The Geology and Ore Deposits of the Red Canyon Mining District, Douglas 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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ABSTRACT

The Red Canyon mining district of southeastern Douglas County has like many other Nevada mining camps yielded a small production and has not previously been studied in detail. Initial discoveries were made in Comstock Lode days and sporadic activity occurred through the mid-1930's. Gold and silver from quartz veins in quartz monzonite accounted for most of the early production.

Eugeosynclinal strata of Mesozoic age exceed 9,000 feet in thickness in Red Canyon and generally become more volcanic higher in the section. After a Late Jurassic episode of deformation, this sequence was intruded by a compound pluton in Early Cretaceous time. This plutonism was accompanied by or followed by regional metamorphism to the greenschist facies. Cenozoic volcanism produced intermediate rocks which rest unconformably upon the Mesozoic rocks.

Copper, zinc, and lead sulfide deposits which occur in the Mesozoic rocks of the roof pendant previously have been described as replacement lodes, probably a hydrothermal derivative of the nearby pluton. The findings of the present study suggest an entirely different origin for the sulfides. Field relationships indicate a close association between the sulfides and a fine-grained leucocratic hypabyssal rock which is older than the granitic rocks. Laboratory studies in conjunction with field work provide evidence that the sulfide deposits of the Red Canyon mining district have many of the characteristics of volcanigenic origin. Similarities which strongly suggest a volcanigenic origin for the Red Canyon deposits are: (1) regional geologic setting, (2) ore mineralogy and textures, (3) shape and attitude of the ore bodies,
(4) wallrock alteration, (5) trace element associations, and (6) apparent old, pre-orogenic age of the mineralization.
INTRODUCTION

Location

The Red Canyon mining district is situated in T. 11N., R. 22E. of the Mt. Siegel and Wellington 15-minute quadrangles, Douglas County, Nevada, approximately 28 miles southeast of Carson City in the southern Pine Nut Range (Figure 1). The principal early producer of the district, the Longfellow mine, is located one-quarter mile east of the former townsite of Bullionville near the crest of the range. The Lucky Bill mine area, the focal point of this thesis, is in the upper north fork of Red Canyon.

Relief exceeds 3,000 feet within the study area with elevations ranging from about 6,000 feet near the main fork of Red Canyon to over 9,100 feet at the range summit (Figures 2a and 2b).

Access to the district from the east is afforded by an unimproved dirt road which extends from Lyon County roads in Smith Valley; and from the Carson Valley side by a 4-wheel drive trail in Mill Canyon.

Previous Work

J. E. Spurr (1903) briefly described the geology of the Pine Nut Range in his report on selected areas south of the Fortieth Parallel in Nevada and California. Limestones of Triassic age near Eldorado Canyon in the northern Pine Nuts were identified at that time but most of the range was believed to consist of igneous rocks and no mention was made of the large roof pendant of Mesozoic rocks in the southern Pine Nut Range.
Figure 1. Location Map of the Red Canyon Mining District.
Figure 2a. East slope of the Pine Nut Range as viewed from the main fork of Red Canyon.

Figure 2b. North fork of Red Canyon showing Longfellow mine dump in upper right center.
Hill (1915) reported on the geology and mining activities of the Red Canyon mining district from 1852 to 1912 in a U. S. Geological Survey Bulletin dealing with mining districts in northeastern California and northwestern Nevada. At the time of Hill's reconnaissance in 1912, four distinct types of mineralization were recognized. These included: (1) copper-bearing contact metamorphic deposits, (2) replacement lodes in Triassic sedimentary rocks with apparent igneous affiliation, (3) hydrothermal quartz veins in quartz monzonite and granodiorite, and (4) copper mineralization in altered andesites of supposed Tertiary age.

The Mesozoic geology of the southern Pine Nut Range was studied in detail more recently by D. C. Noble (1962, unpublished Stanford University Ph. D. thesis). Noble divided the Mesozoic metasedimentary and metavolcanic rocks into six formations, ranging in age from Late Triassic to Early Cretaceous.

Moore (1959) discussed the geology of Douglas County in a tri-county cooperative report of the U. S. Geological Survey and the Nevada Bureau of Mines and relied heavily upon Hill's 1915 description of the ore deposits of the Red Canyon district. The geology of Lyon, Douglas, and Ormsby Counties is depicted on Moore's map at a scale of 1:250,000.

Purpose of Study

The primary objective of this study was to map this small mining district in detail and to determine the relationship of mineralization and alteration to the various igneous rocks and to the invaded sedimentary-volcanic sequence.

A previous investigator, J. M. Hill (1915), referred to the sulfide mineralization at the Lucky Bill mine as replacement lodes within a "fractured quartzite" which contained abundant disseminated pyrite. Preliminary field studies revealed that this rock was definitely not sedimentary in origin but was in fact a hypabyssal acidic intrusive containing barely discernible plagioclase phenocrysts and a very fine-grained groundmass which on cursory inspection could be confused with quartzite. Further field work disclosed that: (1) the surface expression of the main intrusive was mainly concordant, (2) it seems to have intruded a definite stratigraphic horizon, (3) the igneous body crops out along a considerable strike length across the district, (4) it appears to predate the plutonic rocks of the area, and (5) it exhibits disseminated sulfides or their oxidation products in most outcrops.

The possibility of an older pre-plutonic sulfide mineralization within a sequence of eugeosynclinal rocks caused the author to redirect his investigation toward a possible volcanigenic origin for most of the sulfides associated with the fore-mentioned shallow (subvolcanic?) intrusive.

While Russian and Canadian geologists have acknowledged and documented many such sulfide deposits over the last several decades, it
is relatively recently that American economic geologists have given serious consideration to volcanigenic sulfides and to detailed studies of their formative environment. The main emphasis of this thesis is directed toward the peculiar sulfide mineralization within the roof pendant, bearing in mind both the classical hydrothermal theory and some of the currently evolving geological thought regarding volcanigenic sulfide genesis.

Field Work

A total of 9 weeks of field work was performed between June 1970 and July 1971. During this time approximately 6 square miles were mapped in detail on an enlarged photographic base at a scale of 1 inch to 567 feet. Brunton resection methods were used for locating geologic stations.

Laboratory Work

Standard petrographic and reflected light microscopic techniques were utilized to examine approximately 100 thin sections and 6 polished ore sections. Study of some of the fine-grained rocks was facilitated by the use of sodium cobaltinitrite and amaranth dye to determine feldspar content and to enhance textural relationships. Geochemical analyses were performed by Rocky Mountain Geochemical Company using atomic absorption spectrophotometry.
Acknowledgments

Prof. A. L. Payne suggested the Red Canyon mining district to the author and provided much valuable guidance throughout this study and during the preparation of the manuscript. The writer is also indebted to numerous individuals who graciously assisted by engaging thought-provoking discussions of various field and laboratory problems. Special thanks are extended to Dr. Arthur Baker, III; Dr. E. C. Bingler; Dr. D. B. Slemons; Dr. Malcomb J. Hibbard; Dr. E. R. Larson; Harold F. Bonham; Richard F. Hardyman; and Wayne R. Kemp.

A portion of the expense of petrographic thin section and polished ore section preparation was financed by a grant of the Mackay School of Mines Research Committee. J. B. Murphy of the Nevada Bureau of Mines Mineralogical Laboratory greatly aided in the preparation of specimens. The author is appreciative to L. F. Fleming of the E. L. Doheny Mining Company for access to their mining property, diamond drill core, geochemical data, and for many informative conversations. Gratefully acknowledged is the use of the National Aeronautics and Space Administrations' project facilities at the University of Nevada under the supervision of Jack Quade and Dennis T. Trexler.

An enlarged photographic base for mapping purposes, geochemical analyses, and color air photographs were furnished by the Minerals Department of Humble Oil and Refining Company. Especially helpful was the assistance of Alan R. Jager, Dr. F. P. Schwarz, and other personnel of the Reno office.
Mining History

The Red Canyon (Silver Lake) mining district was organized in 1863 shortly after the discovery of the rich oxidized ore of the Longfellow vein, which was hauled by wagon to Virginia City for treatment. According to Hill (1915) by 1872 a 5-stamp mill and amalgamation plate was built one and one-half miles west of the Longfellow shaft in Mill Canyon.

Development of the Longfellow group of 12 claims during the late 1800's and early 1900's was conducted by the Longfellow Gold Mining and Milling Company (Overton, 1947). The Detroit Gold Mining Company acquired the property in 1922 and treated small lots of ore in the company mill from 1923 to 1926 (Weed, 1926). Over 3,000 feet of underground workings were serviced by a 150-foot adit and a 265-foot winze. Equipment at the property in 1923 included a power hoist, an air compressor, air-driven drills, and a 50-ton mill. No mining activity at the Longfellow mine has been recorded since 1936.

Another mine of the Red Canyon district, the Winters, was discovered by John B. Winters in 1872. It is located on the north side of Oreana Peak, north of the area mapped in this thesis, and is a series of sulfide replacement bodies in calcareous argillite which is intruded by quartz monzonite. The Silver Lake Claim is at the Winters mine and occasionally has been used as the name for the district.

The Lucky Bill group in the upper north fork of Red Canyon was probably first prospected in the 1880's. It contained pockets and lenses of argentiferous galena and stibnite and minor chalcopyrite and sphalerite in what was reported as a "fractured quartzite".
A prospector by the name of Wylie apparently made a living from the claims in the early 1900's and is reported to have carried his hand-sorted and sacked ore out on a mule-driven wagon to Wellington, Nevada, for shipment. (Rene Cardinal, personal communication, 1971). More recently, mineral exploration at the Lucky Bill group has been carried on by the E. L. Doheny Mining Company and has included diamond drilling, geochemical sampling, bulldozing, and the sinking of a shallow winze into a lens of massive sulfide ore (sphalerite-pyrite-chalcopyrite-galena). Slightly more than 20 tons of this ore have been shipped (L. F. Fleming, personal communication, 1970) but the property awaits further development.

Production

The Red Canyon district, the largest producer in Douglas County as of 1943, is credited with a total production of $102,818 from 1863 to 1936. Virtually all of this sum came from the Longfellow and Winters mines and was mainly derived from gold and silver and minor lead values in the oxidized sulfide ores.

The following table (Table 1) from Couch and Carpenter (1943, p. 37) shows the production from 1881 to 1936. One should note that the figure shown for the year 1881, $58,000, represents the estimated combined production of the Longfellow and Winters mines from 1863 to 1881. This amount breaks down into approximately $50,000 for the Longfellow and $8,000 for the Winters. An average ore value of $18 per ton was noted at the Longfellow by Hill in 1912, with about one-quarter of this amount in silver and the remainder in gold.
TABLE 1
GOLD AND SILVER PRODUCTION FROM 1881 TO 1936

<table>
<thead>
<tr>
<th>Year</th>
<th>Tons</th>
<th>Gross Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1881</td>
<td>---</td>
<td>$58,000</td>
</tr>
<tr>
<td>1883</td>
<td>---</td>
<td>9,738</td>
</tr>
<tr>
<td>1884</td>
<td>---</td>
<td>1,500</td>
</tr>
<tr>
<td>1903</td>
<td>300</td>
<td>3,700</td>
</tr>
<tr>
<td>1904</td>
<td>1,020</td>
<td>16,233</td>
</tr>
<tr>
<td>1905</td>
<td>565</td>
<td>1,756</td>
</tr>
<tr>
<td>1907</td>
<td>---</td>
<td>656</td>
</tr>
<tr>
<td>1908</td>
<td>---</td>
<td>1,865</td>
</tr>
<tr>
<td>1909</td>
<td>---</td>
<td>1,085</td>
</tr>
<tr>
<td>1910</td>
<td>12</td>
<td>320</td>
</tr>
<tr>
<td>1911</td>
<td>5</td>
<td>105</td>
</tr>
<tr>
<td>1912</td>
<td>30</td>
<td>571</td>
</tr>
<tr>
<td>1921</td>
<td>---</td>
<td>131</td>
</tr>
<tr>
<td>1926</td>
<td>---</td>
<td>2,957</td>
</tr>
<tr>
<td>1931</td>
<td>---</td>
<td>1,151</td>
</tr>
<tr>
<td>1934</td>
<td>51</td>
<td>300</td>
</tr>
<tr>
<td>1935</td>
<td>5</td>
<td>222</td>
</tr>
<tr>
<td>1936</td>
<td>18</td>
<td>2,528</td>
</tr>
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Total, 1881-1936 2,006 $102,818
GEOLOGY

General Statement

The Mesozoic strata of the Red Canyon mining district represent eugeosynclinal facies rocks which were deposited between typical Cordilleran eugeosynclinal assemblage rocks to the west in California and miogeosynclinal rocks of comparable age in the Hawthorne and Tonopah quadrangles, Nevada, further to the east.

Sedimentary and volcanic rocks of Triassic and Jurassic age crop out in a northwest trending elongate belt which is intruded by and probably floored by granodioritic and quartz monzonitic plutonic rocks of Sierran affiliation. Tertiary volcanic rocks of intermediate composition cover the Mesozoic sequence in the northwest corner of Red Canyon and occur as isolated patches upon the plutonic rocks to the south. Quaternary units consist primarily of Recent detrital alluvium in the active drainages. The stratigraphic column of the Red Canyon mining district is shown in Figure 3.

MESOZOIC STRATIGRAPHY

Introduction

The Red Canyon area in the southern Pine Nut Range affords some of the best exposures of Mesozoic eugeosynclinal strata within the Cordilleran geosyncline in western Nevada. Rapid Late Cenozoic uplift and deep dissection have provided numerous good exposures which permit detailed structural and stratigraphic studies. In this report the formational names as proposed by Noble (1962) are utilized with some
<table>
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<th>THICKNESS</th>
<th>SYMBOL</th>
<th>LITHOLOGY</th>
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<tr>
<td>Quaternary</td>
<td>Hornblende dacite</td>
<td>?</td>
<td>Oal</td>
<td>water borne sand and gravel</td>
</tr>
<tr>
<td></td>
<td>Sugarloaf andesite</td>
<td>?</td>
<td>Ts</td>
<td>coarse-grained andesite and volc. mudflows</td>
</tr>
<tr>
<td>Tertiary</td>
<td>andesite member</td>
<td>900'+</td>
<td>Jva</td>
<td>medium-grained hornblende andesite</td>
</tr>
<tr>
<td></td>
<td>volc. ss. mbr.</td>
<td>2000'+</td>
<td>Jvs</td>
<td>medium to coarse-grained quartz and plagioclase rich volcanic sandstone</td>
</tr>
<tr>
<td></td>
<td>volc. tuff mbr.</td>
<td>500'+</td>
<td>Jvt</td>
<td>c.g. rhyolitic tuff and inter'med flow rocks</td>
</tr>
<tr>
<td></td>
<td>Preachers formation</td>
<td>1200'+</td>
<td>Jp</td>
<td>fine to coarse-grained, well sorted, lithic and feldspathic sandstone</td>
</tr>
<tr>
<td></td>
<td>u. mbr.</td>
<td>70-135'</td>
<td>Jqu</td>
<td>buff ls, white atzt.</td>
</tr>
<tr>
<td></td>
<td>l. mbr.</td>
<td>1400'</td>
<td>Jgl</td>
<td>black, thin bedded carbonaceous siltstone and eriilita, pyrite-rich</td>
</tr>
<tr>
<td>Mesozoic</td>
<td>Oream Peak formation undiff. carb. member</td>
<td>1600-1800'</td>
<td>Roc</td>
<td>Massive to thin-bedded, white to bluish gray limestone with local dolomitic interbeds</td>
</tr>
<tr>
<td></td>
<td>Lower volc. member</td>
<td>2000'+</td>
<td>Rolv</td>
<td>Dark gray to dark green volcanic sediments and buff colored tuffaceous rhyolites and tuffs</td>
</tr>
</tbody>
</table>

Figure 3. Generalized Stratigraphic Column of the Red Canyon District
minor lithologic changes, but the reader should note that these are still informal, unpublished stratigraphic names. These units are designated the Oreana Peak formation, the Gardnerville formation, the Preachers formation, and the Veta Grande formation. The four lower units of Noble crop out in the vicinity of Red Canyon, while the top two, the Gold Bug and Double Spring formations, occur mainly to the southwest of the map area.

Oreana Peak formation

This formation derives it name from Oreana Peak whose 9,309 foot elevation dominates the mountainous landscape just north of the bold limestone cliffs in Red Canyon. In general, the Oreana Peak formation is a thick sequence of volcanically derived sediments and tuffaceous volcanic rocks overlain by a massive to thin-bedded, strongly recrystallized, white to dark bluish-gray cliff-forming limestone with local dolomitic interbeds and sparse chert nodules. Although in the western Pine Nut Range it is possible to subdivide this formation into a lower and an upper volcanic member that separate two carbonate members, the upper volcanic member is absent in Red Canyon and no attempt was made to differentiate the carbonate sequence.

Lower volcanic member

The lower member of the Oreana Peak formation is exposed in a large structural block west of the Lucky Bill mine and in several erosional windows through volcanic rocks of Tertiary age in the northwest corner of the map area. This unit is composed of dark green to dark gray,
interbedded volcanic sediments and buff colored tuffaceous rocks of rhyolitic composition. A stratigraphic thickness of over 2,000 feet may exist in Red Canyon but cross faulting and volcanic cover conceal the base of the unit and do not permit a detailed section description.

The volcanic sediments are typically dark gray to dark green, fine-grained and consist of angular to subrounded quartz and albitic plagioclase fragments in a matrix of granular biotite and actinolite. The latter two minerals are probably metamorphic in nature and likely represent conversion from an original argillaceous matrix. The tuffaceous rocks contain angular to embayed quartz and albitic plagioclase in a cryptofelsitic groundmass with scattered volcanic lithic fragments.

Undifferentiated carbonate member

The undifferentiated carbonate member attains a stratigraphic thickness of approximately 1,600 to 1,800 feet in the Red Canyon section. This is slightly less than the combined thicknesses of the two carbonate members measured by Noble in Buffalo Canyon to the west.

A Late Triassic age has been assigned to the Oreana Peak formation on the basis of pelecypod and ammonite faunas. It is possible to correlate the Oreana Peak formation with similar rocks in adjacent ranges in western Nevada. The upper part of the Oreana Peak formation is apparently equivalent to the massive carbonates at the top of the Triassic section in the Singatze Range near Yerington and to the lower and middle portions of the Gabbs Formation further east. A tentatively correlative bluish-gray limestone sequence has been reported just east of the Northern Lights mine in the Wassuk Range (E. C. Bingler, personal communication, 1971). In general, the upper carbonate
sequence of the Oreana Peak formation is younger than the Luning Formation of Ferguson and Muller (1949).

Everywhere within the map area the contact of the Oreana Peak formation with the overlying Gardnerville formation is marked by an apparent bedding plane fault, usually represented by a 5 to 10 foot thick sheared zone at the base of the Gardnerville formation (Plate 1, in pocket). It is believed that the stratigraphic sequence is essentially preserved due to the bedding plane nature of this dislocation.

Gardnerville formation

The Gardnerville formation was named for the Nevada town of Gardnerville. Where studied in detail by Noble on the west flank of the Pine Nut Range, the Gardnerville formation is comprised of a lower siltstone member and an upper volcanic conglomerate member. In contrast, the Gardnerville formation as exposed in Red Canyon has been divided by the author into a lower siltstone and argillite member and an upper quartzite and limestone member. Rocks which are lithologically similar have been reported by E. C. Bingler in the Wassuk Range (personal communication, 1971).

Lower siltstone and argillite member

The lower member of the Gardnerville formation is a black, carbonaceous thin-interbedded sequence of calcareous siltstones and argillites with local authigenic pyrite-rich bands and local dolomitic interbeds (Figure 4). Where the pyrite-bearing interbeds have been exposed to weathering and oxidation, the resultant hydrous iron oxides are conspicuous and often have been prospected. Metamorphism has
The notable lithologic change from the massive formation of the lower rock sequence to the column and pyrite-rich fine-grained quartzite in the Gardnerville Formation is interpreted as the product of a restricted, reduced environment. This member attains a specific thickness of about 200 feet in the Red Canyon district.

**Figure 4.** Dark siltstones of Gardnerville formation with felsophyre intrusions as exposed in upper north fork of Red Canyon. Note massive limestone of the Oreana Peak formation in top center.
resulted in the formation of tremolitic porphyroblasts in the more dolomitic beds.

The notable lithologic change from the massive carbonates of the Oreana Peak formation to the carbon- and pyrite-rich fine-grained clastics of the Gardnerville formation is interpreted as the advent of a restricted, reducing environment. This member attains a stratigraphic thickness of about 1,400 feet in the Red Canyon district. Its importance as a host for mineralization will be discussed later.

The contact of the lower siltstone and argillite member with the upper quartzite and limestone member is apparently conformable but another change of depositional environment is implied; possibly an upwarp within a mobile belt or the creation of a shallow embayment that received nearly pure quartzose sediments and clean carbonates.

Quartzite and limestone member

This member consists of a basal 20 to 35 foot thickness of relatively pure, fine-grained white quartzite overlain by 50 to 100 feet of buff, fine- to medium-grained recrystallized limestone. The combined unit forms prominent outcrops across the district and provides an excellent marker horizon.

Preachers formation

The Preachers formation was named by Noble for exposures near the Preachers mine in the southwestern Pine Nuts. It is typically a light green to light gray, fine-grained, well-sorted lithic and feldspathic sandstone with local quartz-rich beds. Outcrops of the Preachers
formation vary from massive to flaggy and often display tangential cross-bedding or traction bedding. Locally in Red Canyon the rocks of the Preachers have an unusual mottled appearance, possess a light gray color, and exhibit intersertal biotite in thin section (Figure 5).

The Preachers formation crops out across the entire Red Canyon district and maintains a fairly uniform stratigraphic thickness in excess of 1,200 feet. Its contact with the overlying Veta Grande formation is apparently conformable and is well exposed in the west central portion of Section 1.

Veta Grande formation

The Veta Grande formation was named by Noble for a locality near the Veta Grande mine on the west side of the Pine Nut Range. It can be divided into three members on the basis of lithology within the Red Canyon district and is exposed in varying degrees. The three members are a basal volcanic tuff, a middle volcanic sandstone, and an upper andesite member. Correlations with formations outside of this immediate region appear difficult due to rapid lateral variations within this formation.

Volcanic tuff member

This unit is a crystal poor to crystal rich rhyolitic tuff with abundant lithic fragments and variable amounts of metamorphic alteration and recrystallization. It crops out across most of the Red Canyon district and occasionally forms bold, moderately jointed outcrops. It provides a reasonably good stratigraphic marker, making it possible
Figure 5. Sandstone of the Preachers formation composed of quartz and plagioclase grains with intersertal biotite. (54X, crossed nicols)
to discern several faults, especially within Section 1 in the eastern half of the map area.

In thin section this member consists of angular, occasionally embayed and corroded quartz phenocrysts, albitized and saussuritized plagioclase phenocrysts, relatively unaltered K-feldspar phenocrysts, almost completely altered ferromagnesian minerals (to magnetite) and numerous altered lithic fragments. The groundmass is highly silicified and saussuritized and contains fine-grained zoisite, epidote, calcite, and some chlorite. Lithic fragments consist of recognizable andesites, diorites, recrystallized quartzitic sedimentary rocks, and probable deformed pumice lapilli.

A stratigraphic thickness in excess of 500 feet is present in the Red Canyon district. This figure exceeds that given by Noble, due to the author's decision to include within this unit some acid to intermediate volcanic rocks which are compositionally more like this member than like the overlying volcanic sandstone. The contact with the volcanic sandstone is everywhere gradational.

Volcanic sandstone member

This member is a thick, monotonous sequence of medium- to coarse-grained feldspathic and lithic sandstones with several intercalated thin andesitic flows. For the most part, it is not well exposed. These areas of poor outcrop are a bold stippled pattern on the geologic map. Poorly sorted and poorly rounded grains of quartz and plagioclase each comprise 10 to 25 percent and K-feldspar accounts for 3 to 4 percent, but the majority of the rock usually is composed of intermediate volcanic lithic fragments and a fine-grained groundmass.
A stratigraphic thickness of more than 2,000 feet exists in the Red Canyon district. The contact of the volcanic sandstone member with the overlying andesite member is evidently conformable.

Andesite member

This unit is a medium to dark gray, porphyritic hornblende andesite which shows limited propylitization. It is mainly exposed in a large wedge near the crest of the Pine Nut Range. Elsewhere in Red Canyon it occurs as small dikes and plugs which were probable feeders for once more extensive surface flows and as small xenoliths in the south fork of Red Canyon.

Unlike the andesite member reported by Noble whose major original mafic minerals were augite and biotite, this unit contains phenocrysts of very fresh green hornblende and biotite. Phenocrysts constitute about 50 percent of the rock and consist of andesine (43%), hornblende (5%), and biotite (~2%). The groundmass is microcrystalline and contains stubby, randomly oriented plagioclase laths, shredded biotite, interstitial to patchy quartz, and scattered spherulitic masses of K-feldspar. Accessory apatite, magnetite, and zircon were noted.

A specimen of the andesite member collected near the summit of the Pine Nut Range displays propylitic alteration. In thin section the plagioclase phenocrysts are slightly argillized and replaced by epidote, while the hornblendes are extensively altered to granular magnetite and epidote. Many of the groundmass plagioclase grains are partially (zonally) replaced by a brownish amorphous material, probably glass. The closeness to the pluton probably is responsible for the observed alteration.
This member is the highest unit within the Mesozoic sequence that is preserved in Red Canyon. A complete stratigraphic thickness of this unit is not present due to the intrusion of the pluton, but at least 900 feet of andesites crop out at the far western edge of the district.
IGNEOUS ROCKS

Mafic Dikes

Fine-grained mafic dikes which strike generally northeast and dip steeply to the northwest occur along the eastern margin of Section 1. These dikes crop out in a very local area on the north side of Red Canyon and attain thicknesses of 5 feet or more but are not shown on the geologic map due to their limited exposure.

In thin section this rock is fine-grained hypidiomorphic granular. It consists of subhedral to anhedral lathy plagioclase (46%, andesine?), randomly oriented, lathy to acicular subhedral actinolite (42%), anhedral sphene (7%), minute interstitial quartz (4%), and scattered magnetite and probable pyrrhotite (∼1%) with limonite-hematite rims (Figure 6). Biotite was also noted in a minor amount intimately associated with the opaques as kelpitic-type rims. A tiny zeolite veinlet was noted in thin section.

A suitable name is problematical with this unusual plagioclase-actinolite bearing rock. It may be a contaminated hypabyssal rock, perhaps a diorite which has assimilated calcium from the carbonate rocks lower in the section. Field relationships indicate that it pre-dates and is cut by the felsophyre intrusive whose description follows.

Felsophyre Intrusive

This peculiar igneous rock appears to have been unrecognized in any previous regional study, although Noble (1962) may have referred to it as "rhyolite dikes". Hill (1915) called it a "fractured quartzite" in
Figure 6. Contaminated dike rock with abundant laths of plagioclase and actinolite. Opaque mineral is oxidized pyrrhotite. (54X, crossed nicols)
his report on the Red Canyon mining district. Early in the present investigation the author realized that it was an igneous rock and that it seemed to be spatially related to the sulfide ores within the roof pendant.

Megascopically this rock is porphyritic-aphanitic with sparse plagioclase phenocrysts which exhibit alteration and white rims in some of the specimens. The fine-grained sugary groundmass and the paucity of mafic minerals lead to the early confusion with respect to the origin of the unit. The choice of the name felsophyre is believed to best briefly describe this very fine-grained felsitic intrusive rocks, although early-day petrographers originally used the term to denote a rock with a cryptocrystalline texture (Harker, 1964).

This rock may be analogous to the "quartz albitophyre" which frequently is mentioned in a recent translation of a summary of Russian pyritic ore deposit literature (Smirnov, 1970). Johannsen (1937, p. 139) stated that "it (albitophyre) has been used in recent years for porphyritic leucocratic rocks composed essentially of sodaclase" in reference to a slightly different usage than the original 1857 definition by the French petrographer, Coquand.

Outcrops of the felsophyre intrusive are widespread in the Red Canyon district. Immediately obvious from examination of the geologic map is the peneconcordant nature of many of these intrusions, particularly into the lower member of the Gardnerville formation. Discordant intrusions of the felsophyre are best exemplified where it invades the Preachers formation. Surface exposures are either bold and strongly
jointed or are extremely shattered and show varying amounts of limonite staining.

In thin section the felsophyre consists primarily of albitic plagioclase and quartz with or without muscovite. Texturally the rock is porphyritic-aphanitic with albitic plagioclase phenocrysts comprising less than 2-3% of the rock and set in an aphanitic allotriomorphic granular matrix of quartz and albitic plagioclase. Differences in the aphanitic groundmass of this rock allows the following distinction of three textural types: (1) a very fine-grained aphanitic type with pervasive sericite, (2) a relatively coarse-grained aphanitic type which contains very little sericite, and (3) a relatively coarse-grained aphanitic variety with microvermicular (micromyrmekitic) intergrowths of plagioclase and quartz.

Fine-grained aphanitic type

Felsophyre of this variety consists of an allotriomorphic intergrowth of albitic plagioclase, quartz and sericite with generally only a few plagioclase or rare quartz phenocrysts (Figure 7). The average grain size is approximately 0.05 mm and is always less than 1 mm. This felsophyre variety is distinct in that it is pervasively sericitized. Minute sericite flecks make up perhaps 30-40% of the groundmass and if phenocrysts are present they generally are completely sericitized. In some examples of felsophyre the sericite appears to display a rough preferred orientation or foliation in thin section.

Commonly this felsophyre variety contains irregular, hair-thin limonitized veinlets which cut the rock and impart a limonitic color
Figure 7. Fine-grained aphanitic variety of felsophyre displaying pervasive sericite and large subhedral pyrite grain. (54X, crossed nicois)
to it. Pyrite may or may not be associated in these veinlets. Pyrite also occurs as isolated euhedral grains in the rock, unassociated with the veinlets. Tiny very fine-grained, aplitic quartz veinlets were also found cutting this rock as well as the other felsophyre varieties. Felsophyre of this variety was the most frequently encountered type in the study; discussion of its possible relationship to mineralization is deferred until the ore deposits section.

Coarse-grained aphanitic variety

The coarse-grained variety of felsophyre differs from the fine-grained aphanitic type in that it lacks the pervasive sericite. Texturally it is typically porphyritic with the albitic plagioclase phenocrysts commonly occurring in glomeroporphyritic clots (Figure 8). The plagioclase phenocrysts range in size from about 2.5 mm to 5.0 mm and are subhedral with slightly lobate to sutured margins where encroached upon by the groundmass grains.

The groundmass is allotriomorphic granular and is comprised of approximately 10% albitic plagioclase and 90% quartz. The average groundmass size is 0.1 mm or less. The albite of the groundmass is anhedral and together with the anhedral, sub-interstitial quartz display a saccharoidal fabric. The quartz of this variety of felsophyre typically contains a few small vermicular-like blebs of albite. Anhedral to sub-poikilitic muscovite flakes occur in trace amounts. Secondary, shred-like biotite also occurs in trace amounts and is often associated with minor amounts of opaque grains. Trace amounts of subhedral
Figure 8. Coarse grained-aphanitic variety of felsophyre showing glomeroporphyritic clot of argillized (minor sericitic alteration) plagioclase phenocrysts in an allotriomorphic granular groundmass of quartz and albitic plagioclase. (54X, crossed nicols)
zoisite were noted in several specimens of this felsophyre type, as was some slight argillic alteration.

Coarse-grained aphanitic microvermicular type

A third distinct textural variety of felsophyre is also porphyritic with a relatively coarse-grained groundmass and generally less than 3% phenocrysts. The groundmass has an average grain size of about 0.1 mm and differs from the other varieties in having microvermicular intergrowths of quartz and albite, as shown in Figure 9. Minor sericite is present in the groundmass. Felsophyre of this textural variety is typically slightly to moderately argillized and commonly contains the hair-thin zeolite veinlets which were present in the other textural types. This is the least common variety of felsophyre and is very limited in areal distribution.

Felsophyre age relationships

There are several lines of evidence that indicate that the felsophyre is pre-plutonic, or specifically within the Red Canyon district, pre-Bullionville granodiorite in age. These include: (1) a major offset in the district spanning sill-like felsophyre body by a north-northeast fault which in turn is truncated by the pluton, (2) the areal restriction of the felsophyre intrusions to the pre-plutonic rocks, and (3) most convincing, intrusion of the Bullionville granodiorite into the felsophyre, as seen in the southwestern corner of Section 2 on the geologic map.
The lutecoidal plagioclase, named by Webster for exposures near the upper butte ridge near the Longfellow mine, crops out in an eastward setting slice across the Las Vegas district and clearly comprises and encompasses the previously described sequence. Text and other clastic rocks of the area were completely replaced by the superseding K. F. Webbering (1899), or the Argyle varieties of metamorphic (E)

**Figure 9.** Coarse grained-aphanitic microvermicular felsophyre variety displaying moderate-weak argillic alteration. The groundmass contains pervasive microvermicular quartz-albite intergrowth. (54X, crossed nicols)
Bullionville granodiorite

The Bullionville granodiorite, named by Noble for exposures near the former townsite near the Longfellow mine, crops out in an eastward thinning slice across the Red Canyon district and clearly crosscuts and intrudes the previously described Mesozoic sequence. This and other plutonic rocks of the area were probably emplaced in the mesozone of A. F. Buddington (1959). It is highly variable in mineralogical composition, texture and grain size. Although it is named a granodiorite, it actually ranges in composition from a quartz diorite to a granodiorite.

Petrographically the Bullionville granodiorite is typically a hypidiomorphic-granular rock composed of subhedral plagioclase grains (60-65%, An\text{48-55}), K-feldspar (4-6%), anhedral to interstitial quartz (17%), and anhedral laths of hornblende (19%). Also present in minor or trace amounts are augite, zircon, sphene, epidote, zoisite, magnetite, and rare xenotime. A suitable field name for this rock is hornblende granodiorite.

Longfellow quartz monzonite

The Longfellow quartz monzonite was named by Noble for its exposures at the Longfellow mine near the crest of the Pine Nut Range and crops out in numerous good exposures across the southern margin of the map area. It clearly intrudes the pre-existing arcuate shell of Bullionville granodiorite on a large scale, but frequently has a smooth boundary accented by a thin aplitic border within individual outcrops (Figure 10).
Figure 10. Contact between Bullionville granodiorite (right) and Longfellow quartz monzonite with thin aplitic border.
In thin section it is characteristically medium-grained allotriomorphic-granular and consists of anhedral to subhedral plagioclase (38%, zoned, andesine range), microperthitic microcline and orthoclase (28%), quartz (28%), fine-grained biotite (5%), anhedral hornblende (~2%), and minor chlorite, sphene, monazite, apatite, and magnetite (Figure 11). In general terms, this rock could be described as a biotite hornblende quartz monzonite.

From the standpoint of economic geology there is very little observed hydrothermal alteration of either the main mass of the Longfellow quartz monzonite or the Bullionville granodiorite. However, hydrothermal alteration of both of these plutonic rocks occurs close to quartz veins on the top of the range and will be discussed in a later section concerning ore deposits.

An Early Cretaceous (110 M.Y.) age recently has been assigned to both the Bullionville granodiorite and Longfellow quartz monzonite on the basis of K-Ar age determinations (D. C. Noble, personal communication, 1971). This confirms earlier field and laboratory studies which suggested that the Longfellow quartz monzonite intruded the Bullionville granodiorite while the granodiorite was still at elevated temperatures and only partially solidified.

An age of 110 M.Y. for these plutonic rocks corresponds well with Evernden and Kistler's (1970) Huntington Lake intrusive epoch during Early Cretaceous time. These workers determined through a large number of K-Ar dates on hornblende and biotite pairs that there was a distinct periodicity of magma generation and intrusion when the ages were related to the distribution of genetic types disclosed by geologic mapping. A similar pulsation of magmatic episodes in Arizona and
Figure 11. Unaltered Longfellow quartz monzonite, displaying microperthitic microcline, quartz, zoned plagioclase, hornblende and minor biotite. (54X, crossed nics)
northern Sonora was noted in a previous study by Damon and Mauger (1966).

Also possibly explained by Evernden and Kistler's age dates is the regional metamorphism within the southern Pine Nuts which apparently occurred simultaneously with or post-dated the intrusion of the Bullionville granodiorite and the Longfellow quartz monzonite. Noble (1962) noted a lack of coincidence between the observed regional metamorphic zonation and the plutonic contacts in the southeastern part of the Pine Nuts. He postulated an energy source to the west, based on increased metamorphic grade in that direction. Numerous younger age dates in the 82 to 90 M.Y. range immediately to the west in the Carson Range may have provided the requisite energy source.

Porphyritic quartz monzonite

A small plug of fine-grained porphyritic quartz monzonite occurs in the volcanic sandstone member of the Veta Grande formation near the southwest corner of Section 2. Although its intrusive relationship to the nearby Bullionville granodiorite is unknown, it is tentatively correlated with similar small bodies of quartz monzonite to the east toward the mouth of Red Canyon. One of these small bodies was noted by the author to be intruded by the Bullionville granodiorite in a canyon just north of Red Canyon. The age relationship of the porphyritic quartz monzonite to the Longfellow quartz monzonite is not known.

This rock consists of subhedral to euhedral, normally zoned plagioclase phenocrysts (20%, An$_{24-36}$) in a fine-grained to aphanitic, allotriomorphic granular groundmass of anhedral quartz, plagioclase,
K-feldspar, and small biotite flakes (1-2%). Traces of apatite, hornblende, and chlorite were noted.

Hornblende diorite dikes

Hornblende diorite dikes which generally trend north-northwest occur in both the Bullionville granodiorite and the Longfellow quartz monzonite to the east of the Longfellow mine. These dikes are not shown on the geologic map due to their scarcity and lack of continuity. In thin section this rock is sub-porphyritic and consists of a few scattered plagioclase and hornblende phenocrysts in a fine-grained allotriomorphic granular groundmass. This groundmass is composed of anhedral to subhedral, mutually interfering, zoned plagioclase (60%, andesine), anhedral hornblende (25%), biotite (14%), and traces of apatite, sphene, and pyrite (?).
TERTIARY SYSTEM

Sugarloaf andesite

The northwestern corner of the study area is covered by reddish weathering, coarse-grained andesites and jumbled, interspersed mudflow material (Figure 12). Included within the mudflow are angular cobbles and boulders of granodiorite, several sedimentary lithologies that occur in the roof pendant, and some floral remains. An accumulation of this type could be expected to develop on a surface of moderate relief undergoing explosive eruptions where laharic flows are common. Worthy of mention is the inclusion of granodiorite boulders, similar in appearance to the Bullionville granodiorite, which suggest deroofing of the nearby pluton by Miocene (?) time.

Hornblende dacite

Two exposures of hornblende dacite were revealed by geologic mapping on the plutonic rocks in the southern portion of the study area. It is not known for certain whether or not they intrude the Longfellow quartz monzonite or are perched on it due to talus concealment of the contacts. Elsewhere in the Pine Nut Range, Noble noted that this dacite formed dikes which cut the Minnehaha andesite of Tertiary age.

Megascopically this rock is medium gray in color and shows plagioclase and hornblende phenocrysts in a fine-grained groundmass. A rather ill-defined foliation was seen in a few loose specimens but was not measured in outcrop.
Figure 12. Contact of the Sugarloaf andesite (upper left) with limestones of the Oreana Peak formation.
QUATERNARY SYSTEM

Recent alluvium

Alluvial deposits of probable Recent age cover less than 5 percent of the mapped area and usually reflect local derivation from adjacent country rocks. This alluvium masks the valley bottom near the forks of Red Canyon, below which the perennial stream meanders over a moderately broad flood plain.

There is a possibility of a slightly older alluviated area in the upper north fork of Red Canyon where poorly consolidated and poorly stratified sediments are exposed in an entrenched stream channel. An alluviated upland area of this sort may represent a depositional site related to a former base level of erosion.
STRUCTURAL GEOLOGY

Generalized Regional Structural Setting

The Red Canyon mining district is situated in the Pine Nut Range which is a series of westward-tilted orographic blocks bounded by typical Basin and Range faults (Moore, 1969). Its geographic position is between the Sierra Nevada a few miles to the west and the prominent Walker Lane lineament of Locke and Billingsley (1941) approximately 30 miles to the east. The Pine Nut Range is part of a larger topographic complex which includes the Virginia Range to the north and the Wellington Hills and the Sweetwater Range in a southerly direction.

Definitive structural studies, especially of pre-Tertiary tectonics, essentially are lacking in this region. This is partly due to the limited occurrence of Mesozoic strata as isolated roof pendants and septa and because until recently most geologic attention has been concentrated on the larger and better exposed Paleozoic carbonate sequences in the middle and eastern portions of Nevada.

Structural Features of the Red Canyon District

The present composite exposures of Mesozoic strata in Red Canyon can be described best as a northwest-striking and steeply southwest-dipping, faulted homocline which was intruded along its southern margin by Upper Mesozoic plutonic rocks. Most obvious within the roof pendant are north-northeast and north-northwest trending faults which successively displace the Mesozoic sequence in a left-lateral sense. Also evident is a local thrust fault, here named the Lucky Bill thrust, which transported siltstones of the Gardnerville formation to the
southwest over sandstones of the Preachers formation. Numerous other northwest and west-northwest striking high-angle faults complicated the structural fabric of the district.

It is possible to establish a tentative sequence of tectonic events if a basic assumption is made that the Mesozoic sequence has not experienced complete horizontal or inclined rotational movement as the result of "rafting" during Late Mesozoic plutonic activity. Support for this belief is the general accordance of the district structural grain with post-Triassic orogenic trends within the region (from lecture by W. R. Dickinson at the University of Nevada, April 1971).

At least three episodes of tectonic activity are recognized in the Red Canyon mining district. Although Noble (1962) presented evidence for crustal instability following the deposition of the Gardnerville and Veta Grande formations, the present study did not provide evidence for this instability. The first recorded deformation seems to have been the initiation of a northeast-southwest compressive stress field which culminated in the development of joints, folding, faulting and local thrusting to which a Late Jurassic age has been assigned.

The next documented period of deformation is represented by compound intrusion of leucocratic plutonic rocks with attendant contact metamorphism and probable local faulting and flexing within the intruded Mesozoic sequence. An Early Cretaceous age has been ascribed to this plutonism. Subsequent batholithic intrusion in the 80 to 90 M.Y. age range to the west in the Carson Range has left its thermal imprint on the previous features.

High-angle normal faulting with northwest and east-west trends is indicative of the latest tectonic activity in Tertiary to Recent time.
This activity likely included both new structural breaks and reactivation of pre-existing faults.

Late Jurassic Tectonic Episode

Most of the deformation seen in the Red Canyon district can be assigned with a high level of certainty to a tectonic episode in Late Jurassic time. The question whether or not this was an event of very short duration or a continuing orogenic process through Jurassic and Cretaceous time as advocated by Ferguson and Muller (1949) remains open. One might envision the "Jurassic and Cretaceous orogeny" of Silberling and Roberts (1962) as beginning with regional deformation, spanning 15 to 20 million years, and terminating with a massive granitic intrusive pulse in Early Cretaceous time. Contrary to this supposition is the work of Taliaferro (1942) who asserted that the Nevadan orogeny occurred with great rapidity and was short lived. For the sake of discussion the writer has separated the early deformation from what appears to be somewhat later plutonism.

Consideration of regional aspects of this early tectonic episode in the southern Pine Nut Range strongly suggests the onset of a northeast-southwest oriented compressive stress system in the Late Jurassic (Figure 13). Supporting evidence for this temporal designation consists of the incorporation of Upper Triassic through Upper Jurassic rocks in folds on the west side of the Pine Nuts and the angular discordance of probable Upper Jurassic or Lower Cretaceous rocks (Double Spring formation of D. C. Noble) upon these folded strata.

Similar regional fold orientations which lend credence to the proposed northeast-southwest principal stress direction have been noted.
Figure 13. Schematic Representation of the Probable Stress Field Responsible for Early Deformation in the Southern Pine Nut Range.
in the folded Jurassic rocks of the Mt. Tallac roof pendant to the west in the Sierra Nevada (Loomis, 1960) and in pre-Cretaceous rocks of Alpine County, California, by Parker (1961).

Structural analysis of bedrock joints within the Mesozoic strata of Red Canyon yields an anisotropic distribution with a strong bias for northeast-trending steep joints (Figures 14a and 14b). Such a pattern is in agreement with an area undergoing compressive folding where steep cross-tension joints are developed parallel to the maximum stress axis (Badgley, 1959). This interpretation is dependent upon the homoclinal block in Red Canyon being a limb of a once broad fold whose axial trend would be coincident with folds to the west.

Several of the bedding plane faults recognized in the district are probably attributable to this early phase of deformation in which differential movement probably occurred on the flanks of folds. Figure 15 shows the ubiquitous shear zone between the massive carbonates of the Oreana Peak formation and the black siltstones of the Gardnerville formation. These bedding plane faults are in turn truncated by a major north-northeast trending fault which appears to pre-date the granitic rocks in Red Canyon.

Probably accompanying this early deformation was faulting of a tabular block of the lower volcanic member of the Oreana Peak formation into juxtaposition with the Preachers and Gardnerville formations northwest of the original Lucky Bill mine. Diamond drilling on the western end of the Doheny mine bench has confirmed the vertical attitude of this fault. Stratigraphic throw of over 2,000 feet is necessary to account for the present position of this block. The southern contact of this structure with the Preachers formation and upper member of the
Figure 14a. Rosette diagram for 300 bedrock joints measured within Mesozoic sequence of Red Canyon.

Figure 14b. Lower hemispheric density plot of poles to joints within the Mesozoic sequence of Red Canyon. Contours are 1%, 2%, 3%, 4%, and 5% of a 1% area. (equal area net)
Figure 15. Sheared contact between the Oreana Peak formation and Gardnerville formation. Troc = Oreana Peak formation (Triassic), Jol = Gardnerville formation-lower member (Jurassic), fi = Felsophyre intrusive. Refer to Plate 1, Geologic Map, for detailed explanation.
Gardnerville formation is a high-angle fault. A small sliver of the carbonate member of the Oreana Peak formation in apparent conformable contact with the lower volcanic member crops out at the southwest corner of this fault-bound block.

Two structural features whose age is very early in this Late Jurassic episode are the apparent repetition and tectonic elimination of the volcanic tuff member of the Veta Grande formation along the west central and southern sides of Section 2. This tectonic activity appears to have transpired prior to the intrusion of the felsophyre and may be related to an extension of the fault which brought in the lower member of the Oreana Peak formation. The absence of the volcanic tuff member just north of the pluton within Section 2 is interpreted as elimination by faulting. The trace of the fault is now obscured by alluvium.

Intrusions of felsophyre and attendant sulfide mineralization followed the initial faulting and folding, probably along zones of structural weakness created during the early disruptions of the sequence. An almost continuous sill-like body of felsophyre north of the old Lucky Bill mine passes along bedding in the Gardnerville formation into the lower volcanic member of the Oreana Peak formation with only slight offset.

One of the most spectacular features of the district which is tentatively assigned to this early tectonic activity is the Lucky Bill thrust (Figure 16). This thrust of a local nature displaces rocks of the lower member of the Gardnerville formation in a southwesterly direction over the Preachers formation (Plate 2, in pocket). An estimate of the magnitude of movement is complicated by subsequent
Figure 16. Lucky Bill thrust fault which displaces Gardner-ville formation over Preachers formation.
high-angle faulting but a dislocation of 300 to 400 feet in a southwesterly direction appears reasonable. The eastern extension of the Lucky Bill thrust is apparently truncated by a high-angle fault in an area of extreme structural complexity.

The Lucky Bill thrust zone attains a thickness of 12 to 15 feet and is accentuated by extreme brecciation of both upper plate (Gardnerville formation) and lower plate (Preachers formation) rocks. Important from the economic geology standpoint is the occurrence of totally granulated and attenuated felsophyre and pods of highly oxidized sulfides within the thrust zone (Figure 17).

The last recorded tectonic activity prior to or commensurate with the intrusion of the plutonic rocks in the Red Canyon district was the bifurcation of the Mesozoic sequence by what may be primary first-order left-lateral shear. A post-felsophyre age is confidently assigned to this faulting because it greatly displaces sill-like felsophyre intrusions in the Gardnerville formation. This fault displaces the eastern block approximately 3,500 feet to the north with respect to the western block and juxtaposes rocks of the Preachers formation against the volcanic sandstone member of the Veta Grande formation near the forks of Red Canyon (Figure 18). Large-scale drag effects are particularly evident in the upper member of the Gardnerville formation on either side of this shear. Parallel faulting in the volcanic tuff member of the Veta Grande formation in the eastern block and the fault sliver between the two blocks almost certainly are the result of this movement.
Figure 17. Lucky Bill thrust with granulated felsophyre and pods of oxidized sulfides. Rocks in the upper plate are badly broken siltstones of the Gardner-ville formation.
Figure 18. Major northeast-trending fault which juxtaposes limestones of the Oreana Peak formation against Preachers formation.
Early Cretaceous Deformation

A tectonic episode punctuated by compound plutonic intrusion in late Early Cretaceous time is recorded in the Red Canyon district. Recent radiometric age dating has confirmed previously observed intrusive relationships that implied an Early Cretaceous age for the Bullionville granodiorite and the Longfellow quartz monzonite.

Substantiated by K-Ar dating is the notion that the Bullionville granodiorite and the Longfellow quartz monzonite are very closely related in time and space. A tentative sequence of events is the possible evolution of both plutonic types from the same parent magma, initial intrusion of the Bullionville granodiorite into the Mesozoic sequence, and pursuant intrusion of the Longfellow quartz monzonite even before the granodiorite had undergone rest crystallization except on the outer margins. Epidote-covered primary joints which cut both intrusive types suggest a concurrent joint origin following the emplacement of the Longfellow quartz monzonite. Figures 19 and 20, which reveal generally isotropic joint patterns for both the Bullionville granodiorite and the Longfellow quartz monzonite, seem to point toward similar cooling and tectonic histories.

Some indications of forcible plutonic intrusion are evident in the Mesozoic rocks of Red Canyon. A change in strike from north-northeast to northwest of the main fault that divides the district may be attributable to stresses produced by forcible intrusion from a south-southwesterly direction. Moreover, the offset of the contacts of both plutonic rocks near the forks of Red Canyon may reflect local structural adjustments to this proposed stress system. Other
Figure 19a. Rosette diagram for 200 joints measured in the Bullionville granodiorite.

Figure 19b. Lower hemispheric density plot of poles to joints within the Bullionville granodiorite. Contours are 1%, 2%, 3%, 4%, and 5% of a 1% area. (equal area net)
Figure 20a. Rosette diagram for 200 joints measured in the Longfellow quartz monzonite.

Figure 20b. Lower hemispheric density plot of poles to joints within the Longfellow quartz monzonite. Contours are 1%, 2%, 3%, and 4% of a 1% area. (equal area net)
indications of non-passive magma ingress include local overturning of beds and shearing along some of the plutonic contacts.

Tertiary and Quaternary Faulting

High-angle Tertiary and Quaternary age faults with both large and small displacements occur in the southern Pine Nut Range. Moore (1969) provided evidence for at least 3,200 feet of displacement on the major normal fault at the east base of the range, based on displaced erosional remnants of the Hartford Hill Rhyolite of early Miocene age. Other north-trending normal faults with downthrown eastern sides separate the Pine Nuts into several structural blocks which dip gently to the west.

The current study did not disclose any faults of Cenozoic age with such large magnitude but downfaulting of Tertiary volcanic rocks against the Oreana Peak formation was noted in the north central part of the mapped area (Plates 1 and 2). More subtle was probable recurrent movement and new breaks along some of the northwest-trending bedding faults. These faults appear to exert considerable influence over the drainage pattern.
The depositional record prior to Late Triassic time is absent in the Red Canyon district, but shallow-water marine sedimentary rocks of the Luning Formation were being deposited to the southeast during the Middle Triassic. This sedimentation evidently continued as the dominantly detrital volcanic rocks of the lower member of the Oreana Peak formation were deposited. Widespread carbonate deposition in Late Triassic time is indicated by the massive limestone member of the Oreana Peak formation and coeval thin-bedded limestones and calcareous fine-grained clastics of the Gabbs and a portion of the Sunrise Formations to the east.

A change to a probable deeper, more restricted marine depositional environment occurred in the Early Jurassic as represented by carbonaceous fine-grained clastics of the Gardnerville formation. To the east, fine-grained carbonate deposition continued whereas a thicker section of a dominantly volcanic and detrital character was accumulating to the west.

A period of regional crustal instability with local erosion in Middle Jurassic time following the deposition of the Gardnerville formation was proposed by Noble (1962). This event may be correlative with the "Dunlap orogeny" of Ferguson and Muller (1949) in which continued orogenic activities from Early Jurassic time were indicated by their work within the Hawthorne and Tonopah quadrangles.

Sedimentation which followed in the Middle Jurassic with the deposition of the Preachers formation was once again indicative of shallow-water conditions. A partly volcanic terrane provided lithic
and feldspathic material under conditions of rapid erosion, short transport, and hastened burial.

Late Middle and Late Jurassic time marks a change to the accumulation of intermediate volcanic and volcanically-derived sedimentary rocks, as shown by the Veta Grande formation. Here the geologic history of Mesozoic sedimentation in the Red Canyon district ends due to subsequent deformation and Early Cretaceous plutonism. The record of any further Late Jurassic or Early Cretaceous sedimentation or volcanism as seen on the western side of the Pine Nut Range has been eliminated.

Uplift and deroofing of the plutonic rocks in the immediate area and the eruption of intermediate volcanic rocks in the Tertiary are the next documented events in the geologic record. Continued Quaternary uplift and erosion are responsible for the present topography and bedrock exposures which permit this brief reconstruction of the geologic history of the Red Canyon district.
ORE DEPOSITS

Introductory Statement

The ore deposits of the Red Canyon mining district that were encompassed by this study can be divided into four types which include: (1) disseminated sulfides related to a set of contaminated mafic dikes, (2) small sulfide replacements along fractures and shear zones in massive limestones, (3) disseminated and massive sulfides which appear to be closely related to intrusions of felsophyre (quartz albitophyre), and (4) mesothermal sulfide-bearing quartz veins in granodiorite and quartz monzonite. Contact metamorphic copper-bearing deposits which occur at the mouth of Red Canyon and on the southern slopes of Oreana Peak are not included in this discussion.

Disseminated Sulfides Related to Mafic Dikes

Disseminated sulfides occur within a set of northeast-trending contaminated mafic dikes and for 4 to 5 feet into the adjacent wallrock in a very local area on the north side of Red Canyon (refer back to Figure 6 for a petrographic description of this rock). The principal sulfide mineral is pyrite with lesser amounts of chalcopyrite and pyrrhotite. These sulfides occur in tiny oxidized disseminations which consist mainly of an enveloping intergrowth of hematite-goethite (Figure 21).

The pyrite in the dike rock occurs as irregular corroded grains up to 350 μm in diameter. Most of the grains exhibit a caries texture with hematite-goethite replacing the pyrite, whereas some grains show a core replacement of hematite-goethite forming an
Figure 21. Oxidized sulfides found as disseminations in and adjacent to mafic dikes. Pyrite (py), chalcopyrite (cp), and pyrrhotite (po) are enveloped in hematite-goethite (hm-goe). (56X)
atoll-like texture. Pyrite occurs only within areas of hematite-goethite. Chalcopyrite in sparse amounts forms small anhedral grains seldom exceeding 70 μm in longest dimension and occurring with the hematite-goethite intergrowth or within pyrite. Pyrrhotite is found as small oval-shaped blebs within hematite-goethite and occasionally is associated with pyrite in the center of the atoll-like textures. A few of the pyrrhotite blebs appear to be replaced by goethite along cleavages. A tiny mineral grain tentatively identified as pentlandite was observed as an intergrowth in one of the pyrrhotite blebs. Subsequent geochemical analysis of the specimen revealed 20 ppm of nickel, part of which might be due to the presence of pentlandite rather than entirely to nickeliferous pyrrhotite.

It is difficult to give a valid paragenesis on the basis of a few mineral relationships seen in one polished section except to say that the sulfides are early and the oxides are obviously later. The hematite-goethite intergrowths attain dimensions of 1.4 mm or more and form octahedral pseudomorphs after an isometric mineral (magnetite?). In general the hematite tends to be restricted to the central areas around the sulfides and in turn is rimmed by goethite. Some of the oxide areas display contact rim textures which could either represent a true reaction rim or a mineralogic change in response to changing supergene conditions.

Sulfide Replacements in Limestone

A few small and scattered sulfide replacement bodies in limestone of the upper member of the Oreana Peak formation occur northeast of the Lucky Bill mine area. These weakly mineralized areas are usually
marked by a deep reddish-brown gossanous capping. At a shallow depth in very old workings, oxidized galena and surrounding cerussite was seen. Irregular fractures and shear zones seem to have been the locus for mineralization. L. F. Fleming reported silver values in excess of 50 oz/ton for a high-grade sample from this locale (personal communication, 1971).
Disseminated and Massive Sulfides Associated with Felsophyre

Throughout the mapped area disseminated sulfides are seen spatially related to widespread felsophyre intrusions and two mineralogically distinct massive sulfide varieties were noted near the Lucky Bill mine area. One variety of massive sulfide, mainly chalcopyrite-pyrrhotite-sphalerite, was obtained from diamond drill core. The other mineralogical type consists of sphalerite-galena-pyrite and came from a sulfide lens discovered in the sinking of a winze north of the original Lucky Bill mine.

Disseminated Sulfides Related to Felsophyre Intrusions

Disseminated sulfides occur in nearly every outcrop of the felsophyre which has intruded the Mesozoic sequence on a wide scale. These intrusions are particularly evident as peneconcordant bodies in the lower member of the Gardnerville formation. Elsewhere it forms both concordant and discordant intrusions, as seen in the Preachers formation. Regardless of the site of emplacement of the felsophyre, the accompanying sulfides often have some geochemical expression other than one derived from simple iron sulfides or their oxidation products. Plates 3 and 4 (in pocket) show the geochemical distribution of copper, zinc, nickel, and cobalt from 58 surface rock chip samples and identifies the rock type by generalized geologic contacts.

Examination of Plate 3 reveals several areas of apparently anomalous copper and zinc values. Especially noteworthy in the central portion of the district are high zinc values in the felsophyre in the upper plate of the thrust and to the north in the Gardnerville formation.
adjacent to the felsophyre sill. Within the eastern part of the district anomalous copper, zinc, and cobalt values were mainly detected in altered sandstones of the Preachers formation, whereas samples from the felsophyre body to the north were relatively low.

A sample of the felsophyre collected from the sill-like body east of the Lucky Bill mine consists of a fine aggregate of several sulfide minerals (Figure 22). In polished section pyrite occurs as several generations and shows various degrees of formation. One variety of pyrite, probably early or at least hypogene, shows subhedral to euhedral crystals with inclusions of carbonate gangue. A second form of pyrite is anhedral and grades into or is rimmed by a fine-grained intergrowth which may be pyrite and marcasite and is called a "birds eye" texture. These "birds eyes" range in size from 25 to 75 μm, show concentric zoning, and have a distinct brownish cast. According to Ramdohr (1969, p. 596), this "birds eye" texture is a fine-grained intergrowth of pyrite and marcasite derived from the oxidation of pyrrhotite. This observation is supported by numerous occurrences of unoxidized pyrrhotite within the felsophyre elsewhere in the Red Canyon district.

There is considerable petrographic evidence that not all the sulfides are epigenetic as seen in the above polished section. As mentioned in the discussion of igneous rocks, pyrite and pyrrhotite occur as isolated euhedral grains in much of the felsophyre, completely unassociated with any veinlets or fractures. The felsophyre magma quite possibly could have been a sulfide-rich system that produced sulfide minerals upon crystallizing and later yielded sulfides to fluids that permeated and mineralized the solidified and fractured felsophyre itself and in some instances, the adjoining wallrock.
There is a large discordant telophyric intrusion into the Preachers Formation in the western half of the district. Southeast of this main body of telophyres are several smaller, elliptical contacts. Tiny quartz veins cut into these contacts, and published analyses indicate the Preachers which yields anomalous copper, zinc and lead values (Figure 29). These altered zones are reported to show intense alteration patterns on the porphyry cap, and values are recorded that are significant in the determination of orebodies which control the mineralization. Massicot was detected in the analyses.

![Figure 22. "Birds eye" intergrowths of pyrite (py) and marcasite (mr) in calcite gangue (CaCO₃). (86X)](image)

A thin section of porphyry caprite can show the presence of pyrite grains, galena, chalcopyrite, and other minerals intergrown in calcite matrix.

The pyrite appears as adhered to, adhering, or partly separated from calcite matrix. It is often in thin form, from 50 to 600 by 0.1 to 0.6 mm in diameter, and occurs usually in clusters of...
There is a large discordant felsophyre intrusion into the Preachers formation in the eastern half of the district. Southwest of this main body of felsophyre are several bleached, silicified (exhibit tiny quartz veinlets in thin section), and limonite stained areas in the Preachers which yielded anomalous copper, zinc and cobalt values (Figure 23). These altered areas are indicated by an orange stippled pattern on the geologic map. As shown on geologic cross section B - B', Plate 2, the felsophyre probably underlies the area of anomalous geochemical values at a very shallow depth and is perhaps responsible for the anomaly. The reader will also note that the altered areas contain beds which are steeply overturned to the north, implying some structural control for mineralization.

Massive Sulfides Associated with Felsophyre

A lens of sulfide ore consisting mainly of sphalerite-galena-pyrite was discovered and partly mined during mining operations north of the original Lucky Bill mine by the E. L. Doheny Mining Company in 1969 (Figure 24). This body apparently had an east-west strike and raked gently to the west toward a north-northwest trending fault zone. The shaft and short drift are now flooded and inaccessible. Smelter analyses on slightly less than 23 tons of ore shipped to the Shelby Smelter of the American Smelting and Refining Company are shown in Table 2.

A dump grab-sample of massive sulfide ore from the Doheny winze was studied in polished section (Figure 25). It consists of pyrite, galena, sphalerite, and very minor chalcopyrite in calcite gangue. The pyrite occurs as anhedral to euhedral crystals which vary in size from 50 to 650 μm and which can either occur alone or in clusters of
Figure 23. Contact relationships between altered and unaltered Preachers formation. Bedding is steeply overturned to the north, as seen in the upper left.
Figure 24. Winze sunk into felsophyre sill in 1969. Light felsophyre sill is above winze and intrudes Gardnerville formation (dark).
<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au</td>
<td>0.0175 oz/ton</td>
</tr>
<tr>
<td>Ag</td>
<td>32.45 oz/ton</td>
</tr>
<tr>
<td>Pb</td>
<td>9.05%</td>
</tr>
<tr>
<td>As</td>
<td>0.2%</td>
</tr>
<tr>
<td>Sb</td>
<td>0.1%</td>
</tr>
<tr>
<td>Fe</td>
<td>12.4%</td>
</tr>
<tr>
<td>Ca</td>
<td>11.3%</td>
</tr>
<tr>
<td>Zn</td>
<td>19.8%</td>
</tr>
<tr>
<td>S</td>
<td>21.3%</td>
</tr>
<tr>
<td>insoluble</td>
<td>11.9%</td>
</tr>
</tbody>
</table>
grains. In some of the clusters, pyrite has a cataclastic texture with galena and calcite acting as a "cement" in the interstices. Where pyrite has incursions of galena, sphalerite, and arsenopyrite, galena appears to replace the pyrite and is associated with open fractures. Galena also occurs as blebs within sphalerite and as blebs on grain boundaries in the calcite matrix. Occasionally, these blebs extend into surrounding interstices of galena to form clusters. The blebs are small.

Figure 25. Clusters of pyrite with cataclastic texture. Galena (gn) and calcite occupy much of the intervening space. (86X)
grains. In some of the clusters pyrite has a cataclastic texture with galena and calcite acting as a "cement" in the interstices. Where pyrite has inclusions of galena, sphalerite, and carbonate, galena appears to replace the pyrite and is associated with fine fractures. Galena also occurs as inclusions within sphalerite and as isolated grains in the carbonate gangue. Sphalerite forms anhedral grains with abundant inclusions of galena and in some areas shows chalcopyrite emulsion textures. Deep reddish internal reflections suggest that the sphalerite is an iron-rich variety. A tentative paragenetic sequence for the single specimen of Doheny ore is shown in Figure 26.

A zone of narrow massive sulfide stringers of contrasting mineralogy to the one just described was disclosed in a vertical diamond drill hole approximately 900 feet south of the Doheny winze. The hole was collared in carbonate rocks of the upper member of the Gardner-ville formation and first encountered sparse chalcopyrite at a shallow depth of 16 feet. Chalcopyrite and pyrrhotite in calcite gangue were scattered through the core to a depth of 27 feet. The attitude of these mineralized intercepts was not determined nor was this drill hole location and others tied into a land survey.
Figure 26. Paragenetic diagram of sulfide ore from Doheny winze.
A general description of the opaque mineralogy follows which is based upon study of two polished sections from the shallow intercepts within the fore-mentioned diamond drill hole. Chalcopyrite, sphalerite, pyrrhotite, pyrite and marcasite in a calcite and minor quartz gangue were positively identified. An unnamed mineral may also be present. Megascopically the mineralization shows a crude mineralogical banding.

Chalcopyrite occurs as isolated anhedral grains in carbonate gangue and as anhedral grains associated with other sulfides, as shown in Figures 27a and 27b. Sphalerite usually occurs with chalcopyrite as anhedral grains but no emulsion texture was seen where chalcopyrite was included in sphalerite. Unoxidized pyrrhotite forms large fractured, anhedral grains that are veined by gangue minerals.

Some interesting oxidation textures are developed within the fractures and cleavage planes in pyrrhotite. The most common of these oxidation textures is the already mentioned "birds eye" texture which consists of a fine-grained intergrowth of pyrite and marcasite (Figures 28a and 28b). The second characteristic texture is a cellular pseudomorph after pyrrhotite and is comprised of complex intergrowths of pyrite, an "intermediate product", and true marcasite. The "intermediate product" is an unnamed mineral whose properties are similar to marcasite according to Ramdohr (1969, p. 596-697). Most of the pyrite seen in polished section appears to have resulted from oxidation of pyrrhotite, although some very small euhedral pyrite crystals of probable hypogene origin were seen in a few pyrrhotite grains.

Gangue minerals include predominantly calcite with subordinate quartz and appear to have been introduced in at least two generations, one pre-sulfide and the other very late in the history of the mineral
Figure 27a. Anhedral chalcopyrite (cp) and sphalerite (sl) in calcite gangue (gg). (86X)

Figure 27b. Oxidation products of pyrrhotite replacing chalcopyrite. Note irregular blebs of sphalerite. (86X)
Figure 28a. "Birds eye" oxidation texture developed in pyrrhotite (po), consisting of pyrite (py) and marcasite (mr). (86X)

Figure 28b. Cellular pseudomorph of pyrite and marcasite after pyrrhotite. Anhedral sphalerite (sl) and chalcopyrite (cp) are noted on the right of the photomicrograph. (86X)
suite. Alteration around this mineralization consists primarily of a narrow envelope of chlorite and sericite. Also seen in the drill core was a sooty material that resembled chalcocite but it apparently was lost in the preparation of the polished section.
Discussion of Felsophyre-Related Deposits

In recent years there has been an increasing awareness and investigation of sulfide deposits related to deformed eugeosynclinal belts. These deposits are notable for their lack of compelling evidence to genetically relate them to orogenic granitoid rocks. Moreover, support is accumulating which suggests a more complex history involving volcanic processes and the deposition of sulfides either accompanying the placement of the host rocks or shortly following, while others show some indications of later formation generally related to small pre-orogenic intrusions.

The mineralogy of massive sulfide ("pyritic") deposits is relatively simple, consisting mainly of pyrite and/or pyrrhotite usually with amounts of sphalerite, chalcopyrite, and galena whose ratios vary within individual and different deposits. Another characteristic of volcanogenic sulfide deposits is their tendency to form conformable ore bodies (hence the designation "strata-bound"), however cross cutting sulfides do occur in many of the Canadian deposits of Precambrian age. Tertiary analogs of the older sulfide deposits are seen in the Kuroko ores of northeastern Japan. Recent summaries concerning volcanogenic sulfides are presented by Hutchinson et al. (1965), Kinkel (1966), Anderson (1969), and Smirnov (1970).

The sulfide occurrences near the Lucky Bill mine area in Red Canyon show some strong similarities to classic volcanogenic sulfide deposits. Features that are common to the Red Canyon deposits and those documented in the literature are: (1) regional geologic setting, (2) ore mineralogy and textures, (3) shape and attitude of the ore
bodies, (4) wallrock alteration, (5) trace element geochemical associates, and (6) the probable pre-orogenic age of the mineralization. A comparison of the Red Canyon deposits with Canadian massive sulfides is made in Table 3.

Disseminated and massive sulfide mineralization in Red Canyon occurs in a sequence of eugeosynclinal rocks of Mesozoic age. In comparison the pyritic deposits of the island of Cyprus occur at the top of a thick volcanic pile which accumulated in a eugeosyncline during Cretaceous time. Older analogous environments of volcanigenic sulfide deposition are the many Precambrian greenstone belts of Canada, which represent ancient mobile belts and arc-trench systems that have subsequently experienced several orogenic episodes. Other examples of probable volcanigenic sulfide deposits exist in the Foothill copper-zinc belt and in the East and West Shasta districts of California.

The ore mineralogy of the Red Canyon deposits is straightforward. Ores disclosed to date consist of two distinct mineralogical types which are a sphalerite-galena-pyrite ore within and adjacent to felsophyre and a chalcopyrite-pyrrotite-sphalerite variety revealed in a diamond drill hole. Both of these mineralogical groups are similar to those described in eugeosynclinally affiliated rocks throughout the world. Red Canyon ores exhibit cataclastic pyrite like many Canadian deposits but many of the original textures have been obscured by later supergene effects.

One of the first recognized features in this study was the peneconcordant nature of many of the felsophyre intrusions with which the mineralization is intimately associated. However, because there are discordant intrusions, cross-cutting ore bodies might be expected
<table>
<thead>
<tr>
<th>Red Canyon</th>
<th>Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regional Geologic Setting</strong></td>
<td><strong>Keewatin eugeosynclinal belts</strong></td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>few 100 tons to date</td>
</tr>
<tr>
<td><strong>Composition</strong></td>
<td>Massive and diss.</td>
</tr>
<tr>
<td><strong>Shape</strong></td>
<td>lens-like, elongated</td>
</tr>
<tr>
<td><strong>Rock Alteration</strong></td>
<td>Sericite, chlorite</td>
</tr>
<tr>
<td><strong>Mineralogy</strong></td>
<td>py, cp, po, gn, marmatitic sl</td>
</tr>
<tr>
<td><strong>Structural Geology</strong></td>
<td>deformed moderately by later orogeny</td>
</tr>
<tr>
<td><strong>Economic Metallization</strong></td>
<td>5.0% Cu (ddh) 19.8% Zn (Doheny winze) (estimate)</td>
</tr>
<tr>
<td><strong>Attitude</strong></td>
<td>long dimension steep conformable with possible cross-cutting bodies</td>
</tr>
<tr>
<td><strong>Ore Textures</strong></td>
<td>cataclastic py &quot;birds eye&quot; mr and py unmixed po mineralogical banding</td>
</tr>
<tr>
<td><strong>Common Gangue Minerals</strong></td>
<td>carbonates py gypsum</td>
</tr>
<tr>
<td></td>
<td>variable, up to 50 million tons of ore</td>
</tr>
<tr>
<td></td>
<td>massive, underlying stringers of sulfides</td>
</tr>
<tr>
<td></td>
<td>irregular, lenticular, pod-like, elongated</td>
</tr>
<tr>
<td></td>
<td>complex, several types</td>
</tr>
<tr>
<td></td>
<td>py, cp, po, marmatitic sl</td>
</tr>
<tr>
<td></td>
<td>all rocks deformed</td>
</tr>
<tr>
<td></td>
<td>0.5 to 5.0% Cu 0.5 to 12.0% Zn</td>
</tr>
<tr>
<td></td>
<td>0.50 to 4.0 oz/ton Ag 0.005 to .17 oz/ton Au</td>
</tr>
<tr>
<td></td>
<td>long dimension near vert. conformable and locally cross-cutting</td>
</tr>
<tr>
<td></td>
<td>colloform structure, cataclastic py, unmixed po mineralogical banding</td>
</tr>
<tr>
<td></td>
<td>carbonates barite anhydrite or gypsum quartz</td>
</tr>
</tbody>
</table>
too. A possible cross-cutting body is the mineralized zone found in the diamond drill hole, but this cannot be substantiated with the present data. Such geometrical dispositions of sulfide ore bodies of differing mineralogy are described in a paper by Stanton (1960). The ore body mined from the Doheny winze evidently was lens-shaped and had a tendency to pinch and swell in width while the long dimension was very steep. (L. F. Fleming, personal communication, 1971).

Wallrock alteration around the Red Canyon sulfide deposits consists of two types which include coarse-grained sericite-chlorite in the diamond drill core and partial to pervasive sericitization of the felsophyre intrusive rock. The felsophyre previously described as the fine-grained aphanitic variety is the dominant type that is exposed in the sill-like body on the ridge east of the Doheny winze. This felsophyre is highly sericitized while the adjacent black siltstones of the lower member of the Gardnerville formation are scarcely affected. Because the development of sericite seems to be confined to a small area in the district, it is attributed to alteration accompanying mineralization rather than to regional metamorphism to the greenschist facies which should affect the felsophyre everywhere more evenly. Anderson (1969) believes that alteration is a problem closely related to massive sulfide genesis and one which deserves intense study.

Several small areas in the Red Canyon district which show anomalous surface concentrations of copper and zinc also display high amounts of nickel and cobalt (Plates 3 and 4), which are not common geochemical associates in hydrothermal deposits of late-stage igneous derivation. A semi-quantitative spectrographic analysis of very slightly
mineralized felsophyre from east of the Doheny winze is shown in Table 4. Some of the minor elements seen in this table such as arsenic, chromium, titanium, and traces of nickel, cobalt, gold and silver were reported in a geochemical study of Canadian massive sulfide ores by Roscoe (1965), while barium is a common major element associate in volcanigenic deposits.

Evidence has been presented in a previous discussion of the igneous rocks of the Red Canyon district which points to a pre-plutonic age for the felsophyre. In addition, petrographic and polished section examination and field studies indicate an intimate association between the felsophyre (quartz albitophyre) and the observed sulfide mineralization. If one subjects the Red Canyon mineralization to metallogenic analysis of the sort proposed by Bilibin (1955), it fits a class of mineral deposits related to the early (E-3) stage of geosynclinal development. McCartney and Potter (1952) have attempted to apply Bilibin's ideas to the Canadian Appalachians. Other features of early geosynclinal development which appear to be present in the Mesozoic rocks of Red Canyon and which correspond to Bilibin's scheme are: (1) the type of intrusive, or specifically in Red Canyon, small stocks, sills, and plugs of felsophyre, (2) localized folding of probable Jurassic age in the western Pine Nuts was mentioned in the discussion of the structural geology, and (3) the rocks which were accumulating in the Late Jurassic were predominantly volcanic sandstones and andesitic volcanic rocks which are very similar to the lithologies characterized by Bilibin.

Several lines of evidence have been presented in this discussion which indicate that the sulfide mineralization around the Lucky Bill mine area in Red Canyon is not a typical hydrothermal deposit genetically related to acid plutonic rocks. Instead, the sulfides in the Red Canyon mining district show strong similarities to classical
TABLE 4

SEMI-QUANTITATIVE ANALYSIS OF SLIGHTLY MINERALIZED FELSOPHYRE

<table>
<thead>
<tr>
<th>Element</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>trace</td>
</tr>
<tr>
<td>Barium</td>
<td>1.2%</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.1%</td>
</tr>
<tr>
<td>Cobalt</td>
<td>trace</td>
</tr>
<tr>
<td>Copper</td>
<td>0.2%</td>
</tr>
<tr>
<td>Gold</td>
<td>trace</td>
</tr>
<tr>
<td>Iron</td>
<td>9.4%</td>
</tr>
<tr>
<td>Lead</td>
<td>0.3%</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.1%</td>
</tr>
<tr>
<td>Nickel</td>
<td>trace</td>
</tr>
<tr>
<td>Rubidium</td>
<td>trace</td>
</tr>
<tr>
<td>Silver</td>
<td>trace</td>
</tr>
<tr>
<td>Strontium</td>
<td>0.3%</td>
</tr>
<tr>
<td>Tin</td>
<td>trace</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.5%</td>
</tr>
<tr>
<td>Tungsten</td>
<td>0.1%</td>
</tr>
<tr>
<td>Vanadium</td>
<td>trace</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.2%</td>
</tr>
<tr>
<td>Zirconium</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

Sulfide deposits of volcanogenic origin. The Red Canyon sulfide mineralization probably occurred in Late Jurassic time during early tectonic and intrusive activity within the Cordilleran geosyncline and was closely associated with subvolcanic intrusions of felsophyre (quartz albitophyre).
Quartz Veins in Plutonic Rocks

The Longfellow mine at the crest of the Pine Nut Range is developed in one of several parallel mesothermal quartz veins in quartz monzonite and granodiorite. These near vertical veins strike N 70-75° W. The Longfellow vein can be traced for nearly one-half mile along strike. Most of the veins show some indications of pre- and post-mineralization movement. These veins are tentatively dated as Late Cretaceous or Early Tertiary in age. There are many surface trenches along the vein system providing good exposures (Figure 29). None of the reported 3,000 feet of underground workings is accessible.

The Longfellow vein consists of white to slightly limonite-stained, massive quartz with irregular pods and lenses of pyrite and specular hematite. Rich pockets of oxidized chalcopyrite, galena, sphalerite, and pyrite with both free and combined gold and silver were sporadically distributed in the vein and accounted for most of the early mined ore (Overton, 1947). Mining was evidently profitable in the upper oxidized and enriched zone but became unprofitable when protore was reached below 265 feet in the 1920's. A 1-foot chip sample from the limonite-stained quartz vein just west of the caved Longfellow shaft assayed Cu - 15 ppm, Zn - 25 ppm, Au - 2.3 ppm, and Ag - 72 ppm.

Hydrothermal alteration of the Longfellow quartz monzonite wallrock was noted within several feet of the quartz veins near the Longfellow mine (Figure 30). The alteration has resulted in medium-grained sericitization of plagioclase, a turbid appearing argillic alteration of K-feldspar, and transformation of biotite to magnetite and chlorite. Opaque minerals like magnetite exhibit alteration to
Figure 29. Surface trench along narrow quartz vein within Longfellow system.
hematite. Because the hydrothermal alteration itself is so spatially restricted in the area shown, a guide to ore. Although the ore zone is referred to, it looks even less significant on the map than it is given to the geologist.

Figure 30. Altered Longfellow quartz monzonite adjacent to vein near the Longfellow mine. Note abundant development of sericite and chlorite. (54X, crossed nicols)
hematite. Because the hydrothermal alteration of the quartz monzonite is so spatially restricted to the vein walls it does not serve as a guide to ore. Exploration for possible extensions on such deposits looks even less attractive today than in the 1920's, when consideration is given to the present prohibitive high cost of underground mining.
REFERENCES CITED


