Geology and Mineralization of the Pine Grove-Rockland Mining Districts, Lyon County, Nevada

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geology

by

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in

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<table>
<thead>
<tr>
<th>CONTENTS</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGNATURE PAGE</td>
<td>i</td>
</tr>
<tr>
<td>CONTENTS</td>
<td>ii</td>
</tr>
<tr>
<td>Illustrations</td>
<td>iv</td>
</tr>
<tr>
<td>Plates</td>
<td>vi</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>vii</td>
</tr>
<tr>
<td>Abstract</td>
<td>viii</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Previous Work</td>
<td>4</td>
</tr>
<tr>
<td>Scope of Paper</td>
<td>4</td>
</tr>
<tr>
<td>History and Production</td>
<td>5</td>
</tr>
<tr>
<td>GEOLOGIC HISTORY</td>
<td>10</td>
</tr>
<tr>
<td>GEOLOGY</td>
<td>11</td>
</tr>
<tr>
<td>General Statement</td>
<td>11</td>
</tr>
<tr>
<td>Mesozoic Rocks</td>
<td>12</td>
</tr>
<tr>
<td>Quartz Diorite-Granodiorite</td>
<td>14</td>
</tr>
<tr>
<td>Alaskite Dikes</td>
<td>15</td>
</tr>
<tr>
<td>Microgranite Dikes</td>
<td>17</td>
</tr>
<tr>
<td>Rhyolite Porphyry Dikes</td>
<td>18</td>
</tr>
<tr>
<td>Andesite Dikes and-Sills</td>
<td>16</td>
</tr>
<tr>
<td>Cenozoic Rocks</td>
<td>20</td>
</tr>
<tr>
<td>Basal Limestone</td>
<td>20</td>
</tr>
<tr>
<td>Vitrophyre</td>
<td>21</td>
</tr>
<tr>
<td>Quartz Latitic-Rhyolitic Welded Tuffs</td>
<td>22</td>
</tr>
<tr>
<td>Hornblende Andesite</td>
<td>26</td>
</tr>
<tr>
<td>Sediments</td>
<td>26</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Quaternary Rocks</td>
<td>28</td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>29</td>
</tr>
<tr>
<td>ORE DEPOSITS</td>
<td>33</td>
</tr>
<tr>
<td>Pine Grove (Wilson-Wheeler Mines)</td>
<td>33</td>
</tr>
<tr>
<td>Rockland Mine</td>
<td>44</td>
</tr>
<tr>
<td>A Comparative Tabulation of Observations and</td>
<td></td>
</tr>
<tr>
<td>Conclusions of the Wilson-Wheeler Deposit</td>
<td>55</td>
</tr>
<tr>
<td>and the Rockland Deposit</td>
<td></td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>57</td>
</tr>
</tbody>
</table>
The Pine Grove Mining District, twenty-one miles south-southeast of Yerington, Nevada, was discovered in 1866 and produced approximately $5,000,000 in gold and silver, with nearly all the production during the pre-1900 era. Rockland, three miles southeast of Pine Grove, was founded in 1869 and produced an estimated $700,000 to $900,000 in gold and silver. Pine Grove is a mesothermal camp associated with a Mesozoic pluton, whereas Rockland is an epithermal camp associated with Tertiary rhyolites.

The area is principally comprised of a composite Mesozoic pluton, considered an eastern extension of the Sierra Nevada intrusions. Later andesite dikes and sills, alaskite dikes, porphyritic microgranites and rhyolite porphyries intrude the older "basement" rock of the pluton.

Tertiary limestones are overlain by rhyolitic ash-flow tuffs, and late Tertiary fluviolacustrine deposits on the east flank of the Pine Grove Hills.

All units have undergone several stages of faulting. The oldest period of faulting localized the Pine Grove mineralization. Post-ore faulting which has dislocated the mineralization is observed underground. A major range front fault is a suspected conduit for the rhyolite eruptions. Basin and Range, north-south trending normal faulting has displaced the Cenozoic structure leaving irregular patches of rhyolite and Tertiary sediments as terraces and remnant buttes. A number of prominent
Pediment surfaces have been offset by recent faults.

Alteration studies at Pine Grove indicate propylitic (chloritic) alteration away from the veins, grading into potassic alteration (biotitization and sericitization) adjacent to the veins in the quartz monzonite. Alteration is restricted to within several feet of the veins. Rockland has little or no alteration in the basement rock, but pervasive alunitization occurs in a rhyolite erosional remnant southeast of the mine. The correlation of alunitic alteration to the mineralization is not definite due to lack of rhyolitic wall rock between the areas. At Rockland, a characteristic breccia is associated with the rhyolite dike-veins.

Comparison of the two mining camps clearly demonstrates the differences due to epithermal type mineralization at Rockland and mesothermal gold-quartz type mineralization at Pine Grove.
INTRODUCTION

Location and Accessibility

The Pine Grove Mining District is in the Pine Grove Hills, T9N - T10N, R25E - R26E, twenty-one miles south-southeast of Yer~ngton, Nevada (Figure 1). The area is now in Lyon County, although it was formerly included in Mineral and Esmeralda Counties. Access is gained from the Pine Grove Flat Road, twenty miles south of Yer~ngton. From here, an unimproved road leads southwest five miles directly to the camp. Rockland, located two and one half miles south-southeast of Pine Grove, is reached by traveling the same unimproved road from the Pine Grove Flat Road six miles south-southwest. The remaining area in the district is relatively inaccessible.

Maximum topographic relief of the area is approximately three thousand feet, with a maximum elevation at Rockland Peak of 8,520 feet and a minimum elevation in the northeast of 5,600 feet.
Figure 1: Index map of Nevada.
Figure 2. Index map for Pine Grove Mining District.

Scale 1:250,000
1 inch = 4 miles
Previous Work

The most thorough work published on the Pine Grove Mining District is by James M. Hill (1915) in USGS Bulletin 594. This is an eight page account discussing the geology, ore deposits, character of ore, and the alteration of the quartz monzonite.

Francis Church Lincoln (1923), describes the district and presents a bibliography, as does Vincent P. Gianella (1945), in his "Bibliography of Geologic Literature of Nevada." (Nevada Bureau of Mines and Geology Bulletin 43).


Moore (1969) mapped the geology of Lyon, Douglas, and Ormsby Counties. This work was published at a scale of 1:250,000 by the Nevada Bureau of Mines and Geology in cooperation with the United States Geological Survey as Bulletin 75.

Scope of Paper

A detailed study of the geology of part of the Pine Grove Hills area was conducted as background for a thorough investigation of the mineralization. During the
summers of 1970-1971, approximately 10 square miles were mapped at a scale of 1:6,000. Emphasis was placed on stratigraphy, structure, and alteration, which are the controlling factors for mineralization. This mapping was later reduced to include the immediate area of the two districts as no widespread correlations were apparent.

The Pine Grove and Rockland mining camps have formerly been considered to be similar and possibly occurring along the same structural zone. This study was performed in part to prove or disprove this theory, i.e. to make a comparative study of the two mineralized areas.

History and Production

William Wilson located claims on the north side of Pine Grove Canyon on July 9, 1866, having been told of the occurrence of gold by an Indian employed as handyman and woodcutter at the family ranch. Several days later, the Wheeler brothers wanted to be included in the strike and were told by Wilson to locate their claims on the south side of the canyon. Their mines in the end had nearly the same production.

When news of the strike reached Aurora, a typical mining boom started, however, when the miners reached Pine Grove they found the best ground already located and after a short stay many returned to Aurora. The
Prosperous boom days of the two mines were from 1866 to 1871. Population at the height of the boom was estimated to be one thousand.

By 1868 Pine Grove had two stamp mills and three arrastras, with another five-stamp mill being added in 1869. There were eight saloons in the town, with a dance hall in the middle. There were also three hotels, a Wells Fargo Office, a school house, and a large general store.

According to J. I. Wilson (1954), the Wilson Mine was worked to a depth of 200 feet with an estimated production of $3,000,000 prior to being sold to Cutting and Hudgens in 1900 for $50,000, while the Wheeler Mine was also worked to a depth of 200 feet with an estimated production of $2,000,000 prior to being sold to Pope and Talbot for $50,000. Since those times very little productive work has been performed, and the district now lies dormant.

In 1869, a Pine Grove resident, Mr. Kean, found a gold-silver deposit, three miles southeast of Pine Grove, which was later named the Rockland area for the red rhyolite cliffs in the canyon near the mine. Rockland grew into a lively little town of 150 people with a hotel, but it did not last long. Kean found himself unable to pay his miners' wages, and while he was away trying to raise money a disgruntled miner named Rhodes set fire to the mill. He was convicted and sent to state prison but Kean went further in debt and lost the mine. Ex-Governor H. G. Blasdel took over Kean’s interest and
reportedly suffered a loss, although there are no available production figures. Judge Moran produced the last $100,000 at Rockland in the 1930's. Since that time the area has seen little activity.

The total production of the Wilson and Wheeler Mines is very difficult to determine. Couch and Carpenter (1943) put the total production of the Pine Grove District (Wilson and Wheeler Mines) at $778,734. Stoddard and Carpenter (1950) in a more recent publication say that the figure indicates that much of the production was not reported to the State. They cite the example of the USGS figures for 1902 to 1911 inclusive showing a production of $163,741 while the State shows no record. Also one should note that in the earlier bulletin the production for 1866 to 1870, the period of greatest activity in Pine Grove, is missing because the Esmeralda County records were lost in a fire.

By an early State law, the mines were required to report all production, but many kept this figure as low as possible. Couch and Carpenter (1943) give figures for the district in 1870 at $27,912 and 1871 at $35,279. R. W. Raymond (1871, 1872) gives the production of the mills for 1870 at $400,000 and in 1871 he used the shipments of bullion by Wells Fargo and Company which was $137,672.

R. W. Landrum (1901) illustrates the problem of ascertaining production figures in a discussion of the
"The management at the start was anything but scientific and business like. No better evidence of the truth of the above statement need be offered than the fact that the only books kept by the company consist of mine receipts for bullion, and they were preserved only since the eighties, and then only those issued to the owners of the mine, the lessees, of whom there were many, having kept or destroyed their own receipts and the management kept no account of the product obtained by these numerous lessees; and the further fact that there was never an assay office in connection with the mill or mine, ----. Notwithstanding this strange and antiquated method of running a mine, it is safe to say that the product of the mine has been more than two millions of dollars. There is safely 100,000 tons of tailings below the mill, and many tons gone down the wash, and much of the ore, especially in the early history of the mine, has yielded more than $100 per ton while the average is estimated by the management to have been eighteen to twenty dollars per ton. A simple calculation, if these figures are correct, will show that the product has been $2,000,000 or more."

Upon checking all available data, the production figures quoted above by J. I. Wilson for the Wilson ($3,000,000) and the Wheeler ($2,000,000) appear to be the most accurate estimates between the high of $8,000,000 (Mill, 1915) and the low of $398,123 (Couch and Carpenter, 1943).

Lincoln (1923) credits the Rockland Mine with a production of $700,000 up to 1921. Again, accurate production figures are difficult to obtain, but it appears that Lincoln's estimate is fairly reliable or possibly on the low side as W. W. Short (oral communication) said Judge Moran (1930's) produced, $100,000.

Therefore, in summary, a production estimate to the present of the Pine Grove-Rockland Mining District appears to be approximately six million dollars.
<table>
<thead>
<tr>
<th>Mines</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilson Mines</td>
<td>$3,000,000</td>
</tr>
<tr>
<td>Wheeler Mines</td>
<td>2,000,000</td>
</tr>
<tr>
<td>Rockland Mines</td>
<td>1,000,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$6,000,000</strong></td>
</tr>
</tbody>
</table>
GEOLOGIC HISTORY

More than 100 million years ago, but probably less than 140 million years ago, the area that is now occupied by the Pine Grove Hills was intruded by a batholithic complex. The ages of the various phases are not known, other than the younger quartz monzonite porphyry reported by Schilling (1971) to be in the 90 million year range. Quartz diorite-granodiorite and quartz monzonite phases are the main complex with later associated alaskite, rhyolite porphyry, and porphyritic microgranite dikes and sills. Later andesite dikes and sills intruded the quartz monzonite in the Pine Grove area. Shortly afterwards the ore forming solutions were introduced along shear zones in the quartz monzonite at Pine Grove, altering and mineralizing the rocks.

Erosion followed, and several thin layers of "basal limestone" were deposited. Less than 15 million years ago faulting occurred which served as the plumbing system through which the rhyolite ash-flows were extruded. A rhyolite dike grades into the flow at Rockland Peak. Following the introduction of this rhyolite dike at Rockland brecciation and associated gold-silver mineralization took place.

Later faulting continuing to the present produced the present topography and the gravel capped terraces.
GEOLOGY

General Statement

The principal bedrock of the Pine Grove-Rockland area is a batholithic intrusive. The large size of the intrusive body and its composite nature suggest that these plutonic rocks may be an eastern extension of the Sierra Nevada batholith.

Porphyritic microgranite, rhyolite porphyry, alaskite, and aplite dikes intrude the batholith as late differentiates or as separate intrusions. Andesite dikes and sills also cut the intrusive. These andesites are pervasively altered (biotitization), yet do not appear themselves to be mineralized. The batholithic rock and the andesite show both intrusive and fault contacts.

The lowermost unit of the Tertiary sequence is a sandy limestone containing ostracods of Barstovian to Clarendonian age. The erosional remnants indicate a maximum thickness of twenty feet.

Lying unconformably above this sequence is a basal vitrophyre which underlies a series of quartz latitie-rhyolitic tuffs (See Figure 4). Arkoses and-or reworked volcanics are associated with these tuffs in the Rockland area. A rhyolite dike at Rockland appears to have served as a source conduit for at least one of the flows. The vitrophyre attains a maximum thickness of five feet while the thickest section of tuff is nearly five hundred feet.
The easterly flank of the Pine Grove Hills is underlain by a homocline of west-dipping Tertiary sediments. These sediments are correlative with the Coal Valley Formation (Axelrod, 1956) and are younger than the rhyolitic tuffs, having been eroded to a pediment surface. Basin and Range faulting caused rejuvenation which is offset by recent faulting with subsequent dissection of the pediment. The dissected canyons provide good exposures, with several hundreds of feet of sequence seen in one canyon (See Figure 4).

**Mesozoic Rocks**

The oldest rocks exposed in the Pine Grove-Rockland area are Mesozoic in age. They are probably all Cretaceous in the Pine Grove Hills, and form a composite batholith having features comparable to the plutonic complex of the Sierra Nevada batholith.

Evernden and Kistler (1970) state:

"The potassium-argon ages of minerals from Mesozoic granitic rocks in California have a continuity from 210 to 80 million years ago. However, a distinct periodicity of magma generation and intrusion is shown when the ages are related to the distribution of genetic groups of plutons based on geologic mapping. Five epoches of magma generation and emplacement that took from 10 to 15 million years to complete were initiated at approximately 30 million year intervals. Each intrusive epoch was preceded by or was in part contemporaneous with, a period of regional deformation in California or Western Nevada."
Figure 3. Photograph of terraced Tertiary sediments on east flank Pine Grove Hills with Rockland Peak in background (Looking SSW).

Figure 4. Photograph of northeast dipping rhyolitic tuffs with underlying 5 foot thick basal vitrophyre (Looking NW).
The Pine Grove area may exhibit a similar igneous-tectonic history in that the granitic sequence includes quartz diorite-granodiorite, rhyolite porphyry dikes, and andesite dikes and sills. The majority of this sequence is quartz monzonite and granodiorite. Kruger and Schilling (1971) date the porphyritic quartz monzonite on the west side of the range at 90± million years. No exposures of this rock are present in the area under study. Moore (1969) states that this age-dated porphyritic quartz monzonite is clearly seen to be younger than, and intrusive into, the granodiorite in the canyon of the East Walker River south of the area under study.

**Quartz Diorite - Granodiorite Pluton**

The probable earliest intrusion in the area mapped is a medium grained quartz diorite-granodiorite. Petrographically this rock is allotriomorphic granular and slightly porphyritic, consisting of a few large zoned plagioclase phenocrysts (up to 5 mm) in a finer-grained allotriomorphic groundmass of plagioclase, quartz, biotite-hornblende, and minor potash feldspar. Plagioclase, normally zoned in the andesine range \((An_{48-57})\), makes up 42% of the rock. Quartz forms much of the groundmass interstitial to the larger plagioclase grains and comprises 24% of the rock. Biotite and hornblende each make up about 14% of the rock, whereas the potash feldspar (orthoclase) constitutes up to 6% of the rock as an interstitial component in the groundmass.
What can be considered the normal quartz monzonite seen in the area of study has an allotrimorphic granular texture and an average mode of: plagioclase (35%), potash feldspar (25%), quartz (23%), biotite (16%). The finer-grained quartz monzonite in some areas of the Wilson-Wheeler mines grades into normal quartz monzonite, but the exact nature of the contact is not readily apparent due to a masking effect from alteration and oxidation.

The quartz diorite-granodiorite and the quartz monzonite are difficult to differentiate megascopically. The composition of these rocks appears to have a wide variation and microscopically one can see the borderline problem. One representative thin-section has a mode of: quartz (38%), plagioclase (23%), potash feldspar (12%) and biotite (19%). A very slight change in composition one way or the other gives a granodiorite or a quartz monzonite. One answer may be that these are local chemical variations in a single pluton or as Evernden and Kistler (1970) point out for the Sierra Nevada, these variations may represent separate epochs of magma generation and emplacement. If this is so, the contacts are obscure due to lack of outcrops and masking by alteration and oxidation. Considering these as distinct units rather than part of a complex is confusing and petrographic differences are misleading, therefore they have been treated as a single unit.

Alaskite Dikes

Several small alaskite dikes intrude the granitic
sequence. They are medium to coarse-grained, allotriomorphic granular granite consisting of anhedral microperthitic potash-feldspar (microcline 36% of rock), displaying well developed graphic intergrowths with quartz, anhedral plagioclase (17%) and anhedral strained quartz (total quartz 47%) (See Figure 5).

Microgranite Dikes

Rock that megascopically appears to be a rhyolite porphyry is common as dikes and sills in the Pine Grove area. In thin section the rock is seen to be an acid hypabyssal porphyritic rock containing phenocrysts of plagioclase (oligoclase, An14, 40% of phenocrysts), slightly perthitic orthoclase (40%), and quartz (20%) set in a fine-grained groundmass of predominantly myrmekite with some individual plagioclase and quartz grains. Small patches of sericite occur scattered throughout the section. From the texture of this rock it is postulated that an acid magma started cooling at a moderate depth, phenocrysts began to form, and the rock then intruded to a shallower depth where it cooled fairly rapidly at which point predominant potash feldspar and small plagioclase crystals formed which immediately reacted with each other to produce the ubiquitous myrmekitic intergrowths in the groundmass. The petrographic name for this rock should be a porphyritic microgranite (Figure 6).
Rhyolite Porphyry Dikes

Several other narrow rhyolite porphyry dikes are present. In thin section they exhibit a slightly glomeroporphyritic texture. Phenocrysts comprise 20% of the rock with plagioclase (88% of the phenocrysts) occurring in scattered glomeroporphyritic clots or as individual grains, that commonly display rounded and corroded margins. Eight percent of the phenocrysts are quartz which are rounded, embayed, corroded, and commonly display strain features. Biotite (4% of the phenocrysts) occurs as anhedral patches consisting of irregular interlocking mosaics of small biotite grains which possibly indicate some sort of re-crystallization process, perhaps of earlier, larger biotites. In several instances, this biotite occurs as minute stringers throughout the groundmass so it must have been a fairly late generation biotite. The groundmass is a cryptofelsitic matrix probably consisting of quartz and potash feldspar. (See Figures 7-8). The term rhyolite porphyry for these Mesozoic rocks may be misleading, but their aphanitic groundmass lead this author to the use of the above term rather than that of a "granite porphyry."

Andesite Dikes and Sills

Andesite dikes and sills cut the quartz monzonite in the Wheeler area. Fresh surfaces are dark grey, often nearly black, while many outcrops are altered and oxidized to a grey to greenish-black color with brown staining along
joint planes and fractures. The greenish-black alteration mineral is secondary biotite. Thin sections consist almost entirely of plagioclase, biotite, and minor quartz and epidote. It is a hypidiomorphic granular rock having plagioclase phenocrysts, which show replacement by biotite and amphibole, set in an interlocking matrix of fine-grained subhedral plagioclase laths and scattered interstitial patches or grains of quartz epidote (commonly associated with the quartz patches). The rock is pervaded by very fine-grained biotite and opaques. The andesite dikes and sills, like the monzonite, are cut by the veins at Pine Grove but do not show the mineralization as seen in the "basement" rock. The mineralization at Pine Grove is associated with shear zones in the quartz monzonite. The andesite is not sheared and this could be a major factor in the lack of ore in the andesite.

Cenozoic Rocks

Basal Limestone

The lowermost unit of the Tertiary section is a sandy limestone. This unit occurs as several small isolated outcrops in the Pine Grove (Wilson-Wheeler) area, possibly indicating either a deposition in small, local ponds or basins, or an outlier as the result of extensive erosion. Ostracods (Crytheridea Haplocrytheridea subovata) were found in exposures in the canyon north of the Pine
Grove cemetery, indicating a Barstovian-Clarendonian (late Miocene to early Pliocene) age. Maximum thickness for this section is less than twenty feet. It overlies the quartz monzonite and underlies the vitrophyre and rhyolitic tuffs.

Vitrophyre

A series of volcanic rocks overlie the limestone. They are characterized by columnar structure and dark-red or brown weathered surfaces. The basal member of this series is a highly distinctive flow of black porphyritic glass, which attains a maximum thickness of five feet. It rests on the limestone where that member is present, although this relationship is not often seen in the field. More commonly the vitrophyre lies directly on the Cretaceous intrusives. It occurs at widely spaced localities and is therefore an excellent horizon marker.

Knopf (1918) describes similar vitrophyres in the Yerington District as:

"...strikingly fresh, being coated only with a thin film of decomposition products. It consists of black lustrous glass carrying numerous crystals of plagioclase and splendent foils of biotite. Under the microscope the vitrophyre shows a marked fluidal structure, which in its swirls enloses many phenocrysts, mainly of plagioclase, biotite, and pyroxene. The plagioclase, of the composition An50, predominates; it is generally more or less angular, but some of it is partly embayed. Sanidine occurs sparsely in some thin sections but is absent in others, and it is evidently a rare constituent of the vitrophyre. Biotite, commonly bent, is the chief ferromagnesian mineral. Both augite and orthorhombic pyroxene, which is either bronzite or..."
enstatite, are present also hornblende, magnetite, and apatite are accessory minerals. The vitrophyre is a highly flow streaked, deep-brown to green glass alternating with light, almost colorless streaks. The microscope fully confirms the megascopic impression that the rock is ideally fresh."

An analysis made by the Geological Survey shows the Yerington vitrophyre to have a high potassium and silica content indicating a quartz latite composition.

**Quartz Latitic-Rhyolitic Welded Tuffs**

A distinctive series of ash-flow tuffs followed or were contemporaneous with the eruption of the vitrophyre. These tuffs are white to reddish-brown and commonly show joint patterns. They are porphyritic, containing numerous crystals of sanidine, plagioclase, quartz and biotite. A specimen taken from the basal section of those tuffs immediately above the vitrophyre is seen microscopically to be a rhyolitic vitric tuff. Light greyish-brown devitrified felsic material comprises the groundmass which is 96% of the rock. Quartz predominates among the phenocrysts, amounting to 50% of the total, while sanidine comprises 30%, and plagioclase (albite oligoclase range) 20%.

Throughout the tuffs local variations are seen. Some are less crystal rich and lack pumice fragments which are devitrified. The marked banding in some is produced by the devitrification of welded pumice fragments. Figure 9 shows a densely welded, crystal poor, vitric tuff. The
Figure 9. Photomicrograph (sample #49) of densely welded, crystal poor, vitric tuff. Thin streaks or zones of tridymite indicate devitrification or vapor phase crystallization. (10X)
phenocrysts comprising 2% of the section are plagioclase in the albite-oligoclase range (70% of the phenocrysts), biotite as slender laths, and a trace of sanidine. The remaining 98% of the section is groundmass and includes microlites of plagioclase, biotite, and sanidine. Tridymite, making up 15-20% of the matrix, occurs as well developed streaks or zones and may mark highly compressed original pumice fragments. The tridymite might be a devitrification product, or, from its appearance, a vapor phase crystallization product formed during the later stages of cooling of the ash flow. Coarse-grained devitrification products (feldspar and tridymite or cristobalite) often develop in the pumice fragments of welded tuffs; finer-grained products are found in the shards. The alteration of these minute tridymite lenses and the darker-brownish less devitrified glass gives the overall "banding" appearance.

The margins of these tridymite "lenses" or streaks are generally lighter brown than the surrounding glassy matrix suggesting the oxidation of an original pumice margin. Slightly devitrified medium brown glass completes the remaining 75-85% of the matrix.

The tuffs are best observed along the east flank of the Pine Grove Hills, in the eastern half of the area mapped. Due to post-depositional faulting they are not continuous, but tend to dip to the east at moderate inclination. Numerous exposures show prominent columnar jointing
in the lower portion of the section.

The main structure of the Rockland Mine is occupied by a rhyolite dike which is chemically similar to the rhyolitic tuffs except that it has been silicified and pyritized by the ore fluids and that it exhibits a lack of ash flow characteristics. This dike intrudes the quartz diorite–granodiorite intrusive.

Volcanic sandstones or grits occur in several localities in the Rockland area in addition to coarser pyroclastics within the tuff sequence. Microscopically, fragments (averaging 1.5 mm) of angular to subrounded quartz, plagioclase, and potassium feldspar are seen set in a dense, fine-grained siliceous matrix. Samples contain pumice fragments, and some show considerable argillization. A good degree of sorting occurs and these are probably local ash fall tuffs with some later reworking. They are classified thus due to their pyroclastic composition and pronounced bedding. Maximum exposed thickness of this sequence is approximately twenty-five feet. This unit was not mapped separately due to its limited extent within the overall tuff sequence.

From the stratigraphic relationships of the rhyolite tuff with respect to the Ostracod bearing limestone, the postulated age is 15 million years or less; however, C. M. Gilbert (oral communication) is age dating an exposure of this rhyolite from Sugarloaf (the prominent rhyolite peak east of Pine Grove), and expects it to be younger than 6.5 million years on the basis of regional structural and stratigraphic inferences.
Hornblende Andesite

Hornblende andesite occurs as several thin dikes (less than 5 feet thick) intruding the quartz diorite in several areas in the canyon due south of the Wilson Mine at Pine Grove.

This rock is a grey andesite characterized by numerous slender prisms of hornblende in roughly parallel orientation and averaging five millimeters in length. It contains no feldspar phenocrysts. Under the microscope the hornblende is seen to be embedded in a holocrystalline fluidal groundmass composed largely of plagioclase prisms in the andesine-labradorite ($\text{An}^{50}$) range of composition together with subordinate augite and accessory magnetite and apatite. Within this province, E. Bingler (oral communication) brackets these hornblende andesites in a five to twenty million year age. These dikes are probably associated with the andesite tuffs characteristic of Axelrod's Coal Valley Formation.

Sediments

The entire northeast flank of the Pine Grove Hills is covered by west-dipping lacustrine and fluviatile Tertiary sediments consisting of light-colored clays, siltstones and fine-grained sandstones associated with pumice beds and diatomaceous shale. Thin-bedded coarse-grained sandstones, andesite tuffs, breccias and agglomerates interrupt a primarily lacustrine environment. These sediments are
thought to be correlative with the Coal Valley Formation.

At the type locality the Coal Valley Formation rests on andesites, which are in turn being underlain by rhyolitic tuffs. Axelrod (1965) cites these as critical observations for two important reasons:

"In the first place, these andesites and andesitic sediments appear to be identical in all respects with those which are well developed in the Pine Grove and Sweetwater ranges 10 to 15 miles west, and in the Sierra Nevada farther west. This formation has been traced westward into the Sierra Nevada and clearly represents part of the late Tertiary Sierran andesite (Mehrten Formation). Comparison of the andesites at Coal Valley with the Kate Peak (Sierran Andesite) demonstrates that they cannot be distinguished in thin section. In brief, the hornblende andesites which are interbedded in the Coal Valley Formation and which represent its basal member at the west, are considered to represent part of the late Tertiary Sierran andesite. In the second place, it is well known that the Sierran andesite rests on the rhyolitic Valley Springs formation in the Sierra Nevada, which is of Mio-Pliocene age. --- the upper half of the Aldrich Station Formation contains several rhyolite tuffs, and they occupy a stratigraphic position similar to the massive rhyolite tuff which underlies the Sierran andesite. A correlation of these rocks is strongly indicated, and is supported fully by the evidence of the age of the Aldrich Station Formation."
incline driven down the dip of the bed.

These Tertiary sediments are the least erosion-resistant rocks of the pre-Pleistocene section. Remnant terraces and buttes of these Tertiary sediments are capped by resistant gravels of an old Quaternary alluvial sequence.

Quaternary Rocks

Older alluvium occurs as high gravels found capping the Tertiary sediments. These gravels are derived from the Mesozoic "basement" rocks and rhyolites to the west.

Recent alluvial material is seen east of the Pine Grove Hills. This material consists essentially of alluvial fan gravels, stream laid gravels, and unconsolidated sand and silt derived from the Tertiary sediments and volcanics and the Mesozoic "basement" rocks.
STRUCTURE

The average trend of the Sierra Nevada is N.25°-30°W., while the ranges of the Great Basin trend approximately north to N.20°E. For a distance of at least 300 miles these two trends converge. This zone of convergence, approximately 50 miles wide, is seen topographically as discontinuous, often arcuate ranges of random orientation in the mountains to the east of Pine Grove Hills, and is known as the Walker Lane. The Pine Grove Hills are an eastern extension of the northwest trending Sierra Nevada province lying to the west of the Walker Lane.

The Pine Grove Hills trend N.25°W. and are characteristic of the Sierra Nevada Province, however their narrow width is characteristic of the Basin and Range province. They are a southern continuation of the Singatse Range and exhibit similarities. In general they constitute a west-tilted fault block.

The structure to the west of Rockland is horst-like, with a high central plateau of granitic rock bounded by down-dropped blocks, which are in turn capped by Tertiary sediments and volcanic rocks. This is somewhat characteristic of Basin and Range structure. The Pine Grove Hills exhibit a complex structural history and are typical of a range bordering the Sierra Nevada and the Basin and Range provinces.

There are essentially six mappable fault sets in the Pine Grove Hills. The oldest served as the major plumbing
for the mineralizing fluids at Pine Grove. This system of faulting is seen in the underground workings (See Plates 4-9) striking N40°W to N70°W with dips ranging from steep southwest to gently northeast. Most are inclined 20 to 70 degrees northeast. With their occurrence exclusively in the quartz monzonite the direction of displacement has been impossible to ascertain. The faults typically curve and split in a braided pattern. At Pine Grove the high grade orebodies appear to be in flat lying portions of the braided faults.

Slightly premineral complementary N-E faulting destroyed the continuity of this original faulting making individual structures extremely difficult to follow for any considerable distance. The faults appear to be oblique-slip structures. Irregularities along these faults permitted the formation of openings which by a decrease in pressure allowed the precipitation of minerals from the ore solutions.

A zone of post-ore faulting in the Wheeler area struck N60°W to E-W with a steep northward dip. In the ravine northeast of A-6600, there is a line of prospect pits trending N70°W showing this strong post-ore faulting. Northeast of this area there has been no production, thus this fault zone marks the northeastern termination of the ore deposits (See Plate 1). This fault zone probably also occurs north of the Wilson area.

At Rockland, a north-south to N30°E fault structure dipping 45 to 70 degrees to the east-southeast was the
controlling structure for the intrusion of the rhyolite dike (See Plate 2).

Later faulting parallel to the trend of the range, forms a major portion of the contact between the Cretaceous and the Tertiary. These normal faults are downdropped to the east.

Several oblique-slip faults striking N.15°E are present in the Pine Grove area (See Plate I). These faults step blocks of rhyolite to the south. Also and most important, they have cut the Pine Grove ore deposit into two blocks, the northwest block (Wilson) and the southeast block (Wheeler).

North-south Basin and Range faulting occurs along the east flank of the range. Field investigations indicate this faulting was probably initiated in Pliocene and continued to Holocene.

Drs. C. M. Gilbert and M. W. Reynolds are presently conducting a thorough study of the Late Cenozoic evolution and interrelationships of the structural basins near the western margin of the Great Basin in an attempt to date these Basin and Range structures.

A brief summary of the faulting follows:

Youngest: 1. Marginal Basin and Range faulting along the east flank of the range.

2. N.15°E oblique-slip faulting which split the Pine Grove deposit into a southeast block (Wheeler) and a northwest block (Wilson).
3. N.20°-30°W normal faulting. This produced the existing Cretaceous-Tertiary contact.

4. North-south to N.30°E fracture system dipping 45-70 degrees east-southeast. This was the controlling structure for the Rockland dike.

5. N.60°W to E. W. with a steep northward dip. These are post mineral and appear to terminate the northeastward extension of the ore deposits at Pine Grove.

6. N.40°W to N.70°W., dipping 20 to 70 degrees northeast, and also minor N-E. These structures served as the localizing structures for the mineralization at Pine Grove.
ORE DEPOSITS

Gold bearing quartz veins of two ages are present, comprising the ore deposits of the Pine Grove and Rockland Mining Districts.

Mineralization at Pine Grove (Figure 10) is typical of mesothermal gold-quartz deposits and exhibits similarities to the mineralization of the Mother Lode in the California foothills 100 miles to the west. Fine-grained, granular, milky quartz veins occur along shear zones in the quartz monzonite country rock. Propylitic and potassic alteration are characteristic of the mineralization.

Mineralization at Rockland (Figure 11) is typical of epithermal gold deposits associated with Tertiary vulcanism. Vuggy, crustified, glassy quartz veins have formed in a breccia in association with a rhyolite dike that intrudes quartz diorite-granodiorite and spreads out into rhyolitic flows at the surface. Little or no alteration is present in the "country" rock, however, a rhyolite outcrop 2000 feet to the southeast of the camp does have pervasive alunization.

Pine Grove (Wilson and Wheeler Mines)

The Pine Grove District is often referred to as the Wilson or the Wheeler District. In the youthful stages of the camp, they were developed as separate entities as the result of being faulted into two sections: a northwest section (Wilson) and a southeast section (Wheeler). These
Figure 10. Photograph of Wilson Mine, Pine Grove District with rhyolite outcrops to the northeast. The Wheeler Mine is located south of the canyon in the second ravine in the foreground of the photograph. Looking West.

Figure 11. Photograph of Rockland Peak area showing north trend of workings and rhyolite dike. The area near the summit, void of vegetation is the vitrophyre base of the rhyolite flow exposed by stripping. Looking NW.
sections are separated by horizontal fault displacement of approximately 1,000 feet, east block to the south. They are merely faulted sections of the same ore body.

The veins and veinlets strike northwesterly and dip 15° to 70° northeast. Locally these veinlets are sufficiently close to be mineable as a wider zone, leaving stopes with widths up to ten feet. The lack of continuity is the result of post-ore faulting off-setting the veins. Irregular stopes commonly are bounded by faults.

The majority of the underground workings were inaccessible during this study, however, Hill (1915) indicates that at the Wheeler Mine there are, in addition to the above mentioned veins, also lenses of quartz and pyrite two or three feet thick extending for strike distances of 10 to 150 feet. Such lenses contained good ore with the best grade occurring in those portions whose thickness is eight to ten inches. The lenses dip gently to the north at between 10° and 15°, and parallel the andesite contacts, thus indicating some of the veins followed the same shears along which the andesite dikes were intruded. McKinstry (1941) sampled a zone of stringers in adit A-6715 which averaged .177 oz/ton gold for a horizontal width of 80 feet; however, the true thickness was less than 10 feet.

At the Wheeler Mine these lodes are not continuous through steep faults to the northeast, which led McKinstry (1941) to conclude that either the lodes are branches of another vein, which have later been followed by faults, or...
that the steep faults cut off and displace the flat lodes, in which case their extensions would exist. The adits and prospect pits north of this zone encountered no significant mineralization, supporting the conclusion that the flat lodes are cut off and displaced by the steep post-ore faulting. It is possible that extensions to the north may be found at depth.

Later faulting displaces earlier fault-surfaces. The mineralized faults can rarely be correlated due to this later faulting. This lack of regularity and abundant post-ore faulting suggest deformation under a light load. This could be brought about by a pressure release due to unloading or by subsidence of the magma upon cooling.

The ore consists of small veinlets and large lenses of quartz, with abundant pyrite and lesser amounts of chalcopyrite. Pyrite and chalcopyrite occur as small grains ranging up to one-two millimeters in size. The gold always occurs closely associated with pyrite; however, the reverse relation is not true. This is merely indicative of the prolonged paragenetic sequence of pyrite. This was also brought out by a gravity concentrate study Mr. M. P. Allen, of the Nevada Mining Analytical Laboratory, conducted for Mr. W. J. Cavanaugh. In this study the gold was found to be contained in the sulphide concentrates.

McKinstry (1941) indicates that gold appears to be associated with chalcopyrite, as copper staining was the best indication for samples with gold values. Few samples
taken by McKinstry that were free of copper staining gave good gold assays; however, numerous samples with abundant copper staining gave poor gold assays. This indicates the mobility of copper sulphate.

Depth of oxidation (Hill, 1915) is approximately 170 feet. The surface outcrop is an iron-stained gossan. The products of leaching and oxidation are erratically distributed; fresh pyrite and limonite with well developed boxworks occur nearly adjacent to each other. This relationship is probably due to the descending solutions preferentially following local fracturing.

Ore microscopy (See Figure 12-15) indicates a genesis of early pyrite deposition, followed by chalcopyrite, then additional pyrite accompanied by gold. The gold occurs as intergrowths with the pyrite (as seen in several instances megascopically) and as separate anhedral rounded grains. These grains of gold vary in size to several millimeters. With oxidation of chalcopyrite, covellite forms as a secondary replacement. The hypogene silver minerals are pyrargyrite (Ag₃SbS₃) and argentite (Ag₂S), with native silver, cerargyrite (AgCl) and pyrargyrite as the supergene derivatives of these hypogene minerals. Ferguson (1929) indicates the workable silver at Pine Grove was of supergene origin. These supergene silver values are indicated by high fire assay and spectographic analyses of gossan material with no sulfides. State Mineralogist Reports do not indicate appreciable recovery of silver.
The quartz stringers are accompanied by a biotite alteration facies which gives the rock a dense, fine-grained texture, and a dark, nearly black color. Hill (op. cit.), after viewing this obvious correlation, concluded that the mineralization and the development of biotite are part of the same process. Very few of the quartz veins are free of this border effect alteration. The alteration is characteristic, but is not the typical widespread alteration seen occurring in conjunction with the southwestern porphyry copper deposits. The immediate area within the mine area shows scattered biotitization. Quartz monzonite showing fresh feldspar crystals occur within an inch to a foot of the veins. Epidote is sometimes associated with the biotitization and sericitization but is found chiefly outside the ore zone in sulphide-poor veins.

Petrography illustrates the intensity of the alteration, showing essentially two zones of alteration; a propylitic outer zone and a potassic inner zone. The outer zone is characterized by well developed chlorite, epidote and zoisite, with irregular stringy patches of fine-grained aggregated biotite (See Figure 16). This zone extends erratically several inches to several tens of feet outward from the veins. The feldspars are altered to sericite following the initial biotitization. The inner, more intensely altered zone is characterized by "ghosts" of potash feldspar and plagioclase, which have been completely altered to fine-grained mosaics of sericite and quartz (See Figure 17).
Figure 12. Photomicrograph of euhedral pyrite and chalcopyrite crystallizing around actinolite. Wheeler Mine (25.6X).

Figure 13. Photomicrograph (sample #773) of early pyrite being introduced along favorable sheared zones in the quartz monzonite. Pine Grove (16X).
Photomicrograph (sample #774) of anhedral gold (upper center) with fractured chalcopyrite. Covellite is occurring along the edges of the chalcopyrite. Pine Grove un-oxidized ore (51.2X).

Photomicrograph (sample #502) of gold in Pine Grove oxidized ore with abundant goethite along fine fault breccia. (25.6X).
Figure 16. Photomicrograph (sample #811) of propylitically altered Pine Grove quartz monzonite showing extensive development of epidote-zoisite and biotite. (10X, crossed nicols).

Figure 17. Photomicrograph (sample #812) showing potassic alteration of Pine Grove quartz monzonite with complete sericitization of K-feldspar, fine-grained aggregated biotite and recrystallized quartz. This sample indicates a high temperature alteration and was collected nearer the vein than Figure 16. (10X, crossed nicols).
This potassic zone is inferred to represent the thermal center of the system and extends erratically up to several feet outward. Orthoclase, biotite, sericite and quartz occur as pervasive replacements and veinlets within this zone. The matrix is a fine-grained mosaic of sericite and recrystallized quartz (polygonal patterns of quartz with abundant "triple points") with irregular stringy patches of fine-grained aggregated biotite. The overall fabric of the rock gives an impression of a preferred orientation of the larger replaced feldspar grains and the irregular interstitial biotite stringers and patches. This is indicative of the shear stresses exerted on the original quartz monzonite prior to or during mineralization. The secondary biotite forms at the expense of the ferromagnesian minerals, presumably, due to excess potassium and a well defined thermal gradient. It forms as discrete flakes in veinlets, as isolated replacements of individual mafic grains, and as pervasive aureoles bordering the stringers and veinlets. Potash metasomatism of the plagioclase forms orthoclase and sericite and releases sodium, which being extremely soluble may escape from the system. The alaskite dike or vein discussed in the "Geology" section could be a related outlet for the excess potassium (in the form of albite-oligoclase), thus indicating either a tightly closed system or lack of available chloride. An interesting note is that zones of albitization surround or flank the potassium-rich alteration facies at Yerington.
Biotite is characteristic of high temperature mineralization, however, other characteristic high temperature minerals such as garnet, amphibole, tourmaline, scheelite, and pyrrhotite are not observed. The occurrence of albite and the alteration of the ferromagnesian minerals to chlorite, biotite, and sericite are characteristic of Lindgren's mesothermal mineralization. The deposits have no diagnostic epithermal characteristics and therefore one is led to the conclusion that mineralization occurred in the mesothermal temperature ranges.

In summary, two facies of alteration are present, grading into each other, at Pine Grove. The outer zone is characterized by well developed chlorite, epidote and zoisite, with irregular stringy patches of fine-grained aggregated biotite. This could be called the propylitic zone which grades into a potassic zone. The potassic zone is characterized by "ghosts" of potash feldspar which have been completely altered to fine-grained mosaics of biotite, sericite, and quartz. The overall extent is several inches to several tens of feet. The alteration facies, character of the vein, characteristic ore minerals and textures place the Pine Grove ore deposits in Lindgren's mesothermal category of ore deposits.

Exploration possibilities exist for the down dip northern extensions of the flat lodes which have been cut by the high angle northeast fault zone. The alteration and abundant amounts of copper mineralization along with the
scattered albitization could be evidence to support the theory of the possibility of porphyry copper mineralization at depth, with the Pine Grove mineralization being a zonal feature.

**Rockland Mine**

The epithermal deposits in the Western states are often correlative with a large circum-Pacific zone characterized by deposits of a similar nature. They are often in regions of Tertiary volcanism, and may be found associated with volcanic intrusions in the "basement rock," as is the case at Rockland.

The ore deposits at Rockland are localized by fractures and breccias which are genetically related to a rhyolite dike. The country rock is quartz diorite-granodiorite intruded by the rhyolite dike. This dike material extrudes as a rhyolite flow overlying the "basement" rock. The dike is traced through the underground workings at Rockland until it merges into the overlying flow.

The mineralizing solutions followed microfractures and tabular breccia zones up to several feet in thickness. The stopes adjacent to and including these breccias trend N30°E, nearly 1,000 feet. State Mineralologist Reports indicate a dip length of 1,200 to 1,400 feet. The hanging wall of the stopes was competent, so that with the few rock pillars left where the grade was apparently low, impressive cavernous stopes can be seen.
Breciation and branching of the vein is characteristic with breccia fragments surrounded by ore material. The banding of ore around wall rock fragments or ore deposited at an earlier stage is characteristic of "cockade," "ring," or "triangle" textures. The fragments are thoroughly altered by the penetrating solutions with the vein material deposited around them.

The textures are characterized by vugs, comb structures and crustification, which is due to the character of the quartz in the gangue. Lamellar quartz, a diagnostic characteristic of epithermal deposits, occurs at Rockland. It is formed by small veinlets of quartz depositing along calcite cleavage planes and locally cutting across the crystals from one plane to another. Following dissolution of the calcite, the quartz blades remain as pseudomorphs of the calcite cleavage.

At Rockland at least three distinct quartz phases are present:

1. That associated with the initial brecciation. A light to dark grey porcelaneous quartz fills the interstices between the breccia fragments. Its grey color is primarily due to fine-grained disseminated pyrite (Figures 18-19). Some vugs are present and are lined with minute euhedral quartz crystals. This phase is barren of ore minerals.

2. This is the dominant phase. It is grey to white glassy quartz surrounding fragments of the rhyolite dike.
Figure 18. Photograph of typical Rockland breccia indicating vuggy dark silica vein material and minor rotation of fragments. Quarter shows relative size.

Figure 19. Photomicrograph (sample #137) of abundant pyrite which causes the silica vein material between the breccia fragments to be dark grey in color (10X).
Figure 20. Photomicrograph (sample #771) of "pseudobubble" in Rockland vein material. This shows a string of pyrite cubes crystallized along what may have been a gas-liquid interface, being later filled with quartz. (×6X).
and the quartz diorite-granodiorite country rock. Numerous vugs are lined with euhedral quartz crystals. This phase is characterized by disseminated pyrite and hypogene silver mineralization. This silver mineralization occurs as veinlets and blebs of argentite ($Ag_2S$), pyrargyrite ($Ag_3SbS_3$).

3. The last quartz phase is a fine-grained to porcelaneous dark grey quartz. Pyrite commonly occurs in ring textures composed of a chain-like linked series of pyrite cubes (See Figure 20). This texture may be formed by sulphide crystallization on a bubble-ore fluid interface. A gas bubble of $H_2S$ with a high affinity for iron may crystallize pyrite cubes along the gas-liquid interface. Because of the abundance of this texture throughout the mine a boiling or flashing of the ore fluid as the result of a pressure release is postulated. This would be caused by the surface escape of gases and fluids.

A possible fourth quartz phase is characterized by "highgrade" gold mineralization. According to W. W. Short (oral communication), former mine manager at Rockland, several "highgrade" stopes were mined in addition to the lower grade mineralization throughout the mine. These portions of the vein with stronger gold mineralization are indicative of temperature control on the solubility of gold in hydrothermal solutions. Weissberg, (1970), indicates that at Steamboat Springs, Nevada, the water temperature at depth is about 175°C and the metals in the water
are probably carried in true solution. Rapidly decreasing temperature near the surface probably accounts for the precipitation of metastibnite, gold and silver. The "high-grade" at Rockland appears to be part of one of the latest surges of mineralization and one of the last quartz phases. Photographs and photomicrographs of this vein material are shown by Figures 21-24.

Brecciation occurs as a result of the hydrothermal processes responsible for the ore deposits. Figure 18 shows a typical breccia, illustrating the fractured nature of the rhyolite dike material and the vein-flooding dark quartz. There appears to be only minor rotation of the fragments but this is because the photograph is of an early phase of the brecciation. Brecciation starts as a "crackle breccia" along fractures inherent in the rhyolite dike, which has intruded along the N30°E high angle structure. The breccia occurs entirely within the dike, and adjacent to the quartz diorite-granodiorite. This is followed by a wedging outward of the fragments, more or less at right angles to the direction of fracturing as flooding of siliceous vein material occurs, resulting in minor fragment rotation (Figure 18). The fragments range in size from microbreccias to small cobblesized fragments. The brecciated area is elongate-tabular (the same as the dike) and varies in thickness from stope width to near micro-veinlets with the average being approximately a foot. The brecciated zone pinches and swells as does the dike.
Figure 21. Photograph showing distribution of vein-forming gold from which sample #500 was made.

Figure 22. Photograph of sample in Figure 21 after silica was leached with HF to show texture of gold. It is spongy and found filling gaps between euhedral quartz crystals rather than massive as Figure 21 indicates.
Figure 23. Photomicrograph (sample #500) indicating crystallization of euhedral quartz, then gold filling the interstices, followed by pyrite. More massive (earlier) quartz occurs outside the immediate area of gold deposition indicating the euhedral quartz-gold-pyrite filled a vug or open cavity. (32X).

Figure 24. Photomicrograph (sample #500) of gold filling the gaps between euhedral quartz crystals. (25.6X).
The sequence of events for Rockland seem to be continuous. The breccia formation was associated with a late magmatic stage. The fluids ascended under high pressure along the lines of least resistance which is the long dimension parallel to the original platy structure of the foliated rhyolite. The minor rotation of the fragments suggest that explosive action was not important. The fragments do not generally contact each other, which could indicate that the vein material began to crystallize, thus trapping the fragments which were seen suspended in a fairly viscous medium. As seen in the discussion on the various quartz phases, the final solutions were probably carrying the higher gold values and with the decrease in temperature precipitated them out as the richer vein.

The quartz diorite-granodiorite host rocks at Rockland are usually unaltered a few feet away from the dike. Fragments of the quartz diorite-granodiorite found in the vein show complete argillization with only the quartz remaining unaltered. These fragments aside from the argillization show pyritization as do the rhyolite fragments, however the pyritization in the rhyolite is more pervasive. The gold and silver mineralization was never seen in the altered fragments of quartz diorite-granodiorite.

A more pervasive or widespread alteration associated with the mineralization at Rockland is that of alunitization. This occurs in an erosional remnant of rhyolitic tuff which outcrops 2,000 feet to the southeast of the
mine area. The alteration of this rhyolite is strongly dispersed throughout the matrix and is seen replacing the Scinidina phenocrysts (See Figures 25 and 26). Alunite $\text{KAl}$_2$(\text{SO}_4)$$_2$(OH$_6$) is the characteristic mineral produced under conditions of acid-sulfate alteration of silicate rocks. Often abnormal percentages of pyrite account for high concentrations of sulfuric acid through pyritic oxidations; however, this altered rhyolite contains no evidence for an unusually high pyrite content. Since the rhyolite at Rockland does not indicate an unusually high pyrite content, a weathering or supergene origin for the alteration seems questionable and it is assumed to be the result of hydrothermal processes. The area around this outcrop would be favorable to prospect for the southern extension of the vein at Rockland.

Depth of formation of this deposit is near surface as seen by the dike-flow association and therefore the temperature of formation more than likely falls in Lindgren's (1933) epithermal class of ore deposits, i.e. from $50^\circ$ to $200^\circ$C.
Figure 25. Photomicrograph (sample #39) of rhyolitic welded tuff with phenocrysts of sanidine and quartz in a fine-grained groundmass of clay, alunite and devitrified glass (10X).

Figure 26. Photomicrograph of Figure 25 in polarized light accentuating alunite in the groundmass and replacing the sanidine phenocrysts (10X, crossed nicols).
## A Comparative Tabulation of Observations and Conclusions of the Wilson-Wheeler Deposit and the Rockland Deposit

<table>
<thead>
<tr>
<th>Wilson-Wheeler</th>
<th>Rockland</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Occurrence</strong>: In a quartz monzonite stock as quartz veins and veinlets, with some replacement between veins.</td>
<td>Occurrence: As quartz veins in a rhyolite dike which intrudes a quartz diorite-granodiorite stock.</td>
</tr>
<tr>
<td><strong>Shape</strong>: Tabular to sheeted bodies and as high-grade shoots. Sub-parallel stringers and lenses.</td>
<td>Shape: Tabular narrow fissure veins.</td>
</tr>
<tr>
<td><strong>Size</strong>: Small irregular stopes partially indicating extent of ore deposition, partially indicating extent of post-ore faulting.</td>
<td>Size: Tabular fissure veins are of great vertical and horizontal extent. (This is surmised from stoping which is nearly 1000 feet vertical by 1000 feet horizontal.</td>
</tr>
<tr>
<td><strong>Mineralogy</strong>: Pyrite, chalcopyrite, malachite, tenorite, gold. No silver minerals observed, however, Ferguson (1929) states the workable silver was of supergene origin, which is proven by fire assay results. The silver probably occurs as cerargyrite. Majority of the gold is in a sugary quartz and throughout sheared quartz monzonite. Auriferous pyrite.</td>
<td>Mineralogy: Pyrite, pyrargyrite, argentite, stephanite, covellite, gold (electrum). Gold is in a late quartz phase.</td>
</tr>
<tr>
<td><strong>Alteration</strong>: Introduction of chlorite, biotite and extensive sericitization close to vein. Propylitic and potassic alteration.</td>
<td>Alteration: Silicification of breccia fragments. Quartz diorite-granodiorite fragments show complete kaolinization of ferromagnesian and feldspar minerals. Pervasive alunization in rhyolite to southeast of mine.</td>
</tr>
</tbody>
</table>
**Structure:** Northwest flat dipping to vertical shear zones in quartz diorite-granodiorite.

**Ore Control:** Quartz veining along shear zones.

**Temperature:** Hypothermal to mesothermal ranges, i.e. approximately 175°C to 300°C. Temperatures are purely conjectural.

**Pressure and Depth of Formation:** Purely conjectural but probably formed at less than two miles depth, therefore having moderate pressures.

**Age:** Less than 100 million years. Batholithic complex is greater than 100 M.Y. Mineralization is Pre-Tertiary.

**Exploration Potential:** Down dip northern extension along north easterly high angle fault. Questionable possibility for porphyry copper at depth.

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**Structure:** N30°E high angle fault dipping 45° to 70° in quartz diorite-granodiorite.

**Ore Control:** Quartz veining in breccia related to late phase rhyolite intrusion along N30°E structure, temperature-pressure control.

**Temperature:** Epithermal, i.e. 50° to 200°C. Formed near surface, solutions would flash into steam and escape if at a higher temperature.

**Pressure and Depth of Formation:** Rhyolite dike occurs directly below rhyolite flow which originates from the dike. Therefore, pressure is extremely low and depth of formation is less than several thousand feet.

**Age:** Rhyolite ash-flows (vitrophyre) are less than 14 M.Y. old so the mineralization is correlated with this age period.

**Exploration Potential:** Southern extension of Rockland vein in the vicinity of the alunitized rhyolite to the south.
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