Among places where hornblende is the most easily altered mineral in the wall rock are Santa Rita, New Mexico (20, p. 316) and Casapalca, Peru (27, p. 513-515). Chlorite rather than antigorite is the most common hydrothermal alteration product of hornblende. Winchell (49, p. 381-387) suggests that chlorite and antigorite form an isomorphous series. He considers antigorite to be the silicon- and magnesium-rich end member of the chlorite group. Aruja (2, p. 65-74) and others, however, have described a kaolinite type of structure for antigorite, and if this is so, no such isomorphous series could exist.

Antigorite is not a common hydrothermal mineral; however, it has been mentioned previously by Stringham (42, p. 984) as a mineral associated with the copper deposit at Bingham, Utah. Serpentine, a mixture of antigorite and other magnesium silicates, has been described as an alteration of the mafic minerals in the wall rock around the veins at Cripple Creek, Colorado (26, p. 187).

Inner Green Zone

In progressing towards the veins from the outer green zone, the inner green zone is distinguished by hornblende and biotite increasingly replaced by chlorite, calcite, pyrite, rutile, and quartz. In addition some of the plagioclase is partly altered to sericite.

In the transitional area between the inner and outer green zones the chlorite, calcite, pyrite, rutile, and quartz in some places,

where replacing hornblende, surround cores of the antigorite type of alteration which is prominent in the outer green zone. This feature indicates that there has been some growth of the inner green zone at the expense of the outer green zone.

The hornblende crystals in the inner green zone have been completely replaced by an intergrown mass of chlorite, calcite, pyrite, rutile, and quartz (Figure 20). Repidolite is the most common mineral replacing the hornblende. This chlorite is pale green to colorless in plain light and is dark gray under crossed nicols. It usually forms radiating aggregates. The mineral is biaxial positive with a 2V of about 5°, and an Ny between 1.612 and 1.614. According to Winchell it has a composition intermediate in iron-magnesium and silicon-aluminum content.

Diabantite also replaces hornblende in this zone. This chlorite occurs as complete replacements of hornblende or as intimate intergrowths with the repidolite. These forms seem to indicate that at least part of the diabantite in this zone was produced along with the repidolite as a result of hydrothermal rather than deuteric alteration. According to Winchell these two chlorites have very similar compositions. The repidolite measured contains more aluminum and magnesium than the diabantite. These two minerals possibly form an isomorphous series in this zone.

Calcite, pyrite, rutile, and quartz are other alteration products of the hornblende. The calcite forms irregular aggregates which occupy up to 40 percent of the volume of the original hornblende
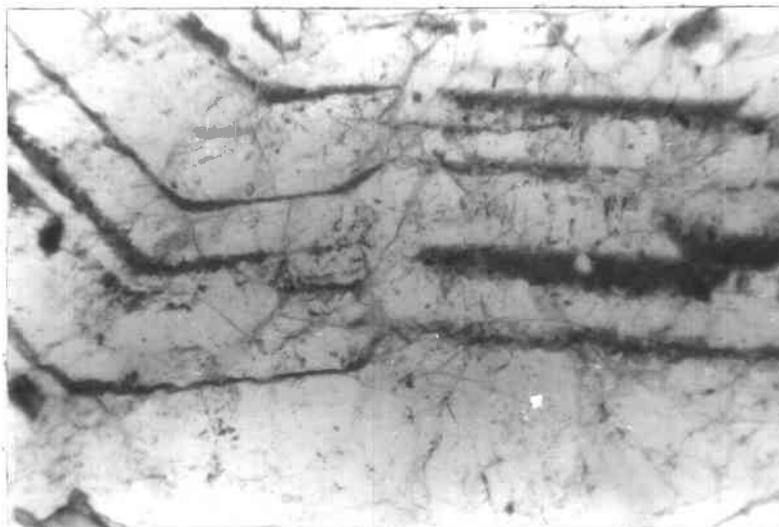
Figure 19. Unknown green, microcrystalline mineral
partly replacing plagioclase. This
mineral is common in the outer green
zone. Width of field is 2 mm. Plain light.
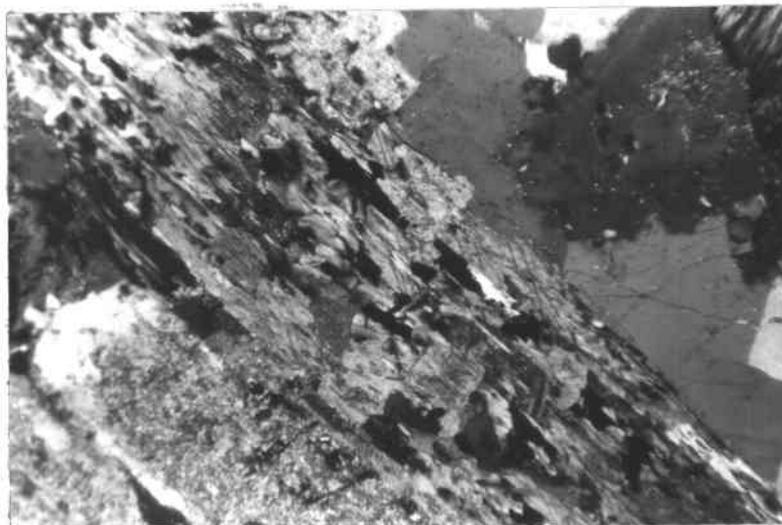
Figure 20. Intergrown mass of chlorite, calcite, and
pyrite replacing an elongate crystal of
hornblende. These are the typical alteration
minerals in the inner green zone. Width of
the field is 4 mm. Crossed nicols.

crystals. The amount of calcite increases towards the veins. Pyrite commonly occurs as small rounded or elongated crystals within the chlorite and calcite. The amount of pyrite increases towards the veins and in some instances replaces over half of the original hornblende crystals. Where the pyrite is most abundant it forms large, irregular masses produced by the coalescence of many smaller crystals. Quartz and rutile are minor alteration products. The quartz occurs as small rounded aggregates. The rutile is present as a few scattered needles.

In the part of the inner green zone most distant from the veins most of the biotite, deuteric as well as primary, is fresh; however, towards the veins the biotite has been altered to the same minerals which replace the hornblende. The structure of the biotite has had a strong influence on the alteration as is indicated by the way the alteration has proceeded and by the form of the alteration minerals.

In the beginning stages of alteration chlorite penetrates the biotite crystals along cleavage planes (Figure 21). Growth of the chlorite proceeded parallel to the cleavage until entire crystals were replaced (Figure 22). Most of this chlorite is repidolite; however, some diabantite replaces entire biotite crystals or is intergrown with the repidolite. The repidolite which replaces biotite has a prismatic form rather than the radiating, fibrous form developed where it replaces hornblende. Calcite forms crystals elongated parallel to the biotite cleavage. Some of these crystals are continuous throughout the entire length of the altered biotite crystals.
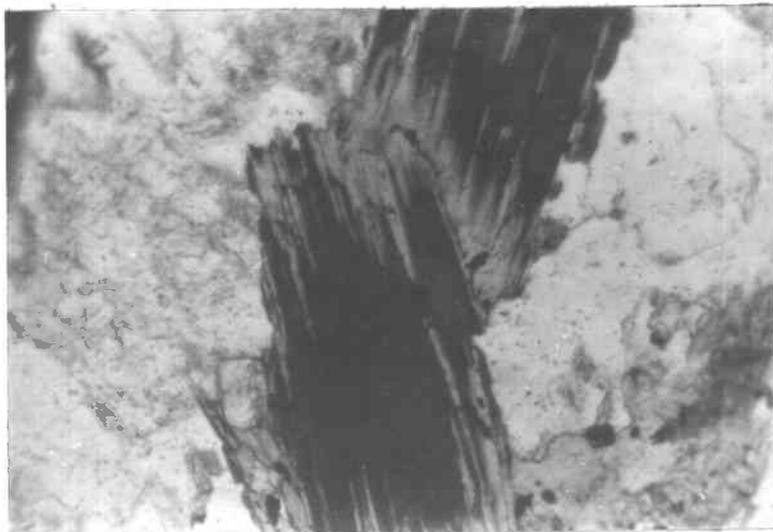
Figure 21. Chlorite in the inner green zone partly replacing biotite. The chlorite is light gray. Note how the chlorite penetrates along the cleavages. Width of field is 2 mm. Plain light.
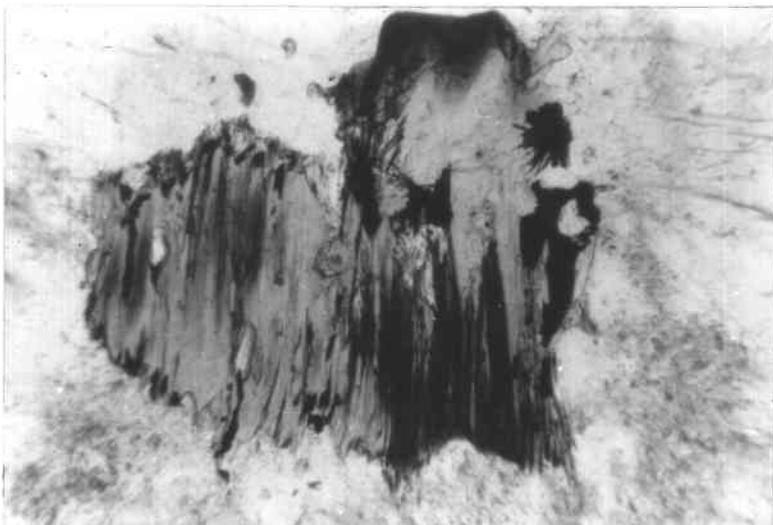
Figure 22. Biotite crystal in the inner green zone almost completely replaced by chlorite. Large dark gray areas are unaltered biotite. Light gray mineral is chlorite. Small dark crystals around edges are pyrite. Radiating needle-like growths are rutile. Width of field is 2 mm. Plain light.

Pyrite commonly forms small rounded crystals which are arranged rough-ly parallel to the biotite cleavage. Larger crystals of pyrite are elongate parallel to the biotite cleavage. Rutile forms radiating or intergrown needles within the chlorite. In some places the rutile and pyrite are so abundant in the positions of the former biotite crystals that these areas are almost opaque when viewed under low magnification.

The alteration of the plagioclase changes from the green micro-crystalline mineral to sericite near that part of this zone where the biotite exhibits its first stages of alteration. The sericite is bi-axial negative with a 2V of about 30°, and Nx between 1.554 and 1.556, and an Ny between 1.588 and 1.590. In the beginning stages of develop-ment the sericite is in small isolated flakes replacing the plagio-clase crystals. As the alteration becomes more intense the sericite forms masses of intergrown flakes. The sericite never replaces more than 20 percent of any feldspar crystal in this zone. Differential thermal analyses indicate that no hydrous clay minerals are mixed with the sericite.

Bleached Zone

The bleached zone is between the inner green zone and the veins. In this zone the original minerals of the tonalite except quartz have been altered to various combinations of muscovite, sericite, calcite, pyrite, and rutile. The quartz is unaltered.

In progressing from the inner green zone to the bleached zone the

first noticeable changes are an increase in the amount of sericite replacing plagioclase and the appearance of a colorless, highly-birefringent mica intermixed with the chlorite-calcite-pyrite alteration of the hornblende and biotite. In the bleached zone the colorless mica takes the place of chlorite which is entirely absent.

The mica is apparently muscovite; however, it has an optic angle which is much smaller than that characteristic of most muscovite. The mineral is optically negative and is nearly uniaxial. Ny and Nz are between 1.588 and 1.590, and Nx is between 1.550 and 1.552. Spectrographic analyses indicate that this mica is essentially a potassium-rich aluminum silicate with all other elements each present in amounts of less than 5 percent. This corresponds to the composition of muscovite. Muscovite with a small optic angle has previously been described from the Sultan Basin in Washington by Axelrod and Grimaldi (3, p. 559-572).

The hornblende crystals in this zone have been altered to irregular groups of muscovite, calcite, and pyrite (Figure 23). A small amount of rutile is sometimes present. The original outlines of the hornblende crystals are completely destroyed.

Biotite is altered to the same minerals as the hornblende, but these minerals tend to have an elongate form where replacing the biotite (Figures 24, 25, and 26). The muscovite commonly occurs as single crystals completely preserving the outlines of the original biotite crystals. The calcite and pyrite are present within the muscovite as elongate crystals or as bands of smaller rounded crystals parallel to
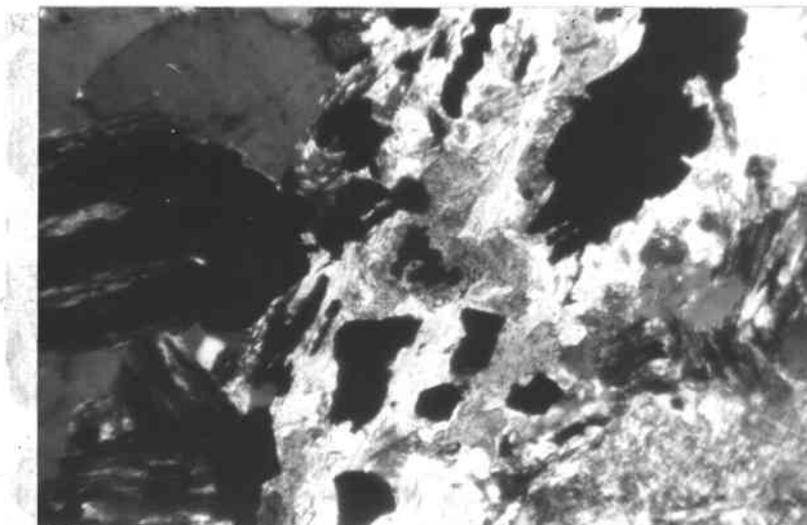
Figure 23.   Intergrown mass of muscovite, calcite,
             and pyrite replacing hornblende in the
             bleached zone.   Hornblende is completely
             altered. Width of field is 2 mm.
             Crossed nicols.
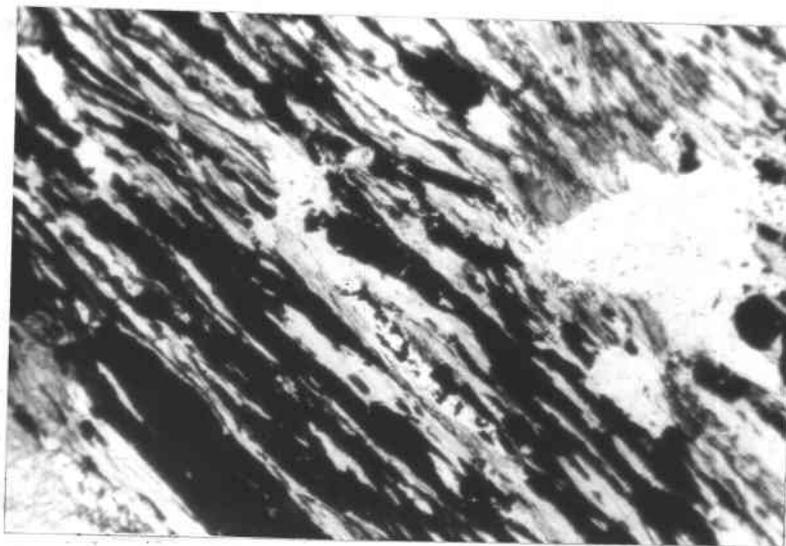
Figure 24.   Elongate crystals of muscovite, calcite,
             and pyrite replacing biotite in the
             bleached zone. Biotite is completely
             altered. Width of field is 2 mm.
             Plain light.

Figure 25. Altered biotite crystal in the bleached
zone. The biotite has been completely
altered to calcite, muscovite, and
pyrite. Note the lenses of calcite
parallel to the original biotite cleavage.
Width of field is 2 mm. Crossed nicols.
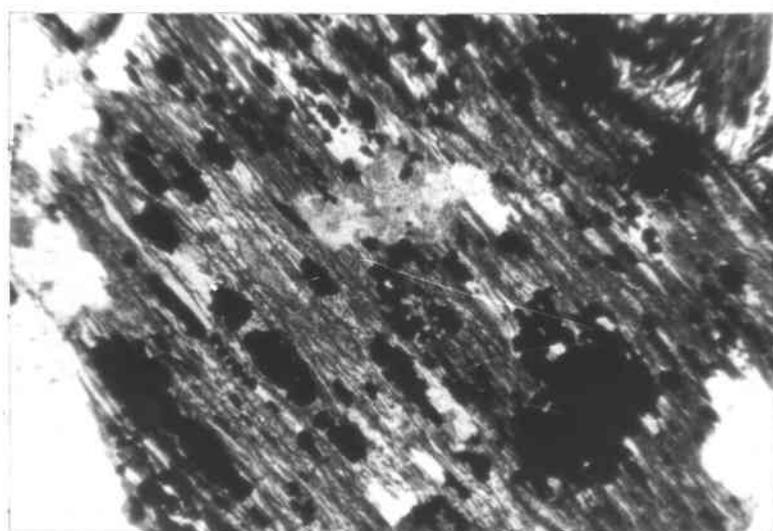
Figure 26. Pyrite, muscovite, and calcite replacing
biotite in the bleached zone. The
biotite crystal is completely replaced.
Width of field is 2 mm. Crossed nicols.

the original biotite cleavage. Rutile is abundant as masses of
intergrown needles within the muscovite.

The feldspar crystals are completely altered to aggregates of
small sericite flakes (Figure 27). Irregular shaped calcite grains
commonly occur within the sericite. Near the veins some disseminated
crystals of euhedral pyrite are present in the altered feldspars.
This pyrite does not replace any mafic minerals.

Both the pyrite and calcite increase in quantity towards the
veins, and in a few places almost the entire space occupied by the
former biotite or hornblende crystal is filled with pyrite or calcite.
These two minerals are distributed unevenly for in some of the bleach-
ed rock either pyrite or calcite is missing entirely even though it
may be abundant in the rock a few feet away.

Near the main sulphide veins the amount of quartz in the tonalite
increases. Many tiny veinlets of quartz cut the bleached tonalite
and are so abundant in some places that the rock consists essentially
of a series of interconnecting veinlets separated by a small amount
of altered tonalite. Some of these quartz veinlets also contain small
rounded crystals of pyrite (Figure 28). There are also some small
veinlets of calcite. Some larger lens-shaped bodies of quartz occur
in the bleached rock where the bleached zones are very wide (Figure
29). The largest of these are several feet long and up to 2 inches
wide. From the alteration of feldspar to sericite, approximately 1
cubic foot of quartz would be produced by alteration of 12 to 18
cubic feet of tonalite. Some quartz in the lenses and veinlets
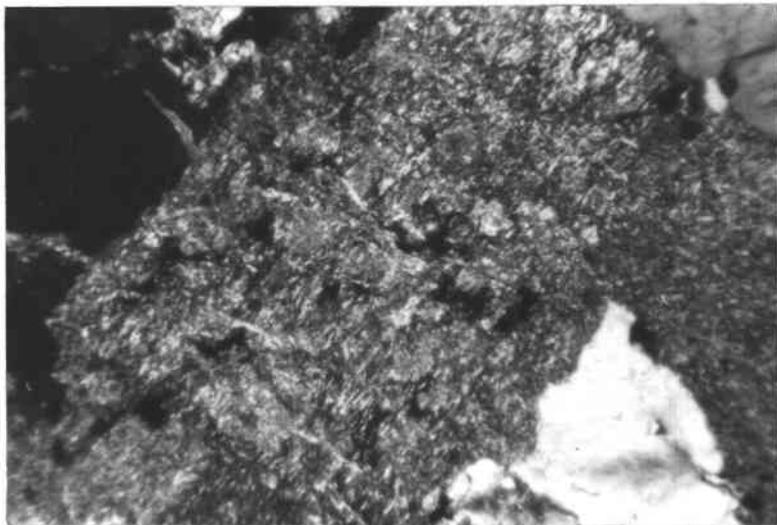
Figure 27. A plagioclase crystal in the bleached
zone showing complete replacement by
fine-grained sericite. Width of field
is 2 mm. Crossed nicols.
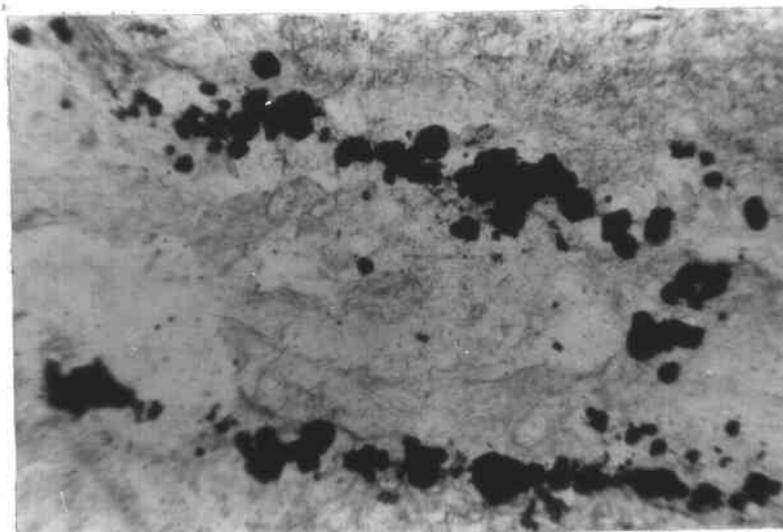
Figure 28. Pyrite crystals occurring along both
margins of a small quartz veinlet in
the bleached tonalite. Width of field
is 2 mm. Plain light.

Figure 29.   An 8-inch quartz lens in bleached
tonalite.
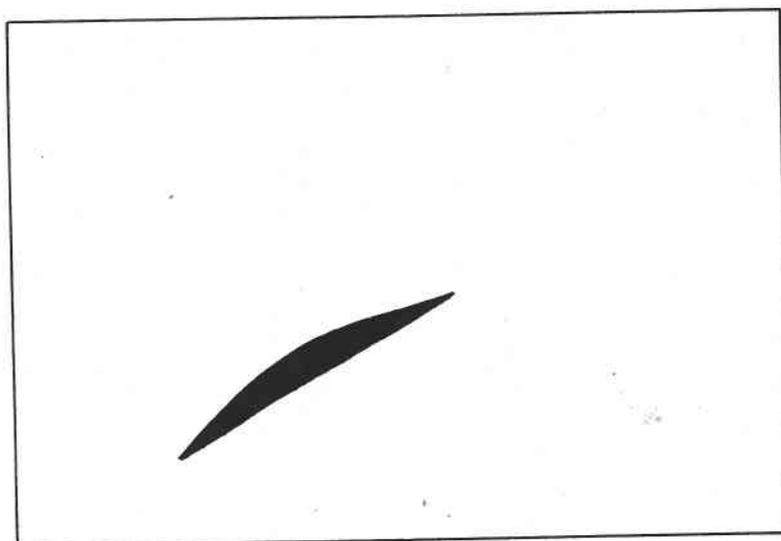
Sketch showing location of
quartz lens.

possibly was derived from the altered feldspars.

The bleached rock along several of the well-developed faults has been stained brown by iron oxides. Because the staining is very irregular it does not appear to be related to the hydrothermal alteration. It was probably deposited by oxidizing surface waters which penetrated the rock along the faults.

Where the faults cut through the bleached tonalite a pure white gouge zone commonly is adjacent to the faults. The gouge consists of finely-ground quartz and sericite which are moist and have been compacted into a clay-like material. Differential thermal analyses show that no clay minerals are present in the gouge.

Relationships of the Alteration Zones

The alteration zones in the tonalite surround small fractures and barren faults as well as veins. The fractures and barren faults which exhibit the alteration all strike northeast parallel to the veins. The type of alteration near the barren fractures does not differ from that near the veins. The total width of alteration varies from about 25 feet near some veins and faults to less than a foot alongside small fractures. The alteration zones are wider near veins which are separated from the wall rock by open faults than beside veins which are frozen to the wall rock. The alterations on the two levels of the mine do not differ.

The outer green zone, characterized by alteration of hornblende, is the widest of the three alteration zones in the tonalite (Plate 8).

Scale: 1"=2"

Scale: 1"= 1'
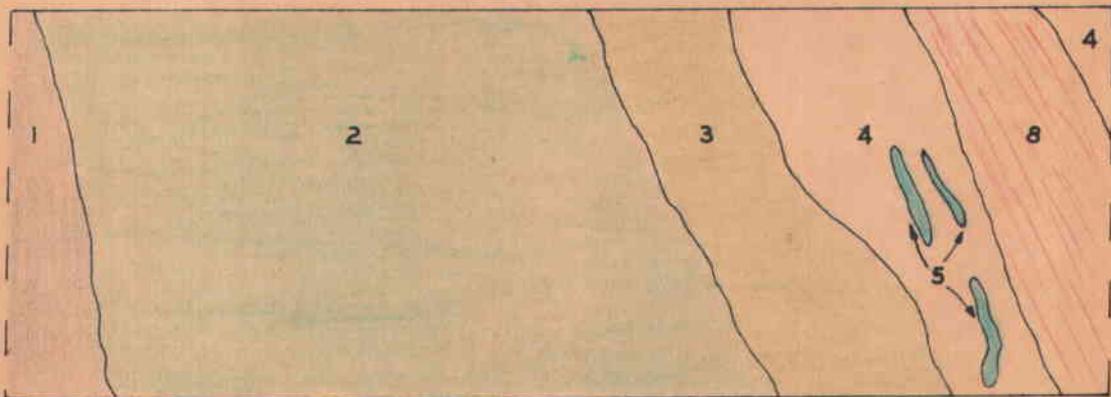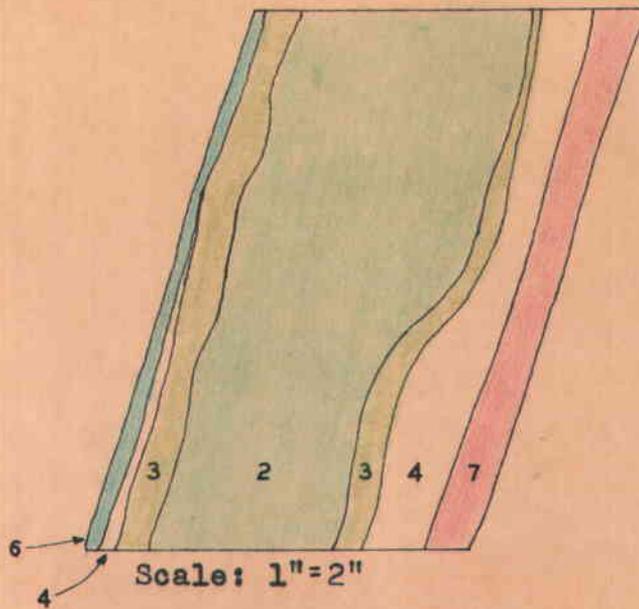
1	Fresh Tonalite	5	Quartz Lenses
2	Outer Green Zone	6	Quartz Vein
3	Inner Green Zone	7	Quartz Vein with Sulphides
4	Bleached Zone	8	Gouge ,with Disseminated Sulphides

PLATE 8. Sketch maps of the alteration zones in the tonalite.

This zone extends as much as 25 feet from some veins for a total maximum width of about 20 feet. In some places the outer green zones from adjacent veins have merged so that no unaltered tonalite remains between the veins.

The inner green zone, characterized by alteration of biotite as well as hornblende, is much narrower. Its greatest width is not over 3 feet. In some places it is represented by only a few biotite and hornblende crystals with chlorite-calcite-pyrite alteration.

Bleached zones up to 10 feet wide occur in the tonalite but these are in places where there are several close-spaced veins or faults. Bleached zones are not over three feet wide beside any single vein, and they are missing entirely near small fractures which have alteration zones only a few inches wide.

A large irregular body of intensely altered tonalite occurs along the trace of the Constitution Vein. The solutions producing the alteration have penetrated this large volume of tonalite through numerous intersecting joints. The vein and the fissure controlling the vein become poorly defined in this soft, altered rock.

Because the different alteration zones have a definite spatial relationship and grade into one another, one may reasonably assume that they are the result of continually varying physiochemical conditions in the wall rock. These variations in conditions were possibly the result of an outward decrease in the temperature of the wall rock away from the veins and of a gradual change in the composition of the solutions producing the alterations as they

penetrated farther into the wall rock. The alteration zones closer
to the veins need not have passed previously through the full sequence
of changes corresponding to the alteration zones which are at great-
er distances from the veins. These zones of alteration may be com-
pared to the zones of progressive metamorphism which according to
Turner and Verhoogen (47, p. 420) formed during the last period of
petrogenesis when the metamorphic temperatures coincided long enough
with the catalytic influences of rock deformation or with incoming
waves of aqueous fluids for a state of equilibrium to develop be-
tween the various solid phases. For this reason the zones of higher
metamorphic grade have not necessarily passed previously through the
lower grades occurring in the same region.

Sales and Meyer (34, p. 14) conclude that at Butte the alteration
grew outward by a continuous reaction between the wall rock and the
altering solutions. As long as this reaction persisted, each zone
moved outward from the veins by simultaneously advancing on its outer
margin and receding on its inner margin. In the altered tonalite at
the Buffalo Mine some outward growth of the alteration zones is in-
dicated where the alteration minerals of one zone replace those of
another. This replacement, however, is not apparent in all specimens
studied, for many of the zone margins are characterized by an inter-
mixing of the alteration minerals of the adjoining zones. Where the
minerals are intermixed evidence of replacement of the minerals of
one zone by those of another is lacking.

Chemical Gains and Losses in the Altered Tonalite

A quantitative measurement of chemical gains and losses in altered wall rock can be determined only by a series of complete rock analyses. These were not made. An estimate of the gains and losses can be had, however, by considering the mineralogical changes in the wall rock. The following is a list of gains and losses determined by the mineralogy in the alteration zones of the tonalite:

	Outer Green Zone	Inner Green Zone	Bleached Zone
Gains	None Apparent	Sulphur Carbonate	Sulphur Carbonate Potassium
Losses	None Apparent	Sodium Magnesium	Sodium Magnesium

In the outer green zone where hornblende and plagioclase are the only altered minerals, the alteration minerals possibly represent only a rearrangement of the elements present in the fresh tonalite. The iron, magnesium, silicon, aluminum, calcium, and titanium present in the original hornblende can be accounted for in the antigorite-jenkinsite-sphene(?) alteration which replaces the hornblende. If the green mineral replacing the plagioclase is montmorillonite, then any sodium and potassium from the hornblende could have crystallized with the clay mineral along with sodium, calcium, silicon, and aluminum from the plagioclase.

In the inner green zone sulphur and carbonate have been introduced into the rock, and some sodium and magnesium have probably been

removed. The hornblende in this zone has been altered to chlorite, pyrite, calcite, and rutile. Part of the iron from the hornblende has combined with sulphur to form pyrite. The calcium from the hornblende has combined with carbonate to form calcite. The titanium has crystallized into rutile. Sodium and potassium present in the hornblende may possibly be in the green mineral partly replacing the plagioclase. The potassium may also have gone into the sericite which partly replaces the plagioclase.

The repidolite which replaces the hornblende apparently formed from iron, magnesium, silicon, and aluminum derived from the hornblende. The change from replacement by antigorite and chlorite (variety jenkinsite) in the outer green zone to replacement by chlorite (variety repidolite) in the inner green zone represents an increase in the iron/magnesium ratio. Because magnesium has been almost completely leached from the adjacent bleached zone, the increase in this ratio likely is a result of removal of some magnesium rather than addition of iron.

Biotite has also altered to chlorite, calcite, pyrite, and rutile in this zone. The chlorite evidently contains some of the iron, magnesium, aluminum, and silicon present in the biotite. Some of this iron has combined with sulphur to form pyrite. The calcite occurring within the altered biotite crystals apparently represents a migration of calcium from surrounding altered plagioclase or hornblende and a combination with introduced carbonate. The titanium has crystallized into rutile. The potassium from the biotite can be accounted for in

the sericite which replaces some of the plagioclase.

The only elements besides oxygen present in the plagioclase which are also present in the sericite replacing it are silicon and aluminum. The potassium present in the sericite may have been derived from hornblende and biotite. The calcium liberated during the alteration of the plagioclase to sericite can be accounted for in the calcite occurring in the altered biotite and feldspars. The sodium in the plagioclase has apparently been removed from the rock.

In the bleached zone sulphur, carbonate, and potassium have been introduced and sodium and magnesium have been completely leached. There the hornblende and biotite are altered to muscovite, calcite, pyrite, and rutile. The iron, calcium, silicon, aluminum, potassium, and titanium present in the fresh hornblende can be accounted for in these minerals. The sodium and magnesium have been removed. Sulphur and carbonate have been introduced and have combined with iron and calcium respectively to form pyrite and calcite. The biotite in the bleached zone has also altered to muscovite, pyrite, calcite, and rutile. All the elements present in the biotite except the magnesium can be accounted for in these minerals. The magnesium has been leached. Calcium may have migrated from the surrounding altered hornblende and plagioclase. Sulphur and carbonate have been introduced.

In the bleached zone the plagioclase has been completely altered to sericite and calcite. Potassium and carbonate have been introduced. Aluminum may also have been introduced since there is more aluminum in sericite than in plagioclase per unit volume; however, since part of

the original feldspar crystals are occupied by calcite, such an introduction can be determined only by chemical analyses. The sodium present in the plagioclase has been leached. The disseminated pyrite present in some of the altered feldspars must represent a migration of iron and an introduction of sulphur.

The minerals present in the altered tonalite show that the solutions producing the alteration carried sulphur, carbonate, and potassium and that they leached sodium and magnesium. Possibly, however, part of the potassium which has been introduced into the bleached zones has migrated into these zones from large volumes of green zone alteration. This potassium would have been derived entirely from biotite and hornblende. Nonetheless, some potassium has been supplied by the altering solutions because in some places where there are many close-spaced veins or fractures wide bleached zones are surrounded by very narrow green zones. Possibly the potassium in the solutions was originally derived from large volumes of green zone alteration at depth; although if these solutions were related to late magmatic activity, they probably carried potassium from their source.

The chemical gains and losses in the altered tonalite at the Buffalo Mine are similar to those described at many other mining districts. Lindgren (24, p. 690) in an early paper on the subject stated that the most prominent metasomatic processes around fissure veins are a progressive elimination of sodium and a concentration of potassium. Schwartz (37, p. 212-226), in a more recent summary of published data on wall rock alteration, states that the usual tendency in wall rock

associated with ore deposits has been a decrease in calcium, magnesium, and sodium, and in potash-poor rocks, an increase in potassium. He notes little change in iron, aluminum, and silicon. Steidtman (39, p. 397-399) concludes that the predominant chemical changes at Morenci, Bingham, and Cripple Creek are a progressive increase in potassium and silica and a progressive elimination of calcium, magnesium, sodium, iron and aluminum.

Alteration characterized by a decrease in calcium, magnesium, and sodium has been described as occurring in a monzonite porphyry at San Manuel, Arizona (36, p. 33); in a chlorite-epidote schist surrounding the pyrite deposits of Kyshtim, Russia (40, p. 628-631); in a quartz monzonite at Bagdad, Arizona (1, p. 617); and in a quartz monzonite at Butte, Montana (34, p. 25-27). Findlayson (8, p. 338) describes a decrease in sodium and magnesium in the altered lavas of the Hauraki gold fields of New Zealand.

Potassium was reported to be concentrated in the altered wall rock at San Manuel (36, p. 33-34), Kyshtim (40, p. 628-631), and Bagdad (1, p. 617). At Butte potassium has apparently remained constant.

Movement of Elements

Elements can move through solid rock in three ways:

(a) In supercapillary-sized openings and cracks in rocks, material in solution can be moved by the bodily movement of the solution through the openings.

(b) In solid rock capillary-sized pores and according to Holser (15, p. 390) many smaller submicroscopic cracks a few molecules wide are available. These cracks are thought to originate thermally, mechanically, and by primary growth. They occur within single crystals as well as along the boundaries between different crystals. In these openings the method of transfer is thought to be by ionic diffusion of a solute through a solvent. This movement depends on temperature and the concentration gradient of the ions concerned. Garrels (9, p. 1827-1828) found that in laboratory experiments this intergranular diffusion can be an effective method for movement of ions and that significant quantities of material can be transferred over distances measured in feet during time intervals measured in tens of years even at room temperatures. He estimates the maximum distance of penetration of an effective concentration front of any ion at a temperature of 100°C. to be more than 2 miles in 1,000,000 years.

(c) A third method of ion migration is through crystal lattices. This process is believed to depend on defects in the lattice structures such as ions interstitial to normal lattice positions or vacancies in normal lattice positions. This lattice disorder increases with increasing temperature. Diffusion of ions through crystal lattices involves the continuous movement of ions from one interstitial or vacant position to another. Many geologists question the effectiveness of this process.

All three of these methods of movement may reasonably have been

effective in producing the minerals characteristic of the altered tonalite, but one cannot determine just how relatively effective each method may have been.

Nature of the Solutions

The role of a gas phase in producing the alteration zones in the tonalite is not known. Likely hot solutions were responsible for the alteration, at least in that part of the rock where there has been leaching as well as addition of elements.

The acidity of the solutions related to ore deposition has been a subject of discussion for many years. Graton and Bowditch (12, p. 678), Hurst (16, p. 682), and Lindgren (25, p. 457) have suggested that sericite forms under alkaline conditions. Gruner (13, p. 578-589) has shown in laboratory experiments that sericite may form by alteration of feldspars in both acid and alkaline solutions. His experiments indicate that sericite can form at high temperatures in acid and alkaline solutions and at somewhat lower temperatures in alkaline solutions rich in potassium and aluminum. Kerr (19, p. 331) and Sales and Meyer (33, p. 272) agree with Gruner's findings.

According to Schwartz (38, p. 204) and Stringham (41, p. 661-664) chlorite forms under slightly acid to slightly alkaline conditions over a wide range in temperatures.

Calcite is stable under neutral or slightly alkaline conditions. Since calcite, as well as chlorite and sericite, occurs in the altered tonalite, the solutions producing the alteration probably were neutral

to slightly alkaline.

Alteration and Atomic Structure

The order of alteration of the minerals in the tonalite is hornblende-biotite-plagioclase. This corresponds to the inosilicate-phyllosilicate-tectosilicate sequence which is characterized by an increasing number of oxygen atoms mutually shared between adjacent silica tetrahedra. Keller (21, p. 787-793 and 22, p. 16-18) has shown that the energies of formation of bonds between the more basic metals and oxygen are relatively small, that aluminum-oxygen bonds have an energy of formation which is somewhat higher, and that the energy of formation of silicon-oxygen bonds is the highest of the three. Apparently, therefore, the stability of the silicates and their susceptibility to alteration are related to their energies of formation. The order of alteration of the minerals is also similar to the reaction series presented by Bowen (4, p. 177-198). Goldich (11, p. 55-56) has pointed out that the order of Bowen's reaction series corresponds to minerals with increasing stability. Goldich called this the stability principle.

The alteration of hornblende to chlorite or antigorite may involve only the breaking of the metal bonds joining the major structural units and a regrouping of these double tetrahedral chains into sheets, each of which becomes joined to a brucite layer through mutually shared oxygen atoms. The hornblende changing from an alteration of antigorite to an alteration of chlorite may possibly be the

result of an increasing replacement of silicon and magnesium by aluminum. The additional layers in the more complex chlorite structure may have formed in response to charge excesses and deficiencies produced by the increase in aluminum.

The alteration of biotite to chlorite may involve only the replacement of the potassium layers by brucite layers, having a net plus-charge as the result of replacement of magnesium by aluminum. Because calcite and pyrite form crystals elongate parallel to the cleavage, sulphur, calcium, and carbonate probably began penetrating the biotite crystals along the relatively weak-bonded potassium layers. The muscovite must represent the same structural changes except with more potassium and less magnesium to fit into the structure.

The alteration of feldspar to sericite involves the breaking of at least some of the silicon-oxygen and aluminum-oxygen bonds and a regrouping into the phyllosilicate structure.

Alteration of the Argillite

The hydrothermal alteration of the argillite was not studied in great detail because this alteration is somewhat restricted in occurrence and because the alteration products are very fine-grained and are difficult to study.

The argillite in the shear zones and within several feet of the veins is lighter gray than the rest of the argillite. The secondary biotite produced during the regional metamorphism of the rock has been altered to sericite which forms complete pseudomorphs after the small

biotite crystals. Pyrite and calcite form tiny elongate crystals within the sericite. Pyrite also occurs as anhedral to euhedral crystals disseminated abundantly throughout the altered argillite. The quartz grains in the argillite occurring in the shear zones exhibit extreme granulation.

Some chlorite replaces the biotite but there are no well defined chlorite zones.

Where the argillite has been most intensely altered it has a silky luster. This luster is produced by the large amount of sericite in the rock. The sericite in this highly altered rock replaces quartz as well as biotite. It commonly forms along the boundaries between adjacent quartz grains. When viewed under high power magnification these tiny sericite flakes are seen to penetrate into the quartz crystals. Some veinlets of calcite also occur in this highly altered argillite. The argillite exhibiting this intense alteration is very restricted in occurrence. It is not developed even in many of the argillite fragments contained within the vein material. Apparently the argillite was not nearly so susceptible to alteration as was the tonalite. The susceptibility of the argillite to alteration was probably influenced by the large amount of quartz, a very stable mineral, contained in it and by the dense, fine-grained character of the argillite.

Potassium, aluminum, carbonate, and sulphur have been introduced into the altered argillite. The magnesium from the biotite has been leached. These gains and losses are very similar to those in the altered tonalite.

Summary

The wall rocks surrounding the veins at the Buffalo Mine have been leached of magnesium and sodium and have gained sulphur, carbonate, and potassium. Aluminum has also been introduced in some places. These gains and losses are best indicated by the various alteration products of the hornblende, biotite, and plagioclase in the tonalite. In the beginning stages of alteration the hornblende has been altered to a magnesium-rich chlorite (variety jenkinsite), antigorite, and other minerals minor in amount. The chemical gains and losses are only apparent nearer to the veins where chlorite (varieties diabantite and repidolite), muscovite, calcite, and pyrite replace hornblende and biotite and where calcite and sericite replace the plagioclase.

The alteration surrounds northeast-striking faults and fractures as well as veins, and, therefore, no definite relationship exists between the vein mineralization and the wall rock alteration.

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