University of Nevada
Reno

Geology and Mineral Deposits of the Pyramid District, Southern Washoe County, Nevada

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

by

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The Pyramid district is thirty miles north-northeast of Reno, Nevada in the northern Pah Rah Range. Known mineralization in the district is confined to west and northwest trending veins along fracture zones and faults cutting the Late Oligocene to Miocene ash-flow tuffs of the Hartford Hill Rhyolite. The vein mineralization is only slightly younger (1-3 million years) than disseminated copper and molybdenum mineralization in the Guanomi quartz monzonite stock exposed six miles from the district. Post-mineralization rocks in the area include dacite stocks and lavas, and also lacustrine sediments, basaltic tuff-breccias, basalt flows, and ash-flow tuffs of the Pyramid Sequence.

Hypogene mineralization in the district displays well-defined zoning with a central enargite (luzonite)-pyrite zone, an intermediate polymetallic zone with tetrahedrite, sphalerite, galena, chalcopyrite, bornite, and pyrite, and an outer zone with galena and pyrite. The ash-flow tuffs of the Hartford Hill are pervasively propylitized with sericitic envelopes around veins, and in the central enargite-pyrite zone, advanced argillic alteration occurs between the veins and the sericitic envelopes.

Mineralization in the Pyramid district is similar to several Peruvian polymetallic vein systems, Butte, Montana, Chinkuashih, Taiwan, several Japanese polymetallic vein deposits, and also to districts in the San Juan Mountains.
of Colorado. At least one of the polymetallic vein systems in Peru (Morococha) is known to directly overlie a porphyry copper deposit and it is suggested that such an exploration target may lie beneath the central zone of the Pyramid district.
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INTRODUCTION

The Pyramid District is in the northern Pah Rah Range, thirty miles north-northeast of Reno, Nevada (Fig. 1). It can be reached by traveling State Route 33 north from Sparks to Mullen Pass where several unimproved gravel and dirt roads lead south into the district (Plate 1). These roads are passable year-round except in periods of heavy snow or rainfall, however maintenance decreases drastically as one proceeds south. A few prospectors live along Mullen Pass, but most of the area is uninhabited. The Guanomi Mine area is six miles east of what is generally considered the Pyramid district (Fig. 2) but is included in this report because the mineralization in the two areas are of about the same age and may be related.

The area is on the western margin of the Basin and Range Province. The Virginia Mountains, the Pah Rah Range, and the Virginia Range form an essentially continuous mountain chain broken by Mullen Pass and the Truckee Canyon. The northern Pah Rah Range is flanked on the southwest by Warm Springs Valley, on the north by Mullen Pass, and on the east by Pyramid Lake. Rugged relief characterizes most of the area and elevations vary from 4,000 feet in Mullen Pass to 7,500 feet at Monte Peak (Fig. 2). All runoff from the range eventually enters Pyramid Lake as Warm Springs Valley drains into the lake through Mullen Pass.

The climate of the area ranges from arid in the valley
Figure 1. Index Map To The Pyramid District And Vicinity
Figure 2. Geologic Map of the Mullen Pass Area. In part modified after McJannet (1957) and Bonham (1969).

- Landslide deposits
- Undifferentiated alluvium, gravels, and lacustrine sediments
- Ash-flow tuffs of the Pyramid Sequence
- Basalt and basaltic andesite lava flows of the Pyramid Sequence
- Basaltic tuff-breccia of the Pyramid Sequence
- Quartz-bearing dacite stocks and lava flows
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- Rhyolite lava flows of the Hartford Hill Rhyolite
- Ash-flow tuffs of the Hartford Hill Rhyolite
floors to semi-arid on the mountain slopes and peaks. Monthly precipitation averages for the long-term recording stations nearest the area indicate 5-8 inches of moisture per year at the lower elevations. More than fifty percent of the precipitation that falls on the area is snow (Glenn, 1968). Nearby Reno has a mean annual temperature of 50.1°F., a January mean of 31.8°F., and a July mean of 70.4°F. Temperatures range from winter lows of -20°F. to summer highs of as much as 105°F. Daily temperature ranges of 50-60°F are not uncommon.

Vegetation is rather sparse in the low-lying areas and becomes denser with increasing elevation. Axelrod (1962) and Bonham (1969) report juniper (Juniperus utahensis), mahogany (Cercocarpus ledifolius), basin sage (Artemisia tridentata), rabbit bush (Chrysothamnus rauseosus), desert peach (Prunus andersonii), plateau gooseberry (Ribes velutinum), and bitterbrush (Purshia tridentata) from elevations above 5,000 feet north of Truckee Canyon. Wild rose (Rosa gymnocarpa), cottonwood (Populus fremontii), several species of willows (salix sp.), chokecherry (Prunus cemissa), dogwood (Cornus californica), and hairy horsebrush (Tetradyinia glabrata) occur along stream courses. Occasional stands of Jeffrey pine (Pinus Jeffreyi) grow on areas underlain by highly altered rock on the eastern side of the range.

Although some land is open for new mineral location in the Pyramid district, patented and unpatented claims cover much of the mineralized area. Lands closed to mineral entry
include most of Warm Springs Valley south of Route 33 which is controlled by McCulloch Corp., the Pyramid Lake Indian Reservation (boundary shown on Plate 1 and Fig. 2), and the Monte Cristo ranch whose northern boundary is just south of the map area of Plate 1. North American Rockwell Corp. controls the Monte Cristo ranch and most of the patented claims in the district.

PREVIOUS WORK

Brief discussions of mining activity in the district are given by Whitehill (1877) and Lincoln (1923). Couch and Carpenter (1943) summarize the production from the district and Overton (1947) briefly describes the ore values and some of the workings.

Brooks (1956) mapped in detail the DeLongchamps and Maue-McCray uranium prospects in the Rainbow and Mine Canyons area (Fig. 2). He recognized several different rock units in the area and was the first to attempt any subdivision of the Tertiary rocks. McJannet (1957) mapped the area in and a few miles north of Mullen Pass and subdivided the Tertiary rocks into many units. Brooks' and McJannet's work was done before relatively recent advances in the understanding of the stratigraphy of ash-flow tuffs (Smith, 1960), and their map units are not consistent with present procedures in volcanic terranes. However their understanding of the relative ages and most of their structural interpretations are valid and were useful in the present study.

Gimlett (1965, 1967) reported the results of a gravity survey in Warm Spring Valley and presents a generalized geologic map of the valley. Glenn (1968) reported the results of a hydrologic study in Warm Springs Valley and also presented a generalized geologic map of the valley.

Reference to Bonham's Washoe and Storey Counties Report (1969) is made throughout this paper. Not only does his study provide the basis for the regional framework and correlation of major units, but his discussion of the district was the first to describe ore mineralogy and to suggest zoning in the district.

Geologists of American Selco Inc. mapped the Guanomi Mine area in detail (Prochnau, 1973). Results of the mapping and also subsequent drilling, sampling, and geophysics were kindly donated by American Selco to the Nevada Bureau of Mines and Geology. Holmes (1973) discussed uranium deposits in the area. McKee, et al (1972) reported strontium isotope values for the Hartford Hill Rhyolite and Zartmann (1974) reported lead isotope data for a sample from the Nevada Dominion Mine. Waggoner (1975) studied geologic hazards around the shores of Pyramid Lake.
The mining geology classes of Dr. Arthur Baker III at the Mackay School of Mines have done underground and surface mapping projects (scale 1:480) for several years in the Pyramid district. These reports were very helpful and several underground surveys were used in this report. In a follow-up to one of these projects, Ivosevic (1970) ran a ground magnetic survey in the district.

METHOD OF INVESTIGATION AND ANALYTICAL TECHNIQUES

Field work in the Pyramid district was done mainly in the summers of 1973 and 1974. The district was mapped on aerial photographs at 1:12,000 scale and these data were transferred to a topographic base of the same scale (enlarged from the Sutcliffe quadrangle, U. S. Geol. Survey 15 Minute series) (Pl. 1). A reconnaissance geologic map of the northern Pah Rah Range, the southern Virginia Mountains, and Mullen Pass was prepared on 1:48,000 aerial photographs and transferred to a 1:62,500 base from the Sutcliffe and Nixon quadrangles, U. S. Geol. Survey 15 minute series. Parts of McJannet's (1957), Bonham's (1969) and Prochnau's (1973) maps were used in the preparation of this map. Underground mapping at the Cinch and Burrus mines was done at 1:480 by the brunton and tape method.

All formations and principal prospects in the area were sampled for petrographic analysis; more than 250 thin sections and 30 polished sections were studied. Mineral identification was often aided by standard x-ray diffraction techniques.
Major element whole rock analyses were done on pressed powder pellets by X-ray fluorescence methods using a method similar to that described by Volborth (1969) employing a Siemens Kristalloflex IV generator and a universal sequential spectrometer (SRS-1). Analyses of water contained in the rocks follow the methods of Shapiro and Brannock (1962) for total water and Hutchinson (1974) for $\text{H}_2\text{O}^-$. Specific gravities of rock samples were determined on a Beckman No. 930 comparison pycnometer.

Copper, lead, and zinc analyses were performed on Perkin-Elmer model 290B and model 303 atomic absorption spectrophotometers. Samples were digested in heated nitric acid following techniques used by the Nevada Mining Analytical Laboratory. Gold and silver analyses were made by Phillip Youngblood of the Nevada Mining Analytical Laboratory using standard fire assay techniques. Results of silver analyses were checked by atomic absorption spectrophotometry.

Arsenic, antimony, and bismuth analyses were performed by Skyline Labs, Inc. Six step emission spectrographic analyses for bismuth were performed on a Jarrell-Ash 1.5 meter wadsworth mount instrument, with values read by visual comparison against standard films. The analytical method for antimony is that of Ward and Lakin (1954), but MIBK is used instead of ether, and the antimony is determined in the MIBK by atomic absorption spectrophotometry. Arsenic analyses involved a sodium hydroxide fusion followed by
arsine evolution from an HCl solution, and colorimetric estimation using silver diethyldithiocarbamate dissolved in l-ephedrine in chloroform (Kopp, 1973).

Semi-quantitative emission spectrographic analyses of selected ores and wall-rocks were performed in the Denver, Colorado laboratories of the U. S. Geol. Survey by D. Siems and B. Crim. The method is essentially that described above for bismuth analyses.

Mineral separates for potassium-argon dating were prepared by standard heavy liquid and magnetic methods. Potassium analyses were performed by Lois Schlocker in U. S. Geol. Survey labs, Menlo Park, California by differential flame photometry using lithium metaborate fusion, with the lithium serving as an internal standard (Sahr and Ingamelli, 1966). Argon analyses were made by standard isotope dilution techniques (Dalrymple and Lanphere, 1969). The samples were fused by RF induction heating and the extracted argon analyzed with a Nier-type, 6 1/2 inch-radius, 60° - sector mass spectrometer operated in the static mode. Argon analyses were made by M. L. Silberman.

Rock colors are described using the Geological Society of America Rock Color Chart. The Cenozoic time scale of Berggren (1972) is used throughout the report.
STRATIGRAPHY

GENERAL

All rocks exposed in the study area are of Tertiary age. Mesozoic metavolcanics, metasediments, and granitic rocks of the Sierran batholith crop out south of the study area and undoubtedly underlie the Tertiary rocks in the Pyramid district. No rocks older than Mesozoic are known in Southern Washoe County (Bonham, 1969).

Overlying the Mesozoic rocks unconformably are tuffs of the Hartford Hill Rhyolite. These tuffs, with minor associated lava, vary from rhyolite to quartz latite and were emplaced from about 28 to 21 million years ago. Six ash-flow tuff cooling units are exposed north of Mullen Pass. The exposed part of the Hartford Hill is thicker south of Mullen Pass in the Pyramid district (as much as 3,000 feet), but was only divided into four units there due to difficulties caused by hydrothermal alteration.

Volcanic rocks of the Pyramid Sequence overlie tuffs of the Hartford Hill in angular unconformity. The use of the word "sequence" follows Bonham (1969). In this paper the Pyramid Sequence has been divided into informal units that apply in the Mullen Pass area but may not apply elsewhere; formal subdivision of the Pyramid Sequence must await detailed stratigraphic studies.

In general, the rocks of the Pyramid Sequence are more mafic than the tuffs of the Hartford Hill. The sequence is
divisible into a lower tuff-breccia, middle basalt lavas, and upper ash-flow tuffs. The basalt lavas are about 16 m.y. old and the uppermost ash-flow at about 12-13 m.y. old (Bonham, 1969).

Tertiary intrusive rocks in the area include a mineralized quartz monzonite stock exposed near the Guanomi mine and quartz dacite stocks along Mullen Pass. Both intrude the Hartford Hill but are overlain unconformably by rocks of the Pyramid Sequence. A few basalt or basaltic andesite dikes cut the tuffs of the Hartford Hill and probably are feeders for overlying lava flows.

**MESOZOIC ROCKS**

Although no Mesozoic rocks are found in the Pyramid district, brief descriptions are included as they are probably at shallow depths in parts of the district and may be penetrated in exploratory drilling projects. The following discussion is taken largely from Bonham (1969).

**PEAVINE AND NIGHTINGALE SEQUENCES**

Metavolcanic and metasedimentary rocks of probably Triassic and(or) Jurassic age occur in small roof pendants and isolated windows in Tertiary and Quaternary rocks in southern Washoe County. Southwest of Pyramid Lake these rocks are dominantly metavolcanic and were called the Peavine Sequence by Bonham (1969). Northeast of Pyramid Lake the rocks are dominantly metasediments and are called the
Nightingale Sequence. The rocks range in metamorphic grade from greenschist facies to pyroxene hornfels near contacts with intrusive rocks. The boundary between the two types may be a facies change or may be due to the Walker Lane structural zone which coincides with the boundary.

PLUTONIC ROCKS

Most of the Mesozoic rocks in southern Washoe County are plutonic rocks, inferred by many authors to be a part of a northern extension of the Sierra Nevada batholith (Smith, et al, 1971). Several ranges west of the study area, such as Dogskin Mountain and Petersen Mountain (Fig.1), are dominantly such plutonic rocks.

Most of these rocks are biotite-and hornblende-bearing granodiorites and quartz monzonites of phaneritic texture. Quartz diorites and gabbros are known but are rare. Pegmatite and aplite dikes and pods are common.

These plutons are inferred to be Mesozoic in age and intrude rocks that are presumably Triassic and Early Jurassic. Bonham reports an age of 88.8 ± 2.6 m.y. for biotite in the Granite Range batholith, about 60 miles north of the Pyramid district. Smith, et al. (1971) reports ages of 91.2 ± 3.1 m.y. on biotite and 91.9 ± 6.1 m.y. on hornblende from the same pluton. These dates correspond with ages of rocks of the Sierran batholith to the south reported by many authors. Hence Bonham mapped these rocks as Jurassic to Cretaceous pending further data.
TERTIARY VOLCANIC ROCKS

HARTFORD HILL RHYOLITE

The Hartford Hill Rhyolite was named by V. P. Giannella (1936) from exposures in the Comstock Lode and Silver City districts; its type locality is Hartford Hill near Silver City. The Hartford Hill Rhyolite is the oldest widespread Tertiary unit in southern Washoe County and overlies Mesozoic metamorphic and granitic rocks with unconformity (Bonham, 1969). The name of the formation is somewhat a misnomer as the unit is almost entirely of pyroclastic origin (Thompson, 1956), not lava flows as originally thought by Giannella (1936) and Calkins (1944). The Hartford Hill in the Pah Rah Range and Virginia Mountains is composed almost totally of ash-flow tuff, although local rhyolite lavas, air-fall tuffs, and mudflows are present.

South of Mullen Pass, the Hartford Hill is hydrothermally altered, but excellent exposures north of Mullen Pass in the Rainbow and Mine Canyons area provide fresh, unaltered rocks for detailed examination. This study is mainly concerned with the mineralized area south of Mullen Pass, but because no detailed stratigraphy has been reported on Hartford Hill rocks since advances in knowledge about ash-flow tuffs (Smith, 1960; Ross and Smith, 1961), each area will be discussed and correlations attempted.

Hartford Hill Rhyolite of the Rainbow-Mine Canyons Area

The best exposures of ash-flow tuffs of the Hartford
Hill Rhyolite are in the Mine and Rainbow Canyons area in Sec. 36, T. 24 N., R. 20 E., Sec. 1, T. 23 N., R. 20 E., and Sec. 6, T. 23 N., R. 21 E. (Fig. 2). The three lower cooling units are best exposed in Mine Canyon and the upper three are best exposed in Rainbow Canyon. Detailed maps of the area by Brooks (1956) and McJannet (1957) are available but their subdivisions do not conform to presently accepted ash-flow terminology. Figure 3 shows a correlation chart of the stratigraphic sections of Brooks, McJannet, and this work.

The basis for my subdivision of the Hartford Hill stratigraphic section is the "ash-flow cooling unit" as described by Smith (1960) and Ross and Smith (1961). Each of the six cooling units have certain features in common which will be summarized in the following paragraphs; the descriptions of the individual units concentrate on distinguishing features.

Each cooling unit shows a well developed vertical zonation in welding, crystallization, and composition. Welding grades from a poorly or non-welded zone near the base to a densely welded zone towards the top of the cooling units. No upper poorly welded zones were identified in the area; they probably were eroded between eruptive cycles. The groundmasses are usually glassy near the base and become progressively more devitrified to spherulitic and axiolitic intergrowths of cristobalite (?) and alkali feldspar toward the upper, more densely welded zones. Composition variation is often reflected in the phenocryst mineralogy as more
Figure 3. Correlation chart for the stratigraphic divisions of Brooks (1956), McJannet (1957), and the present study.
ferromagnesian minerals, more calcic plagioclase, more total crystals, and larger crystals occur near the tops of the units. Compositional zonation in ash-flow cooling units has been described by Lipman, et al. (1966), Smith and Bailey (1966), Byers, et al. (1968), Noble, et al. (1968), Noble and Hedge (1969) and many other authors. Such zonation is generally accepted as the result of progressive eruption from a vertically compositionally zoned magma chamber.

A porphyritic texture dominates with broken and deformed phenocrysts of highly variable percentage and up to 5 mm. in diameter. Figure 4 graphically displays the phenocryst mineralogy of each unit. Groundmasses display eutaxitic textures and are composed of glass shards and glass dust (sometimes devitrified). The porous groundmasses of the basal zones of the cooling units often contain gypsum (?) and an unidentified carbonate that probably were deposited by groundwater long after deposition of the tuffs. Pumice fragments are common to all the tuffs but their percentage varies widely. Lithic fragments are present in all the units and range from minor to a major proportion of the rock.

The ash-flow cooling units are locally separated by air-fall tuffs (distinguished by their well developed bedding and sorting), weathering horizons, and, occasionally, mudflow breccias. No obviously compound cooling units were seen, nor were any vitrophyric zones identified.
Figure 4. Histograms showing phenocryst mineralogy of ash-flow cooling units 1 to 6 of the Hartford Hill Rhyolite, Rainbow and Mine Canyons. The first five columns total 100%. Column 6 indicates percentage of phenocrysts in the tuffs. Vertical compositional changes in the tuffs are averaged.
Cooling Unit 1

The lower contact of cooling unit 1 is not exposed in the Virginia Range, but it is assumed to be the basal unit because the unit is similar to the tuff overlying Mesozoic granodiorite at Dogskin Mountain (Fig. 1). Approximately 400 feet of the tuff are exposed in the base of Mine Canyon.

The tuff contains 30% phenocrysts, of which 85% are plagioclase (up to 3 mm.), 13% are biotite (up to 1.5 mm.), and 1-2% are anhedral sanidine (up to 1 mm.). Minor iron oxide and apatite occur in the groundmass. Pumice fragments (up to 15 mm.) are not very abundant, but occasionally reach 10% of the rock. Lithic fragments of volcanic rock and chert (less than 5 mm.) are 2-3% of the rock. The unit varies from grayish pink (5R 8/2) at the base to pale red (10R 6/2) at the top.

Cooling unit 1 correlates with Brooks' "A" and "U" units. It also correlates to the lower part of McJannet's Tule Peak Formation, specifically the Basal Member and the lower 60' of his Mine Canyon Member. A biotite separate from this unit yielded a K/Ar date of 27.9± 0.8 m.y. before present (Table 1). This age corresponds to a Middle Oligocene age for the lowermost exposed Hartford Hill in the Virginia Mountains.

Cooling Unit 2

Cooling unit 2 is approximately 100 feet thick in the Mine Canyon area. The unit contains 10-15% phenocrysts
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Field No.</th>
<th>Mineral</th>
<th>Weathered</th>
<th>K₂O (wt. %)</th>
<th>Ar⁴⁰ radiogenic (moles/gm. X 10⁻¹⁰)</th>
<th>Ar⁴⁰ rad. / Ar⁴⁰ total</th>
<th>Apparent Age (m.y.)</th>
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<td>Ttcm</td>
<td>plagioclase</td>
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<td>0.2546 42%</td>
<td>21.6 ± 0.6</td>
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<td>0.809</td>
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<tr>
<td>1b</td>
<td>Ttcm</td>
<td>biotite</td>
<td>8.52</td>
<td>2.854 72%</td>
<td>22.6 ± 0.7</td>
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<td>8.49</td>
<td></td>
<td>Average 22.1 ± 0.5</td>
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<td>2</td>
<td>HH-1</td>
<td>biotite</td>
<td>8.00</td>
<td>3.284 60%</td>
<td>27.9 ± 0.8</td>
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<tr>
<td>3</td>
<td>AW-1, CPI</td>
<td>plagioclase</td>
<td>0.606</td>
<td>0.1737 35%</td>
<td>19.3 ± 0.8</td>
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<td></td>
<td>0.607</td>
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<tr>
<td>4</td>
<td>DAC-AF</td>
<td>plagioclase</td>
<td>0.730</td>
<td>0.2268 43%</td>
<td>20.7 ± 0.6</td>
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<tr>
<td>5</td>
<td>NEVDOM</td>
<td>sericite</td>
<td>8.22</td>
<td>2.599 67%</td>
<td>21.3 ± 0.7</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8.15</td>
<td></td>
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<tr>
<td>6</td>
<td>MLS-73-P9</td>
<td>quartz, sericite</td>
<td>2.021</td>
<td>0.6958 39%</td>
<td>23.4 ± 0.7</td>
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Units dated and sample locations:
1a. Cooling unit 6 of the Hartford Hill Rhyolite, SW1/4, NW1/4, NE1/4, sec. 1, T. 23 N., R.21 E.
1b. Same sample as la above.
2. Cooling unit 1 of the Hartford Hill Rhyolite, NW1/4, SE1/4, SW1/4, sec. 36, T.24N., R.20 E.
3. Dacite intrusive, NE1/4, SW1/4, NE1/4, sec. 23, T. 23 N., R. 21 E.
4. Dacite lava flow, SE1/4, NE1/4, SW1/4, sec. 15, T. 23 N., R. 21 E.
<table>
<thead>
<tr>
<th>Table 1: Continued</th>
</tr>
</thead>
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<tr>
<td>5. Sericite produced during hydrothermal alteration, Nevada Dominion adit, NE1/4, NW1/4, SW1/4, sec. 15, T. 23 N., R. 21 E.</td>
</tr>
</tbody>
</table>

K\(^{40}\) decay constants: 
\[ \begin{align*} 
\alpha &= 0.585 \times 10^{-10} \text{ year}^{-1} \\
\beta &= 4.72 \times 10^{-10} \text{ year}^{-1} 
\end{align*} \]

Abundance ratio: \( \text{K}^{40}/\text{K} = 1.19 \times 10^{-4} \) atom percent


(up to 3.5 mm.) of which 75% are anorthoclase rimmed with sanidine. The alkali feldspar, often resorbed, has a blue chatoyancy in hand sample. Euhedral plagioclase (1.5 mm.) makes up 10-15% of the phenocrysts and increases slightly in amount toward the top of the unit. A trace to 1% of anhedral, resorbed quartz (.1 mm.) occurs as phenocrysts. In the upper, thoroughly-devitrified zone anhedral quartz (.02 mm.) occurs in the matrix. Pumice fragments range from 30 mm. in the base to 10 mm. in the top where they are totally collapsed to black, dense glass with fiamme structure. The percentage of pumice varies from 10% in the top to 40% in the base of the unit. Lithic fragments of quartzite and various volcanic rocks range up to 20% in the upper part of the unit where they are more common. The unit ranges from moderate pink (5R 7/4) in the base to pale red (5R 6/2) with black, collapsed pumice in the densely welded zone.

Cooling unit 2 corresponds to Brooks' unit "B". The unit also corresponds to McJannet's Mine Canyon Member and a few feet of the lower part of the Pumice Member of his Tule Peak Formation.

Cooling Unit 3

Cooling unit 3 is well exposed in prospects in the Mine Canyon area where it hosts small amounts of uranium. The unit is approximately 380 feet thick.

The percentage of phenocrysts varies from 10% near the base to 50% in the upper, densely-welded zone. Phenocrysts
are mostly equal amounts of sanidine and quartz, but re­sorbed plagioclase and oxybiotite become 10% of the phenocrysts in the top of the unit. The sanidine (2 mm.) is subhedral to euhedral and has a brilliant blue chatoyancy. The quartz (2 mm.) is resorbed near the base of the unit but occurs in euhedral bipyramids in the upper parts. Pumice (up to 5 mm.) is 5-10% of the rock and only minor lithic fragments are present. In the upper, strongly-devitrified zone, the phenocrysts are occasionally overgrown with fibrous material, and tiny crystals (.02 mm.) of quartz and feldspar are 50% of the matrix. The phenocrysts of quartz are reported to become smoky near uranium occur­rences (Brooks, 1957; Holmes, 1972). Color varies from pinkish gray (5YR 8/1) at the base to moderate reddish orange (10R 6/6) at the top. Two major element chemical analyses of this unit are included in Table 2.

The lower poorly welded zone of this cooling unit corresponds with Brooks' "C" unit and McJannet's Pumice Member of the Tule Peak Formation. The upper more densely-welded and devitrified part of this cooling unit corresponds to Brooks' "D" unit and McJannet's Crystal Tuff Member of the Tule Peak Formation.

Cooling Unit 4

Cooling unit 4 is approximately 320 feet thick in the Rainbow Canyon area where an almost complete vertical section is exposed. The percentage of phenocrysts varies
<table>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<tbody>
<tr>
<td>SiO₂</td>
<td>72.3</td>
<td>76.6</td>
<td>65.8</td>
<td>67.7</td>
<td>64.9</td>
<td>51.5</td>
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<tr>
<td>Al₂O₃</td>
<td>13.5</td>
<td>11.2</td>
<td>15.3</td>
<td>14.3</td>
<td>15.0</td>
<td>18.1</td>
<td>15.7</td>
<td>17.6</td>
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<td>Fe as</td>
<td>2.45</td>
<td>1.48</td>
<td>3.76</td>
<td>3.52</td>
<td>3.55</td>
<td>8.52</td>
<td>8.90</td>
<td>4.24</td>
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<tr>
<td>FeO</td>
<td>0.12</td>
<td>0.36</td>
<td>1.70</td>
<td>2.56</td>
<td>2.43</td>
<td>4.80</td>
<td>7.07</td>
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<td>MgO</td>
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<td>0.92</td>
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<td>3.60</td>
<td>3.41</td>
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<td>CaO</td>
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<td>3.4</td>
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<tr>
<td>Na₂O</td>
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<td>3.44</td>
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<td>3.59</td>
<td>1.34</td>
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<td>K₂O</td>
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<td>0.34</td>
<td>0.16</td>
<td>0.13</td>
<td>0.54</td>
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<tr>
<td>H₂O⁺</td>
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<td>2.74</td>
<td>1.45</td>
<td>0.26</td>
<td>0.51</td>
<td>0.71</td>
<td>0.56</td>
<td>0.92</td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>0.31</td>
<td>0.12</td>
<td>0.62</td>
<td>0.46</td>
<td>0.52</td>
<td>1.23</td>
<td>1.11</td>
<td>0.58</td>
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<td>TiO₂</td>
<td>0.05</td>
<td>0.04</td>
<td>0.16</td>
<td>0.18</td>
<td>0.16</td>
<td>0.53</td>
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<td>P₂O₅</td>
<td>99.89</td>
<td>100.28</td>
<td>100.27</td>
<td>100.14</td>
<td>97.81</td>
<td>98.92</td>
<td>97.27</td>
<td>99.55</td>
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1. RC-3, upper part of cooling unit 3 of the Hartford Hill Rhyolite, Mine Canyon.
2. RC-9, middle part of cooling unit 3 of the Hartford Hill Rhyolite, Mine Canyon.
3. RC-12a, middle part of cooling unit 6 of the Hartford Hill Rhyolite, Rainbow Canyon.
4. 50-1, Guanomi quartz monzonite stock, central part, propylitized.
<p>| | |</p>
<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>5</td>
<td>Guanomi quartz monzonite stock, outer part, propylitized.</td>
</tr>
<tr>
<td>6</td>
<td>47-4, Pyramid Sequence basaltic lava flow.</td>
</tr>
<tr>
<td>7</td>
<td>47-14, Pyramid Sequence basaltic lava flow.</td>
</tr>
<tr>
<td>8</td>
<td>DAC-AF, slightly propylitized dacite lava flow, upper part, near the Burrus mine.</td>
</tr>
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</table>
from 30% in the base to 60% near the top. Phenocrysts are 50% anhedral, resorbed quartz (1.5 mm.), 35% euhedral sanidine (2.5 mm.), 10% euhedral plagioclase (2 mm.), 5% biotite (1.5 mm.), and a trace of hornblende (.4 mm.). The very top of the unit contains only a trace of plagioclase and no hornblende, and is devitrified to coarse spherulites with patchy areas of quartz and alkali feldspar crystals (.02 mm.). The phenocrysts in this zone have well developed overgrowths. The base of the unit is very rich in pumice, with unoriented and tubular pumice fragments ranging up to 30% of the rock and 10 cm. in length. Lithic fragments of foreign volcanic rock are abundant throughout the unit and locally make up to 10% of the rock. Color varies from grayish orange pink (10R 8/2) at the base to reddish brown (10R 5/4) at the top.

Cooling unit 4 corresponds to McJannet's Rainbow Canyon Member of the Tule Peak Formation, and also to Brooks' units "E", "F", and probably "G" and "H".

**Cooling Unit 5**

Cooling unit 5 is approximately 225 feet thick in Rainbow Canyon. The lowermost 150 feet of the unit is not exposed.

The unit averages 40% phenocrysts of which 70% are plagioclase (3.5 mm.), 20% are biotite (2 mm.), 8% are resorbed, anhedral quartz (2.5 mm.), and 1-3% are hornblende (.5 mm.), and the hornblende is highly resorbed. The matrix
contains traces of apatite, zircon, and iron oxides. Pumices range up to 5 mm. in length and up to 10% of the upper part of the unit. Color varies from light gray (N7) in the lowermost exposures to moderate orange pink (10R 7/4) in the upper part.

The uppermost part is brecciated with fragments averaging about 2 cm. The fragments are similar to their cementing matrix in thin section, but the matrix may be slightly more silicic. The lowermost exposure is partially devitrified and altered but was probably fused glass at one time as evidenced by common perlitic cracks and the lack of shard structures. Although now altered, this lowermost exposure may be as close to a vitrophyric horizon as there is in the Hartford Hill. The upper breccia contains some fragments that are similar in mineralogy and structure to the lowermost part; these may be fragments of non-vesiculated magma.

Cooling unit 5 corresponds to Brooks' "I" and "J" units and also to McJannet's Maue-McCray Member of the Tule Peak Formation.

Cooling Unit 6

The uppermost ash-flow cooling unit exposed in the Rainbow-Mine Canyons area is approximately 400 feet thick. The unit bears 50-60% phenocrysts of which 60% are plagioclase (1.4 mm.), 25% are resorbed bipyramids of quartz (2 mm.), 10% are biotite (1.2 mm.), 5% are oxyhornblende, and a trace are sanidine (.8 mm.). Apatite, zircon, rutile,
and iron oxides are disseminated in the groundmass. The lower part of the unit is 20-30% pumice fragments which range up to 10 cm. in length. Lithic fragments up to one foot in diameter are common near the base of the unit; most are of earlier Hartford Hill units, some are metavolcanics. Color varies from pale blue (5PB 7/2) at the base to light greenish gray (5GY 8/1) near the top. A major element chemical analysis from this unit is shown in Table 2.

Cooling unit 6 corresponds to Brooks' unit "K" and to McJannet's Cascade Member of the Tule Peak Formation. A plagioclase separate from this unit yielded a K/Ar age of 21.6± 0.7 million years before present and a biotite separate yielded 22.6± 0.8 m.y.

Mudflow Breccias

Mudflow breccias are interbedded with the Hartford Hill ash-flows. The best exposure of mudflow breccia is in the head of the canyon in the SW 1/4, SW 1/4, Sec. 31, T. 24 N., R. 21 E., where it crops out beneath cooling unit 3. Cooling unit 2 has been almost totally stripped away at this locality by erosion that occurred before the eruption of the overlying ash-flow and the mudflow is localized along an ancient stream channel. The mudflow breccia is about 75 feet thick at this locality. Most other outcrops of mudflow in the Rainbow and Mine Canyons area occupy the same stratigraphic position but are only a few feet thick.

Fragments in the breccia range in size from a few
millimeters to four feet in diameter. Most of the fragments (80%) are augite andesite, but fragments of phaneritic granodiorite, ash-flow tuff, metavolcanic rocks, chert, and quartzite were observed. Several types of fossil wood are also contained in the unit, some of which have been replaced by calcite and chalcedony. The augite andesite fragments contains glomero-porphyritic clots and isolated phenocrysts of large titaniferous augite (6 mm.) and plagioclase (An$_{50}$, 1 mm.) in a groundmass of subophitic and felty augite and plagioclase with minor glass. The matrix mineralogy is identical to the augite andesite fragments but is finer-grained and more equigranular. Pyroxenes are commonly altered to nontronite (?).

Bonham (1969) reports similar mudflows, which he named the Pah Rah Formations in the southern Pah Rah Range. These mudflows appear to lie beneath the Hartford Hill, but the lower contact is not exposed. Prochnau (1973) reports mudflows interbedded in the Hartford Hill from the Guanomi area. These mudflows may be roughly correlative as they have similar mineralogy and textures. It is not known if all the mudflows occupy the same stratigraphic horizon or where the source area of the mafic material is located.

Hartford Hill Rhyolite of the Pyramid District

The Hartford Hill rocks south of Mullen Pass in the Pyramid District have been pervasively hydrothermally altered, and individual ash-flow cooling units cannot be
differentiated as in the Rainbow and Mine Canyon area. In the altered tuffs, the section was only divided into three units, each of which could be easily recognized in the field. These units (plus one of rhyolite lavas) were adequate for mapping purposes. In some areas of the district where alteration is slight, these units definitely contain more than one cooling unit.

Alteration has made stratigraphic work in these tuffs difficult in several ways. The welding zonation is made much less prominent; the lower glassy zones have undergone secondary devitrification and are more cohesive, whereas the densely welded zone became less cohesive with alteration. The glass structures, such as pumice size, etc., are not as easily distinguished in hand sample. The color throughout several of the units is a monotonous light green, instead of the vivid colors and variations of the fresh tuff.

Phenocryst mineralogy is the most useful tool for division of the altered ash-flows into map units and for correlation with unaltered area cooling units. Several of the Hartford Hill units are rich in phenocrystic quartz and sanidine which do not alter readily. The phenocrysts that are altered can usually be recognized by their pseudomorphs. The form and size of the various phenocrysts were also useful; for example, large crystals of bipyramidal quartz were common in only one unit.

Mostly on the basis of phenocryst mineralogy the Hartford Hill was divided into four units, three of ash-
flow tuff and one of rhyolitic lava. The units were chosen as to be easily recognizable in the field. Many relict structures and minor features are visible in thin sections of the units and these features allowed confirmation of questionable correlations in the district and to the Rainbow and Mine Canyons section.

The rocks described in the following paragraphs have been hydrothermally altered. The dominant alteration type is propylitic; sericitic and advanced argillic types occur near veins. The various alteration products will be discussed in a later section on alteration.

**Lower Hartford Hill**

The lower unit of the Hartford Hill in the Pyramid district is best exposed near the head of Perry Canyon in Secs. 24 and 25, T. 23 N., R. 21 E. (Pl. 1). It is also well exposed along the ridges just east of Warm Springs Valley in Sec. 28, T. 23 N., R. 21 E. At least 890 feet of the unit can be measured in Perry Canyon and no lower contact with Mesozoic rocks was seen. Three ash-flow cooling units can be seen where alteration is slight; more may exist in the unit.

The distinguishing feature of the tuffs of the lower unit is that in general they are highly silicic quartz and sanidine bearing tuffs. They have few or no mafic minerals, a smaller percentage of phenocrysts, and lighter color than the overlying units. The upper part of the lower unit
is very distinctive with large bipyramidal quartz and euhedral sanidine phenocrysts. When altered this upper part is white on a freshly broken surface, and makes a distinctive marker horizon. Local air fall tuffs mark hiatuses in two places between eruption of lower unit ash-flows. One small rhyolite lava flow was seen interbedded in lower unit tuffs in NE 1/4, NE 1/4 of Sec. 25, T. 23 N., R. 21 E.

The lower unit correlates to cooling units 1, 2, 3, and 4 in the Rainbow and Mine Canyons area on the basis of similar phenocryst mineralogy and similar stratigraphic position relative to the more mafic upper tuffs.

**Middle Hartford Hill**

The middle unit of the Hartford Hill in the Pyramid district is about 325 feet thick. The base of the unit is best exposed in NE 1/4, SE 1/4, of Sec. 20, T. 23 N., R. 21 E. A vertical section of the upper part is totally exposed in NE 1/4, SE 1/4, Sec. 21, T. 23 N., R. 21 E. (Pl. 1). The contact of the middle and the upper Hartford Hill is also well exposed in that drainage.

The middle unit probably represents only a single ash-flow cooling unit. The unit contains about 25% phenocrysts in its base and 50% phenocrysts near the top. Plagioclase (3 mm.) is 75% of the phenocrysts, biotite (1-1.5 mm.) 10%, and resorbed quartz (1-1.5 mm.) is 15%. A trace of hornblende was seen near the top of the unit. Pumice
fragments range up to 25 mm. near the base of the unit and make up to 15% of the rock. Lithic fragments of tuff, meta-volcanics, and chert were seen, but only make 1% of the rock. The upper 15 feet of the unit are bleached white, probably by intereruptive weathering. The color of the unit varies from light gray (N7) at the base to medium gray (N5) at the top. The high percentage of plagioclase phenocrysts, minor but visible amount of biotite and quartz phenocrysts, and the white upper 15 feet are sufficient to distinguish the middle unit.

Hornblende latite lava flow and flow breccia locally overlies the middle unit. The lava is twenty feet thick and also was mapped as middle Hartford Hill. It is best exposed along the contact of the middle and upper units mentioned above. The lava does not stand well, and is usually represented by rubbly slopes. The unit bears 15% phenocrysts of which 70% are oxyhornblende (.5-1 mm.), 20% are plagioclase (1.5 mm.), and 5% are biotite (up to 1 mm.). The phenocrysts are well oriented and are set in a pilo-taxitic matrix of plagioclase laths, sanidine, and quartz which average .05-1 mm. in size. The color of the lava is medium dark gray (N4).

No equivalent unit was seen in the Rainbow and Mine Canyons area.

Upper Hartford Hill

The upper unit of the Hartford Hill in the Pyramid
district is at least 850 feet thick; the top is not exposed. The lower part of the unit is best exposed in SE 1/4 of Sec. 17 and the NE 1/4 of Sec. 20, T. 23 N., R. 21 E. The upper part of the unit is well exposed in the canyon walls near the mouth of Perry Canyon (Pl. 1).

The most distinguishing feature of the upper unit is large biotite phenocrysts which make up as much as 10% of the tuffs. The other phenocrysts vary in importance: the lower part has 10% quartz and 20% plagioclase, and the upper part has 5% hornblende and 30% plagioclase. Large phenocrystic biotite are present throughout the unit however, and range up to 3 mm. in size. Lithic fragments are much more abundant in this unit than in the underlying units, occasionally making as much as 10 to 20% of the rock and ranging up to one foot in diameter near the base.

The lower part of the upper unit correlates with cooling units 5 and 6 in the Rainbow and Mine Canyons area. The upper part (hornblende-biotite-plagioclase tuff) is more mafic than any seen in the Rainbow and Mine Canyons area.

Rhyolite Lava Flows

Rhyolite lava flows are exposed along Mullen Pass. They overlie parts of the upper unit of the Hartford Hill, but no rocks can be seen overlying the lavas. This fact led McJannet to think the lavas were quite young. However the rhyolite flows are cut by veins which, as shall be
shown later, are only slightly younger than the upper Hart­ford Hill tuffs. Also the lavas are intruded by dacite stocks which are only slightly younger than the upper unit tuffs. Therefore I include the rhyolite lavas in the Hartford Hill.

The lavas are exposed along the northern and southern margins of Mullen Pass (Fig. 2 and Pl. 1). They are seldom over fifty feet in thickness and are usually underlain by a few feet of white air-fall tuff (alters to light gray, N7) which was included with the lavas for mapping purposes.

The lava contains about 10% phenocrysts of plagioclase (1-3 mm.). Occasionally rare biotite and sanidine pheno­crysts are seen. The flow banded matrix is composed of quartz, plagioclase, and sanidine in about equal propor­tions. Magnetite, apatite, and sphene are accessory minerals. Clay minerals replace areas that were probably once glassy. In some of the lavas the entire groundmass may have originally been glassy as relict perlitic cracks are present, however no glass remains. The color varies from grayish red (10R 4/2) to medium brown (5YR 3/4).

Feeder dikes for the lavas are seen in several areas along Mullen Pass (Pl. 1). The dikes have mineralogy identical to the flows but often contain more biotite, and one con­tains about 2% disseminated pyrite.
Local Correlation and Regional Significance
of the Hartford Hill Rhyolite

Figure 3 shows the stratigraphic sections in the Rainbow and Mine Canyons area and in the Pyramid district. The main differences in the two are:

1. The lower part of the section is thinner in the Pyramid district. This may be due simply to deeper exposure in the Mine Canyon area.

2. The upper unit thickens considerably in the Pyramid district. Perhaps the upper part of the section was eroded in the Rainbow-Mine Canyons area, or perhaps the upper tuffs were not deposited there.

3. The middle unit in the Pyramid district does not extend into the Rainbow and Mine Canyons. It is doubtful that this unit could have been completely eroded from that area before the next eruption. Evidence that some relatively deep erosion occurred between eruptions can be seen in that section but is only along relatively narrow stream channels.

Correlation between McJannet's, Brooks', and my sections is relatively straight-forward except in the case of McJannet's Sutcliffe Formation. McJannet thought this formation (a group of ash-flow tuffs) overlaid his Tule Peak Formation. However it can be shown in at least two
areas that members of his Sutcliffe Formation are the same as members of his Tule Peak Formation. McJannet's description of the lower member of the Sutcliffe Formation sounds very similar to my middle unit in the Pyramid district. It is probable that the appearance of this unit only in and south of Mullen Pass caused the confusion.

Bonham (1969) correlates the Hartford Hill Rhyolite with parts of the Delleker Formation which occurs in the Blairsden, Portola, Colfax, Chilcoot, and Milford quadrangles of California (Durrell, 1959). Bonham also correlates the Hartford Hill to parts of the Valley Springs Formation and other rhyolitic tuffs in the central Sierra Nevada. Similar tuffs also occur in the Gillis, Gabbs Valley, and Wassuk Ranges of Mineral County (R. L. Hardyman, oral commun.; Silberman and McKee, 1974).

On a larger scale, the ash-flows of the Hartford Hill Rhyolite are part of an extensive group of silicic ash-flow tuffs which erupted from 28 to 21 m.y. ago in western Nevada and the western United States (Silberman and McKee, 1972; Noble, 1972). Many of these eruptions appear to have taken place along an arcuate belt (concave to the northeast) from central Oregon through Nevada to southwestern Utah (Noble, 1972). The significance of this pulse of activity is discussed in Noble (1972) and Silberman and McKee (1974) and references cited therein. Thus a large number of volcanic centers were erupting similar materials at about the same time, and units temporally correlative
to the Hartford Hill should abound. However little detailed stratigraphic work has been done to trace individual ash-flows of the Hartford Hill in the region, and their extent is not known.

McKee, et al. (1972) report initial strontium $^{87}/$strontium $^{86}$ values ranging from .7047 to .7051 for ash-flows of the Hartford Hill Rhyolite in the Rainbow and Mine Canyons area and in the Dogskin Mountains. Other, temporally equivalent, rhyolitic tuffs and lavas of the northwestern Great Basin yield similar values which are compatible with a deep-seated (mantle?) origin for the magmas with little or no assimilation of pre-Cenozoic salic crustal material.

Potassium argon age dates on rocks of the Hartford Hill from the Pyramid district are summarized in Table 1. Evenden and James (1964) report 3 K-Ar ages for the Hartford Hill in the Virginia Range (Fig. 1) ranging from 22.7 to 22.8 m.y. The age span from 27.9± 0.8 to 21.6± 0.6 m.y. places Hartford Hill volcanism as Late Oligocene to Early Miocene in age. The six million year duration is considerable for a series of cogenetic ash-flows (Doell, et al. 1968; Marvin, et al. 1970; Christ and Blank, 1974) and it is probable that cooling unit 1 (27.9 m.y.) of Mine Canyon erupted from a different source. Additional evidence for such an interpretation is that only cooling unit 1 departs from a gradual compositional change in the tuffs. Not only are individual cooling units compositionally zoned,
but each cooling unit becomes more mafic proceeding upsections, with the exception of Cooling Unit 1 which is more mafic than the overlying cooling unit. Major element analyses to confirm this trend were considered but major element analyses are inadequate to define petrochemicals trends due to the lack of non-hydrated glass, rather thorough groundmass alteration by groundwater and devitrification, and major element buffering during crystallization in the highly differentiated rocks (Noble, et al. 1972).

The correlation of the mudflow breccias with the Pah Rah Formation of Bonham has already been discussed. Similar pyroxene andesite mudflows are also in the Ingalls Formation of the Blairsden area 55 miles to the west (Durrell, 1959; Bonham, 1964). The age of the mudflow breccias is bracketed between 27.9± 0.8 and 21.6± 0.6 m.y., probably ruling out a correlation with the similar Cedarville Series in the Warner Range in northeastern California (Duffield and McKee, 1974). Axelrod (1966) demonstrates that the lower Cedarville is Late Eocene in age.

Source Area of the Hartford Hill Ash-flow Tuffs

The source area for the tuffs of the Hartford Hill has not been identified. Bonham (1969) suggests that the tuffs may have been erupted from linear vents. However, almost all of the ash-flow tuffs of Nevada whose source areas have been identified have been erupted from large,
circular calderas. The exact location of such a source area for the Hartford Hill is not known but several lines of evidence indicate that it is near the Pyramid district:

1. The Hartford Hill tuffs are thickest in the Pah Rah Range and southern Virginia Mountains and more cooling units exist there than elsewhere in the region.

2. Reconnaissance of Hartford Hill sections to the west at Petersen Mountain and to the south near Reno indicate thinner cooling units as well as fewer cooling units, less phenocrysts, and less lithic fragments than in the study area. The lithic fragments in the study area are also generally larger. Air fall tuffs are also much more common in the Pyramid district.

3. The Guanomi intrusive body is equivalent in age to some of the Hartford Hill volcanic rocks (Table 1). As far as I know this is the only large intrusive body of Hartford Hill age in the region.

4. Mineralization of the type in the Pyramid district is almost invariably closely associated with volcanic vents or is in the vent structure. This point will be discussed more fully in a later section.
DACITE LAVAS

Dacite lava unconformably overlies the Hartford Hill rocks in small areas of the Pyramid district. These lavas are volcanic equivalents of the dacite stocks along Mullen Pass and will be discussed in the section dealing with the intrusive rocks.

PYRAMID SEQUENCE

Overlying the Hartford Hill rocks in angular unconformity are tuff-breccias, basalt and basaltic-andesite lava flows, ash-flow tuffs and lacustrine sediments of the Pyramid Sequence (Bonham, 1969). Bonham included the Pyramid Formation of McJannet (1957), the Chloropagus Formation, and the Old Gregory Formation in the Pyramid Sequence. K/Ar dates (Table 1) indicate most of Pyramid Sequence in the Mullen Pass region erupted from about 15 to 12 m.y. ago, or during the Middle Miocene.

Five informal units have been recognized in the Pyramid Sequence for mapping purposes in the present study. Figure 5 shows a correlation chart with the seven members of McJannet's Pyramid Formation.

Basaltic Tuff-Breccia

The lowermost unit of the Pyramid Sequence is tuff-breccia or agglomerate. This unit is only occasionally exposed, and is usually only a few tens of feet in thickness, but it thickens to at least 150 feet near its vent area.
Figure 5. Correlation chart of the units of the Pyramid Formation of McJannet (1957) and the units of the Pyramid Sequence recognized in the present study.
The unit is exposed beneath basalt flows along the east wall of Perry Canyon in the SW 1/4, SW 1/4 of Sec. 14, and in eroded vent structures along the boundary of Secs. 14 and 15, T. 23 N., R. 21 E. (Pl. 1). Intercalated arkose, silt-stone, and diatomite are common away from the vents, and rarely occur near the vents.

The tuff breccia consists of various types of rock fragments set in a matrix of plagioclase laths, titanaugite, hypersthene, glass, and devitrified glass. The fragments are most augite – hypersthene basalts, but altered tuff, and various types of an altered quartz monzonite intrusive (?) rock are present. The angular to sub-rounded rock fragments average four cm. in diameter away from the vents and some approach four feet near the vent structures. None of the structures characteristic of volcanic bombs are seen in the larger fragments; most were probably solid when ejected. A large variety of textural types of basalt fragments is present, which is unusual considering that the tuff-breccia was probably erupted before any of the basalt flows in the Pyramid Sequence.

In the vent area, two tuff-breccia or agglomerate spines and a well-preserved cone are exposed. About one third of the cone has been stripped away by a landslide. The tuff breccia is well-bedded on the flanks of the cone, with the thickest beds up to about four feet. The dips of the beds steepen as the center of the cone is approached. The bedding continues amazingly far into the center of the
cone and becomes disarranged only near the very center. Bedding is not very evident in the two spines, which are interpreted as remnants of the centers of cones.

The tuff breccia and its vent structures were produced by the initial basaltic volcanism in the area, and probably were in part produced by phreatic explosion. The lacustrine diatomite beds suggest that at least part of the area must have been under water at the time of eruption and the area probably had abundant groundwater. The tuff breccia unit correlates with McJannet's Members 1 and 2 of the Pyramid Formation, which include what he thought was a mudflow. The distal occurrences of the tuff-breccia north of Mullen Pass may indeed have been emplaced by a mudflow mechanism, but the most extensive exposures of the unit are in the vent structures south of Mullen Pass.

Basalt and Basaltic Andesite Lava Flows

Basalt and basaltic andesite lava flows cap the ridges and plateaus to the east of the Pyramid district (Pl. 1). The basalt capping is often only 20-30 feet thick, but in a few areas, such as near the Guanomi Mine (Fig. 2), several basalt flows may total as much as 250 feet in thickness. Flow tops are generally scoriaceous and often in the thicker sections, flow-top and flow-bottom breccias are well-developed. Columnar jointing is beautifully displayed by the lava flows capping the east wall of Perry Canyon.

The lavas are generally slightly porphyritic with
with hypersthene and titanaugite being the most abundant phenocrysts. The groundmass crystals vary in size from 0.4 mm. to .08 mm. in different areas. The groundmass usually consists of weakly subophitic intergrowths of plagioclase (65%) and augite (30%). Iron and/or titanium oxide are 5% and apatite is 2%. Glass is abundant in some areas. Highly resorbed olivine was seen in only one sample. A reddish alteration product (iddingsite?) commonly replaces the pyroxenes and the rare olivine. Two major element chemical analyses of the unit are shown in Table 2. The silica percentage (when recalculated water-free) approaches the range of basaltic andesite. The color of the basalt is generally brownish black (5YR 2/1).

The basalt or basaltic andesite lava flows correspond to McJannet's Member 3 of the Pyramid Formation. Bonham reports a K/Ar age on a plagioclase separate from basalt in Mullen Pass of 15.2± 2.4 m.y. before present.

Ash-Flow Tuffs

Three cooling units of ash-flow tuff comprise the upper part of the Pyramid Sequence. The ash-flows are generally best exposed in flat-topped buttes along Mullen Pass and the upper cooling unit has been seen only in Mullen Pass. For convenience, the cooling units will be called, from bottom to top, A, B, and C. In general the tuffs of the Pyramid Sequence are more mafic, bear fewer phenocrysts and are more glassy (even in the upper zones) than the ash-flow
tuffs of the Hartford Hill Rhyolite. The lower two cooling units are dacites and the upper unit probably averages latite.

**Cooling Unit A**

Cooling unit A is either not often exposed or is only of local extent. The upper, densely-welded zone of the cooling unit is exposed in the NE 1/4 of Sec. 4, T. 23 N., R. 21 E. (Fig. 2) where the tuff is approximately 100 feet thick and overlies a highly vesicular basalt flow. The unit was not seen elsewhere.

The densely welded zone has only 5-8% phenocrysts of which 85% are plagioclase (An45, slightly zoned), 10% are augite with traces of hypersthene and hornblende. Fifty to sixty percent of the densely-welded zone is black fiamme of fused glass resulting from the collapse of pumice fragments. Lithic fragments, most of which are basalt, are 10% of the rock. Occasionally fragments of altered tuff and rhyolite lava are seen.

Cooling unit A was not recognized by McJannet.

**Cooling Unit B**

Cooling unit B is well exposed overlying cooling unit A in the NE 1/4 of Sec. 4, T. 23 N., R. 21 E. but is not well exposed elsewhere. The unit ranges up to 240 feet in thickness.

The tuff is crystal-poor with phenocrysts making only
5% of the upper welded zone. Eighty percent of the phenocrysts are plagioclase (slightly zoned, averaging 1 mm. and An$_{50-55}$), with 5% hypersthene (.5 mm.), and 15% augite (1 mm.). Traces of hornblende and oxybiotite are in the lower zones. Pumice fragments range up to 35 mm. but average only 2-3 mm. and comprise 25-30% of the rock. Lithic fragments of basalt, altered ash-flow tuff, and chert are 10-15% of the rock. The lithic fragments range between .3 and 50 mm. in size. The tuff is quite dark in color with black pumices set in a dark gray (N4) matrix.

Cooling unit B corresponds to McJannet's members 4 and 5 of the Pyramid Formation.

Cooling unit C

Cooling unit C is excellently exposed in the SE 1/4 of Sec. 4, T. 23 N., R. 21 E. where it overlies cooling unit B. The unit is about 220 feet thick. Evidence for several eruptions before the main eruption of this tuff can be seen in the basal part of the unit at the above locality.

The percentage of phenocrysts varies from 15% in the base to 30% in the top. Plagioclase (2.5 mm., An$_{35-45}$) is 80% of the phenocrysts along with 10% hornblende (.6 mm.), 5% augite (.5 mm.), and 5% hypersthene (.3-.8 mm.). Biotite is 10% of the phenocrysts in the base of the unit, but becomes only a trace in the upper part. A trace of sanidine (.2 mm.) is also seen in the base of the unit. Pumice fragments, 10-15% of the rock, are about 3 mm. in the base.
but reach 50 mm. in the densely welded zone. Clots of non-vesiculated magma are common in the upper part of the tuff and reach 75 cm. in size. The clots contain only plagioclase, pyroxene, and hornblende phenocrysts. Lithic fragments compose 5-20% of the rock, increasing in percentage toward the top of the unit, and range from 2-8 mm. in size. Columnar jointing is well-developed in the upper welded zone. The color ranges from light gray (N7) in the base to medium gray (N5) with black pumice and clots of non-vesiculated magma in the top.

Cooling unit C corresponds to McJannet's Member 6 and 7 of the Pyramid Formation. Evernden and James (1964) report a K/Ar age of 12.4 m.y. from a "volcanic flow" which most probably is this ash-flow.

Miscellaneous Units of the Pyramid Sequence

Diatomite beds containing the Pyramid flora of Axelrod (1958, 1962, 1966) crop out in the southern part of Sec. 4, T. 23 N., R. 21 E. These beds were assigned Member status by McJannet (Member 2 of his Pyramid Formation). They are very irregular in occurrence and I think they are probably equivalent to other lacustrine and stream-laid beds intercalated with the basaltic tuff-breccia in the lower part of the Pyramid Sequence.

A small outcrop of rhyolite ash-flow tuff was seen in the SW 1/4 of Sec. 23, T. 23 N., R. 22 E., unconformably overlying the Guanomi intrusive body (Fig. 2). This tuff
is associated with a series of basalt flows and most probably belongs to the Pyramid Sequence. The unit was not seen elsewhere.

Regional Correlation of the Pyramid Sequence

Potassium-argon dating and paleobotanical evidence (Bonham, 1969; Axelrod, 1958, 1962, 1966) place the age of emplacement of the Pyramid Sequence from about 16 to 12 m.y. ago, or Middle Miocene.

Bonham (1969) maps rocks of the Pyramid Sequence in the Nightingale Mountains, Lake Range, Fox Range, Virginia Mountains as well as the Pah Rah Range of southern Washoe County. He also correlates the Pyramid Sequence in part to the Bonta Formation of eastern Plumas County, California, Relief Peak Formation of the central Sierra Nevada, Chlorogagus Formation near Fallon and in the Hot Springs Range, and to the Canon Rhyolite, Virgin Valley Formation, and unnamed Miocene units in northern Washoe County described by Noble et al. (1970, 1973).
TERTIARY INTRUSIVE ROCKS

GUANOMI QUARTZ MONZONITE STOCK

A quartz monzonite stock intrudes tuffs of the Hartford Hill in Sec. 26, T. 23 N., R. 22 E., near the Guanomi Mine. Alteration and mineralization in the stock will be discussed in detail in a later section.

In the center of the pluton the rock consists of 45% plagioclase, 20% quartz, 25% orthoclase, 5% hornblende, and 5% biotite. Plagioclase (up to 3 mm.) occurs as euhedral to subhedral phenocrysts and in the groundmass, averaging An\textsubscript{35-40} for the zoned phenocrysts. Orthoclase and quartz occur in interlocking granophyric intergrowths rimming the plagioclase and an occasional resorbed quartz phenocryst. Trace amounts of sphene, apatite, and rutile are disseminated throughout the rock. Progressing toward the edge of the pluton, the rock becomes more porphyritic with plagioclase ranging up to 6 mm. Orthoclase and quartz occur in discrete grains (up to .5 mm.) in the groundmass and phenocrystic, resorbed quartz becomes more common. The groundmass texture becomes felty and a few miarolitic cavities lined with euhedral quartz occur. Both the central and the porphyritic parts of the pluton are propylitized. Near the edges of the pluton, a quartz-sericite-pyrite alteration assemblage is present, and the contact between altered intrusive and sericitized wall-rock is difficult to locate precisely.
A K/Ar date of $23.4^{+0.7}_{-0.7}$ m.y. was obtained on quartz-sericite alteration of intrusive rock from the Guanomi Mine. Assuming this date is roughly equivalent to the time of crystallization or emplacement of the stock as is the case in many porphyry copper deposits, there are no equivalent intrusive rocks known in the region. The date overlaps that of the uppermost Hartford Hill volcanism and the stock may represent a sub-volcanic equivalent to the Hartford Hill eruptives.

It is possible that correlative intrusive bodies in the region may have been overlooked. In hand sample the texture of the central zone of the pluton appears phaneritic, and the rock greatly resembles granodiorite or quartz monzonite of the Sierra Nevada batholith. Bonham (1969) points out the lack of age-dating on the supposed Mesozoic plutons in the area.

**DACITE STOCKS**

Dacite occurs in stocks and plugs along the Mullen Pass structural zone, and much smaller intrusive bodies of irregular shape occur south of the pass within the Pyramid district (Pl. 1). Several of the smaller bodies occur near the contact of the middle and upper Hartford Hill in the district. The large stocks are propylitized and some of the smaller bodies are slightly sericitized.

The distinguishing characteristic of the intrusive dacite is large, phenocrysts of plagioclase and
quartz (up to 4 mm.). Twenty to thirty percent of the rock is phenocrysts of which 65% are plagioclase (An$_{45}$, average of zoned crystals), 10% are anhedral and resorbed quartz, 10% are biotite (.8-3 mm.), and 10% are hornblende (.6 mm.). The matrix is composed of 50% plagioclase, 45% quartz and 2-5% magnetite, apatite, and rutile. The most common matrix crystal size is .02-.05 mm. Small amounts of glass are often present near the margins of the stocks. The color varies from light bluish gray (5B 7/1) to medium light gray (N6). Several dikes cut the larger stocks and are similar to them in mineralogy, but have more hornblende and are medium dark gray (N4).

Dacite lavas occurring in Secs. 14 and 15 of T. 23 N., R. 21 E. are probably extrusive equivalents of the dacite stocks. In fact, flow structures in the westernmost lava occurrence indicates that it occupies a vent structure, as the flow foliation changes dip from east through vertical to west progressively from west to east across the outcrop (Pl. 1). The lavas are 50-100 feet thick and unconformably overlie the upper unit of the Hartford Hill, and like the stocks and the Hartford Hill, the lavas are in part propylitized. Phenocryst mineralogy is the same as in the stocks but grain sizes are smaller. The lava bears 30% phenocrysts of which 65% are plagioclase (zoned, average An$_{45-50}$, up to 3 mm.), 15% are euhedral and slightly resorbed quartz (1.3 mm.), 10% are oxybiotite (1 mm.), and 5-8% are oxyhornblende. The matrix consists of 35% flow-
oriented plagioclase laths (.05 mm.), a few percent of magnetite and apatite, with the rest being altered and devitrified glass. Near the top of the unit, the matrix has patchy areas of spherulites grading outward into granophyric intergrowths of quartz and sanidine. These devitrification structures often occur along flow-layering and produce a prominent banding in some of the lava. Color varies from medium bluish gray (5B 5/1) in the base to medium dark gray, (N4) in the top.

The contacts between the stocks and the rocks of the Pyramid Sequence are never exposed, but the dacite lava seems to be overlain unconformably by lavas of the Pyramid Sequence near the Bluebird Mine. A plagioclase separate from one of the smaller stocks yielded a K/Ar date of 19.3 ± 0.8 m.y. Plagioclase from the equivalent lavas dated at 20.7 ± 0.6 m.y. (Table 1). The stocks are petrographically quite similar to intrusive feeders for the lavas of the Kate Peak Formation, and Bonham had tentatively made this correlation. However the K/Ar dates place the units as several million years older than the Kate Peak Formation. The Alta Formation, exposed to the south in the Virginia Range, may be temporally equivalent to the stocks, as Axelrod (1966) believes part of the Alta may be Early Miocene in age. Preliminary radiometric evidence gives a minimum age of Middle Miocene for the Alta Formation (Silberman and McKee, 1972).
DIKES

Three types of dikes were seen in the Pyramid district. Rhyolite and dacite dikes have already been mentioned. The rhyolite dikes are essentially identical to the lava flows which they feed, and were seen only near Mullen Pass. The dacite dikes mostly occur in the dacite stocks and differ only in containing more hornblende. The most common type of dike in the district has the composition of basalt or perhaps basaltic andesite. These dikes are usually propylitized and often occur along in the same structure as veins.

The pyroxene basalt dikes have 40% phenocrysts of which 65% are plagioclase (An\textsubscript{50}, 2 mm.) and 35% are euhedral titan-augite (up to 1.5 mm.). The matrix is 70% plagioclase laths (.1 to .2 mm.) and 30% augite (up to .25 mm.) in subophitic intergrowths. Minor glass or devitrified glass are often present. The dikes along fault zones are commonly sheared and deformed. The fresh dikes are grayish black (N2) in color but most commonly the dikes are propylitically al- tered and have white phenocrysts in a medium light gray (N6) matrix. The altered dikes appear quite felsic in hand sample.

The pyroxene basalt dikes cut the dacite stocks and Hartford Hill and may be feeders for the basalts of the Pyramid Sequence.
QUATERNARY SEDIMENTS

Quaternary deposits in the area consist of landslide debris, lake sediments, and alluvial material. The lake sediments and alluvial material were grouped together in the mapping. The reader is referred to McJannet (1957) for a more thorough discussion of the Quaternary materials.

An older group of Quaternary-Tertiary gravels probably underlie the lake sediments and young alluvium at shallow depth. Such gravels are exposed in up-faulted blocks in northern Warm Springs Valley (Bonham, 1969). Quaternary (?) landslide deposits are most extensive along the eastern side of the Pah Rah Range (Fig. 2). Lacustrine sediments deposited in Pleistocene Lake Lahontan mantle the landslide debris and cover most of Mullen Pass and much of Warm Springs Valley. Young Quaternary-alluvial fan deposits, stream sediments, and eolian deposits occur along drainages and the margins of the Pah Rah Range.
STRUCTURAL GEOLOGY

REGIONAL STRUCTURE

The Walker Lane structural zone is the dominant feature in the regional structural pattern. Most of the early work on the Walker Lane and its sense of displacement was done in southern and central Nevada, but Bonham (1969) showed that the zone extended into northwestern Nevada and southern Washoe County and presented a good case for both vertical and right lateral strike-slip displacement along the zone. Much of Bonham's evidence comes from the area immediately surrounding the Pyramid district. The influence of the Walker Lane on the fault pattern observed in the Pyramid district is not clear, but must be considerable. The deformation of several young (≤30 m.y.) Tertiary volcanic fields in western Nevada is much greater along the zone than away from it. The importance of such broad zones of strike-slip faulting in the localization of ore deposits has been pointed out by many authors including Schmitt (1966) and Jerome and Cook (1967).

Another element to be considered in a discussion of regional tectonics is a large circular feature about 30 miles in diameter first seen on ERTS satellite photographs. A photograph of the feature is shown in a recent article by Eliason, et al (1974). The feature is also visible on the map of Banham as an area of circular outline in which the outcrops are dominantly Mesozoic granitic rocks of the
Sierran batholith while the dominant rock type exposed in the surrounding ranges are Tertiary volcanic units.

The eastern boundary of the feature passes between Dogskin Mountain and the Virginia Mountains through Warm Springs Valley just west of the Pyramid district. This eastern boundary corresponds with the trace of the Walker Lane as pointed out by Sales (1974).

The origin of the circular feature is not known. Suggested origins include meteor impact, the intersection of several structural trends such as the Walker Lane and the Mullen Pass zone, and volcano-tectonic events such as caldera formation. No good evidence exists as of yet for any of the suggested origins. Several investigators have examined the area for impact features and have found none (D. Trexler, pers. commun.). The area is a structural high, in fact the vertical displacement between Dogskin Mountain and the Pah Rah-Virginia Mountains block that has been attributed to the Walker Lane (Bonham, 1969) may belong to the development of the circular feature.

The district is near the periphery of the Basin and Range province and the extensional tectonics characteristic of that province are dominant in at least the younger deformations. Problems arise, however, when one tries to separate Basin and Range faulting from other types, for example that produced along the Walker Lane. It is possible that Basin and Range faulting in the area took place along pre-existing fracture zones created by Walker Lane tectonism.
STRUCTURAL GEOLOGY OF THE PYRAMID DISTRICT

Structure in the Pyramid district is dominated by northwest and west trending faults that mainly affect rocks of the Hartford Hill. A few northeast trending faults occur near Mullen Pass. The youngest faults are north-northwest trending and may be of the Basin and Range type. Many of the faults show evidence of being active for long periods of time or of being reactivated under different tectonic stresses.

Detailed structural analysis in the Pyramid district is hampered by several factors other than the reactivation of faults, including:

1. the lack of deep mine workings.
2. weak stratigraphic control particularly in areas of intense hydrothermal alteration.
3. the fact that compaction foliation was not necessarily originally horizontal and may not always be trusted to indicate tilting or folding. The original attitude of the compaction foliation was in part controlled by basement topography, at least for the oldest ash-flows.
4. the fact that many breccia types besides tectonic breccias occur in the district, including various types of volcanic breccias and solution breccias produced during hydrothermal alteration. All of the breccias look or can look similar to tectonic breccias.
The maps of Brooks (1956) and McJannet (1957) of areas mostly north of Mullen Pass show the same structural pattern as is present in the Pyramid district. Figure 2 shows the main faults north of the pass and is in part after McJannet.

**NORTHEAST TRENDING FAULTS AND MULLEN PASS**

Northeast trending faults are common along the margins of Mullen Pass but decrease in number and magnitude away from the pass. Displacements along these faults have in most cases been only a few feet with dip-slip dominant. The dips of most of the fault planes are steep, usually within a few degrees of vertical.

Mullen Pass itself trends northeast and is probably structurally controlled, but the type of structure is not known. The zone has localized igneous activity since the eruption of the rhyolite lavas of the Hartford Hill. The emplacement of the largest dacite stocks was also controlled along the structural zone. Also the tuffs of the Pyramid Sequence are best preserved along the pass, suggesting that it may have been a topographic low for the last 13 or 14 m.y. There is no major offset between the Virginia Mountains and the Pah Rah Range, however, and the units of the Hartford Hill and Pyramid Sequence can be correlated across the zone.

A northeast trending zone of topographic discontinuity and structural trends extends from near Midas in Central Nevada into the Mullen Pass zone with perhaps a little right lateral offset along the Walker Lane. The origin or signifi-
The significance of this structure is not known, but it is clearly shown on aerial photographs of the state.

The northeast trending faults of minor displacement seem relatively young as they displace most of the other fault trends, however they are interpreted to represent recurrent movements along the Mullen Pass structural zone which itself originated at least before the last Hartford Hill volcanism.

NORTHWEST AND WEST TRENDING FAULTS

The most common structures in the Pyramid district are northwest (N. 35° W. to N. 55° W.) and west (N. 70° W. to N. 90° W.) trending faults. The faults generally dip vertically but 45° S. dips can occur as in the Surefire and Wet Adit prospects (Pl. 1). The wall rocks near these faults are commonly highly jointed with the main joint set paralleling the faults. This is beautifully displayed in the SE 1/4, NE 1/4 Sec. 21, T. 23 N., R. 21 E. where a large mass of jointed rock forms a topographically prominent knob along a fault.

Displacement along these faults are highly variable and range from a few feet to about 600 feet of stratigraphic separation along the northwest trending fault in the eastern half of Sec. 20, T. 23 N., R. 21 E. Most offsets are probably less than 50-100 feet and many northwest trending mineralized fracture zones show essentially no offset (Pl. 1).
Age relations between these two trends of faults are confusing as each may offset the other or they may cross with no apparent offset (Sec. 22 and 27, T. 23 N., R. 21 E.). Such relationships often indicate that the faults originated at the same time in response to a common cause (Billings, 1954). Other evidence supporting the contention that the faults originated at the same time is the K/Ar ages of the mineralization (which both sets of faults must precede) and the upper Hartford Hill (which the faults cut). The time span left for inception of both trends of faulting is probably less than 500,000 years. The structures originated before the mineralizing event and hence are older than the Pyramid Sequence, as will be seen in a later section. However, recurrent movement has occurred as a few of the faults offset the Pyramid Sequence, several of the veins have been deformed and brecciated, and two northwesterly faults in Warm Springs Valley offset Quaternary-Tertiary alluvium (Bonham, 1969).

Although the offsets are interpreted to be mainly dip-slip, the outcrop pattern produced by the faults could in many cases be produced by strike-slip, dip-slip, or oblique-slip movements. Several of the faults could have considerable strike-slip components. Slickensides commonly rake from horizontal to vertical. McJannet (1957) and Brooks (1956) mapped the same trends in the area north of Mullen Pass where stratigraphic control is excellent and both interpreted the displacements to be dip-slip.
Although the latest movements may be dip-slip, movements are recurrent and several lines of evidence indicate that original movements may have been strike-slip:

1. The faults mostly dip vertically, a feature common in strike-slip faults.

2. Cymoidal loop structures are often seen on a small scale in underground mapping and are well-developed north of Mullen Pass (e.g., at the common corner of Secs. 1, 6, 31, and 36, Fig. 2). For the loops to develop in their present vertical position, some movement along the fault should have been horizontal or strike-slip.

3. If the faults indeed originated at the same time, then they may be a conjugate set of shear fractures. The angle between the two sets is not the usual 60 degrees, but the medium in which they developed is far from homogeneous.

4. The northwesterly faults parallel the Walker Lane which in the opinion of many geologists was produced by strike-slip faulting.

Bonham (1969) noted northwesterly faults in the southern Pah Rah Range and interpreted them as first order right-lateral strike-slip faults along the Walker Lane. He also noted an associated set of N. 60-80° E. trending faults which he interpreted to be second order left-lateral strike-slip
faults. This interpretation is difficult to apply in the Pyramid district because initial right-lateral motion cannot be demonstrated for the northwesterly faults and the other set trends westerly instead of N. 60-80° E.

One possible interpretation, considering the regional structural pattern, is that the faults initially formed in response to forces produced along the Walker Lane. Whether the faults represent a conjugate set or first, second, or third order faults is difficult to decipher, especially after later dip-slip movements. After the zones of weakness were formed (and perhaps mineralized), later dip-slip movement occurred, perhaps due to extensional forces during formation of the Basin and Range province. It is interesting that the fault system along the western margin of the Pah Rah Range which probably produced the uplift of the range trends northwesterly - exactly parallel to the northwesterly faults in the district.

However, Nielsen (1965) and Stewart (1971) suggest that movement on the Walker Lane began at about 17 m.y. The K-Ar data on the mineralized fracture zone at Pyramid suggests that it originated at about 21-22 m.y. The 17 m.y. date of inception of Walker Lane faulting has not been proven valid for northwestern Nevada, but other possibilities must be considered for the origin of the northwest and west trending faults and fracture zones in the Pyramid district.

Reconnaissance of the literature reveals that no regional tectonic influence has been recognized in western
Nevada at about 21 m. y. Basin and Range faulting had probably not begun (McKee, et al., 1970; McKee, 1971; Noble, 1972). It has also been suggested that activity along the Walker Lane had not yet begun (Nielsen, 1965; Stewart, 1971). In fact, Noble (1972) suggests that unbroken crust characterized much of the Great Basin in this period, providing a possible reason for the predominance of highly explosive ash-flow tuff eruptions during this period. Many of the faults originating in this time period appear related to more local stresses, such as the formation of volcanic vents (for example, see Ashley, 1974). If the vent area for the Hartford Hill is indeed near the Pyramid district, the northwest and west faults could perhaps be related to its formation, but the demonstration of such a relationship (or lack of relationship) must await the discovery of the vent structure.

NORTH TRENDING FAULTS

Faults trending N. 0-15° W. are the only faults that affect the Pyramid Sequence rocks in appreciable amounts. Displacements range from 50-200 feet along these faults which appear to be of the Basin and Range dip-slip type. The northerly faults are not common in the mineralized areas but are sometimes seen to displace westerly and northwesterly faults and veins.

The faults seem to have originated after the eruption of the Pyramid Sequence which they cut. Evidence was also seen for recurrent movement along these faults, as one offsets
a Quaternary lake terrace and a drainage in the NE 1/4 of Sec. 11, T. 23 N., R. 21 E. The offset of the terrace and drainage is only a few feet, whereas offset of the Pyramid Sequence rocks south of the fault approaches 100-150 feet.

MISCELLANEOUS STRUCTURES

Relatively flat-lying fault-lying fault zones were seen underground in several workings, including the Good Hope and Nevada Dominion adits. The zone exposed in the first 200 feet of the Good Hope adit is slightly discordant to bedding and dips about 10° south. The one foot wide zone is filled with what was interpreted to be fault gouge. Unfortunately these zones were never seen where stratigraphic control was good enough to determine if they had any offset, nor were these zones ever seen where stratigraphic control was with what was interpreted to be fault gouge. Unfortunately a few radial faults of minor displacement are distributed around the dacite stock in Sec. 17, T. 23 N., R. 21 E.

Pyramidal Sequences were also slightly dome-shaped around the Hartford Hills. Rocks are often tilted up along their margins and the dacite stocks were emplaced discordantly and the Hartford Hills. Rocks are often tilted up along their margins.

The Hartford Hill rocks are often tilted up along their margins. A few radial faults of minor displacement are distributed around the dacite stock in Sec. 17, T. 23 N., R. 21 E. They are seen on the surface, but no offset has been determined. The one foot wide zone is filled with what was interpreted to be fault gouge. Unfortunately, these zones were never seen where stratigraphic control was good enough to determine if they had any offset, nor were these zones ever seen where stratigraphic control was with what was interpreted to be fault gouge. Unfortunately, these zones were never seen where stratigraphic control was with what was interpreted to be fault gouge. Unfortunately,

McJannet (1957) mapped several very broad folds north of Mullen Pass. It is my opinion that the areas can be more clearly interpreted with faults. The exposures are not good enough to allow one to walk out folded beds. Also, the strike and dip of compaction foliation is not consistent.
enough to permit mapping of folds in which the difference in the dip of the limbs is only 5-10 degrees.

SUMMARY OF AGES OF FAULTING

It is probably best to discuss the age of inception of the various trends of faults as they all show evidence of being reactivated. The northeast trending Mullen Pass zone is probably the oldest structure as it controls the emplacement of rocks as old as the rhyolite lavas of the Hartford Hill. The northwest and west trending faults are interpreted to have been formed almost simultaneously and later than the Mullen Pass structure. The northwest and west trending faults must also be pre-mineralization and post-Hartford Hill volcanism. The north trending faults are probably the youngest, originating after (or during?) the eruption of the Pyramid Sequence.
ECONOMIC GEOLOGY

PYRAMID DISTRICT

Mining activity began in the Pyramid district in about 1863. The following description of the early days of the district in Thompson and West's 1881 History of Nevada cannot be improved upon:

"Pyramid district lies a few miles west of the south end of Pyramid Lake. As early as 1860 prospectors were through this region, and ledges were discovered, but were considered of little value and were not worked. The crop­pings along the surface are exposed to view for a long distance, and lay unnoticed for a number of years. On the sixth of March, 1876, Dr. S. Bishop, of Reno, located the Monarch and was soon followed by many others. The doctor had been on a professional visit to the neigh­borhood, and had found on a table in the house a piece of the rock, which he took home with him, the result of the assay inducing him to make the above location.

A two-stamp prospect mill was erected by Bishop, and the result of its workings caused quite a rush of people to the new district. The ore so closely resemb­led that of the Comstock that it was proclaimed that "another Comstock" had been found, and some went so far to assert that it was the same vein as its noted pre­decessor of Mount Davidson.

Pyramid City was at once laid out, and a boarding house and a few buildings were erected, the population soon amounting to nearly 300. During the summer of 1876 daily crowded stages ran from Reno to Pyramid City. Another town, called Cold Springs, was also started some three miles to the east. The district was organized at a miners' meeting, held April 12, 1876. Five town sites were surveyed, and all the springs and mill sites in the vicinity were located.

Jonesville was laid out two miles from Pyramid City, at which point is situated the Jones and Kinkead Mine, the most important in the district, and the one on which the most work has been done.

Work has been temporarily suspended on this mine, and as the developments in other claims has not proved as satisfactory as hoped, the district is but lightly populated. Pyramid City contains a post office and four buildings, and the town of Jonesville, a hotel, a store and a dozen cabins."
Whitehill (1877) reports that 110 claims and 5 town sites had been located by 1876 and that many miners and entrepreneurs were active in the area. He also reports that a large number of shafts, adits, and prospect pits had been dug on 10 distinct veins. According to Whitehill, the ore ran from 10 to 1000 dollars a ton and was free-milling but a large amount of copper was present in two of the veins.

Table 3 presents the recorded production from the district from 1881 until the present. The main period of production was from 1881 to 1890 and according to Overton (1947) all this early production came from the Nevada Dominion mine (also known as the Franco-American or the Blondin). These records are probably incomplete as the largest working in the district by far, the Jones-Kincaid mine, is credited with no production. Also ore was treated at a mill near the Crown Prince and at least some was probably shipped.

There are a large number of workings in the district but most are shallow prospect pits and even the larger workings generally open only about 100 feet of vein. One of the reasons for the large number of shallow workings is the tendency for the precious metal values, particularly gold, to be much higher in oxidized vein outcrops. As shall be later shown, the hypogene mineralization has relatively poor precious metal values, and many of the diggings are only as deep as oxidation. It is certain that the "free-milling, high-grade ores" described by Whitehill (1877) were in oxidized rock, although no assays even approaching 1000 dollars per ton.
## Table 3:
Production figures for the Pyramid district, Washoe County, Nevada. Table after Bonham (1969) and based upon Couch and Carpenter (1943) and figures reported in Mineral Resources of the United States, U.S. Bureau of Mines Minerals Yearbook.

<table>
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<tr>
<th>Year</th>
<th>Lode Matter (short tons)</th>
<th>Lode Gold (oz.)</th>
<th>Lode Silver (oz.)</th>
<th>Total Value (dollars)</th>
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<tr>
<td>1967-1973</td>
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</table>

Totals for available information: 3,066 short tons of lode matter, 35.5 oz. of lode gold, and 2,722 oz. of lode silver, totaling $95,478.

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1. Minor production, no figures available.
2. Uranium production, no data available.
were found in the present study, even using today's higher prices.

Uranium was discovered in the area in 1954 and many new claims were staked in the district. Bonham (1969) reports that a small tonnage of uranium ore was shipped but the grade and actual tonnage figures are unavailable.

There is little mining activity at present. A few prospectors, mostly part-time, live on claims and small plots of private land along Mullen Pass or control claims in the district. A few are actively engaged in trying to re-open several of the mines, but most only fulfill the yearly assessment requirement. Some of the best prospects are on patented claims controlled by North American Rockwell, Inc. which evidently has no interest in mining as the patented claims have lain dormant for years.

MINERAL DEPOSITS

Mineralization in the district consists of narrow veins (generally less than 1 foot wide) along west and northwest trending faults and fracture zones. The veins are mostly confined to tuffs of the upper unit of the Hartford Hill.

Hypogene sulfide mineralogy is zoned with enargite and pyrite in the center of the district and galena, sphalerite, tetrahedrite, chalcopyrite, pyrite, and bornite concentrated in an outer zone. The tuffs are pervasively propylitized throughout the district. Sericitic alteration envelopes (10-15 feet wide) border the veins and in the central en-
argite-pyrite zone, and advanced argillic assemblage, 1 to 4 feet wide, occurs between the veins and the sericitic envelopes.

**Ore Mineralogy**

In general the ores are open-space fillings, with sulfides and sulfosalts intergrown with euhedral quartz and barite or encrusting vugs in brecciated wall rock. In several prospects the ore has been brecciated by post or syn-ore movement producing tiny angular sulfide fragments healed with quartz (Fig. 6). In such cases the ore mineralogy is difficult or impossible to identify in hand sample.

Pyrite, by far the most common abundant sulfide, occurs in three forms. The cube typically occurs as disseminations in propylitized rocks or in more highly altered wall rocks near veins. In the veins themselves or in closely neighboring wall rock, octahedrons are the usual forms with the pyritohedrons and particularly are more common. Cubes range up to 2 mm. and pyritohedrons up to 5 mm. in diameter. Almost all the pyrite is euhedral or subhedral; occasionally anhedral outlines are seen in pyrite that has been brecciated or partially replaced by another sulfide. The pyrite in the wall rocks adjacent to veins is often intergrown in sericite pseudomorphs after amphibole or biotite (Fig. 7) indicating that the original ferromagnesian phenocrysts may have provided some iron for the pyrite. However, some iron was probably introduced into the system, as the pyritized rocks are
Figure 6. Photomicrograph of brecciated sphalerite (sl) healed with quartz (qtz) and galena (gn). Width of field 1.12 mm. Reflected light.
Figure 7. Photomicrograph of large crystals of pyrite (opaque or black in the photomicrograph) in sericite (se) pseudomorph after biotite. Opaque iron and manganese (?) oxides coat the biotite cleavage planes. Groundmass is quartz and smaller sericite pseudomorphs after biotite and hornblende also with pyrite. Width of field 1.12 mm. Transmitted light, crossed nicols.
enriched in iron and also elements that have a geochemical affinity with iron, namely Co, Ni, and Cr (compare P1 and P6 in Table 4). Pyrite is also often localized in lithic fragments in the tuffs.

Three copper-bearing sulfosalts, enargite, luzonite, and tetrahedrite are common in the veins. Luzonite is the low temperature tetragonal polymorph of enargite and the two are always intimately intergrown. Their optical properties are quite similar but luzonite can be recognized in polished section by its polysynthetic twinning and pinkish cast in comparison to the more grayish untwinned enargite. Luzonite, being the denser polymorph, can also be formed by grinding enargite (Maske and Skinner, 1971) and, perhaps could be formed in polished section preparation. The luzonite in the Pyramid veins is probably primary, however, as arsenopyrite (?) is controlled along the boundary of luzonite in enargite (Fig. 8) which would not be the case if the boundary was produced in the lab. There are no published reports of luzonite being formed in polished section preparation.

Enargite is usually 7 or 8 times as abundant as luzonite in polished section and much larger in size. Luzonite is generally about .01 to .5 mm. whereas enargite ranges from .01 to 10 mm. and averages about .7 mm. Enargite varies from anhedral to euhedral; when coating the walls of open vugs it is generally euhedral, but is anhedral when intergrown with quartz and other sulfides.

Tetrahedrite occurs in three ways: as subhedral to
Figure 8. Photomicrograph of enargite (en) with intergrown pinkish, twinned luzonite (lu). Note white specks along the margin of the two larger grains (arsenopyrite?). Width of field 1.12 mm. Reflected light.
anhedral masses up to 5 mm. in size, as small, round inclusions (.02 to .05 mm.) totally enclosed in galena, and as intergrowths with enargite and luzonite. The intergrowth of all three sulfosalts was observed in samples from only the Burrus and Cinch mines. The optical properties of all three are similar but tetrahedrite is distinguished by its higher reflectance and isotropism.

There are complete and partial As and Sb solid solutions among these sulfosalts with complete solid solutions between luzonite and famatinite (Gaines, 1957; Springer, 1969), and between tetrahedrite and tennantite (Feiss, 1974). Enargite can also accept up to 6 wt. percent antimony, but the solid solution is only partial as no natural, orthorhombic, antimony-bearing end-member exists.

Exact determinations of the compositions of the Pyramid sulfosalts was prevented by the difficulty of separating the intimate intergrowths. There also is no accepted x-ray diffraction technique for these determinations. It is known that the d-spacings of the crystals are affected by As and Sb substitutions but the spacings are also affected in unknown ways by other impurities, such as Bi, Ag, Zn, Cd, and Sn. This is particularly true for tetrahedrite-tennantite which is generally much more impure than enargite or luzonite-famatinite (Gaines, 1957). Also microprobe work by Springer (1969) showed tremendous variation in composition of these same sulfosalts across a single polished section, so multiple analyses would have been necessary for meaningful results.
Feiss (1974) shows that the most common composition of these minerals is enargite with 4 mole % Sb and approximately tetrahedrite-tennantite when they are associated in the same deposit. Feiss's work involved Peruvian deposits that shall be shown later to be very similar to the Pyramid deposits. Such compositions are compatible with the optical data on the Pyramid sulfosalts. Also the x-ray diffraction patterns of Pyramid enargite and tetrahedrite are fairly close matches for their end-member patterns reported by Skinner, et al (1972) and Maske and Skinner (1971). Feiss did not report typical luzonite compositions and the amount of Sb in the Pyramid luzonite is unknown.

Chalcopyrite occurs in several ways in the veins. The most common occurrence is as isolated anhedral to subhedral crystals up to .55 mm. filling vugs and fractures. It also occurs as small inclusions (exsolutions?) up to .01 mm. in size in tetrahedrite and much more rarely in enargite. Chalcopyrite also occurs along the boundary of tetrahedrite and pyrite, perhaps as a reaction product of the two (Fig. 9). Chalcopyrite was also tentatively identified as small, round inclusions (less than .01 mm.) in pyrite from the Bluebird mine. If this mineral is chalcopyrite, it may be non-stoichiometric (high iron?) as its color in polished section is slightly anomalous brownish yellow.

Sphalerite most commonly occurs as anhedral to subhedral grains and masses up to 3 mm. and is commonly associated with galena and tetrahedrite (Fig. 10). Sphalerite was also
Figure 9. Photomicrograph of tetrahedrite (td) and pyrite (py) with chalcopyrite (cp) mostly confined to the boundaries of the two. The tiny white specks in the tetrahedrite are galena (gn). Note euhedral quartz. Width of field 1.12 mm. Reflected light.
Figure 10. Photomicrograph of sphalerite (sl), galena (gn), pyrite (py), dark gray quartz, and tetrahedrite (td) which occurs as roundish blebs enclosed and along the borders of galena. Width of field 1.12 mm. Reflected light.
tentatively identified as tiny inclusions in pyrite (less than .005 mm.) from the Bluebird and Burrus mines. The sphalerite is yellow in hand sample and has whitish internal reflections in polished section and therefore is low in iron content.

Galena occurs in isolated euhedral crystals and in anhedral masses when associated with sphalerite and tetrahedrite. The galena averages .5 mm. in size, but a few large cubes up to 20 mm. on a side were seen.

Bornite was observed only as inclusions (less than .015 mm.) in tetrahedrite. Hypogene chalcocite (.01 mm.) is intergrown with the bornite in samples from the Bluebird mine. The inclusions are rounded blebs and are not confined to any particular crystallographic plane in the tetrahedrite, but are always quite near to or touching inclusions of chalcopyrite. Some type of exsolution relationship may exist among the minerals, but the textural evidence was far from clear.

An unidentified mineral was seen as inclusions (.005 to .01 mm.) in enargite and tetrahedrite. This mineral may be arsenopyrite but the small grain size prevented positive identification.

Quartz and barite are the most common gangue minerals in the veins. The barite and some of the quartz are euhedral and coat the walls of vugs and fractures in brecciated wall rock. Pyrophyllite, diaspopre, kaolinite, and other products of wall rock alteration are closely associated with the ore.
in the central part of the district. Oxidized vein outcrops contain chalcedony, opaline silica, allophane, and other products of supergene alteration which will be discussed in detail in a later section.

Table 4 shows emission spectrographic analyses of ore from the Burrus mine and pyritized rock from the Jones-Kincaid mine. Several elements, other than those normally belonging to minerals already described, have rather high or at least, anomalous values in the Burrus ore including Ag, Au, Bi, Be, Cr, Mo, Sn, and Sr. W, Co, Ni, and Cr are anomalous in the pyritized rock from the Jones-Kincaid mine. It is not positively known which minerals contain these elements, but some generalizations can be made. Silver values are generally highest from mines that contain tetrahedrite. The highest silver assays from the district known to me are from the Bluebird, Nevada Dominion, Burrus, and Jumbo mines and these mines also contain abundant tetrahedrite. Silver has been reported to substitute for Cu in the tetrahedrite structure (Riley, 1974). Bismuth and perhaps tin are probably contained in the sulfosalts. Bismuth is known to substitute for As or Sb and Gaines (1957) reports tin as a common impurity in tetrahedrite. Co, Ni, and Cr probably substitute for Fe in pyrite as they have much higher values in the heavily pyritized Jones-Kincaid sample.

In general, the precious metal content to the Pyramid ores is low. Gold values of hypogene mineralization rarely exceed .02 oz./ton and are usually .01 oz./ton even for solid
TABLE 4: SEMI-QUANTITATIVE SPECTROGRAPHIC ANALYSES OF SPECIMENS FROM THE PYRAMID DISTRICT. VALUES IN PPM.

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<th>P4</th>
<th>P4a</th>
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Six step D.C. arc semiquantitative spectrographic analyses, D. Siems and B. Crim, U.S. Geol. Survey, Denver, Colo. Results reported as midpoints of geometric brackets whose boundaries are 1.2, 0.83, 0.38, 0.26, 0.18, 0.12, etc. The precision of a reported value is approximately plus or minus one bracket at 68% or two brackets at 95% confidence. Detectability limits: Ag 0.5, As 200, Au 10, B 10, Ba 20, Be 1, Bi 10, Cd 20, Co 5, Cr 10, Cu 5, La 20, Mn 10, Mo 5, Nb 20, Ni 5, Pb 10, Sb 100, Sc 5, Sn 10, Sr 100, V 10, W 50, Y 10, Zn 200, Zr 10.

G indicates greater than value shown in parentheses.

Pl - Propylitized upper unit of Hartford Hill Rhyolite, sec. 17, T. 23 N., R. 21 E.
P2 - Propylitized dacite intrusive, sec. 17, T. 23 N., R. 21 E.
P3 - Sericitically altered upper unit Hartford Hill Rhyolite bordering vein in Nevada Dominion adit.
P4 - Advanced argillic alteration of upper unit Hartford Hill Rhyolite bordering main Burrus vein, adit level.
P4a - Ore from main Burrus vein, adit level.
P6 - Heavily pyritized wall rock from Jones-Kincaid shaft dump.
P8 - Sericitized and pyritized lower unit Hartford Hill Rhyolite from SW1/4, sec. 24, T. 23 N., R. 21 E.
P9 - Sericitized and pyritized Guanomi quartz monzonite from Guanomi mine dump.
sulfide samples. Silver values are quite erratic but are low when compared to other vein camps in young volcanic rocks (less than 30 m.y.) along the Walker Lane (e.g. Comstock, Tonopah). Most silver assays across minable widths are 2-3 oz./ton. The highest assays known to me are about 25 oz./ton for "specimen" ore with about 50% tetrahedrite. This assay is respectable but very low compared to the high values of most "epithermal" camps of Nevada.

Oxidation and Supergene Products

Oxidation products of the hypogene sulfides and sulfosalts vary from prospect to prospect. Copper minerals produced during oxidation of the deposits include malachite, azurite, and chrysocolla but the most common "oxide" copper mineral is chalcanthite. It occurs as beautiful, delicate blue crystals which coat the walls of many of the underground workings. Most of the chalcanthite has formed since the mines were opened as a precipitate from meteoric waters which have percolated through the veins. Fibers and needles of gypsum are common associates of the chalcanthite and have the same origin.

Iron oxides are abundant in all the oxidized veins with many colors and forms present. The most common type is "transported limonite" which is derived from the oxidation of pyrite. Limonites of the indigenous type after sphalerite and chalcopyrite occur at a few workings such as the Wet Adit prospect and near the Nevada Dominion shaft. In
polished section the "limonite" after pyrite (and perhaps the other types) consists of intergrown lepidocrocite and goethite. Jarosite (and natrojarosite?) was seen in several thin sections of oxidized vein rock.

The only secondary lead mineral identified was cerussite in a specimen from the dump of the shaft in SW 1/4, SW 1/4 Sec. 16, T. 23 N., R. 21 E. No secondary zinc minerals were positively identified; a trace of hemimorphite (?) was seen on the dump of the Owl Lode prospect. The only secondary silver mineral identified is cerargyrite which is present in several workings. Claude Chaplin, a prospector active in the district, reports native silver from oxidized outcrops near the Nevada Dominion shaft.

Supergene sulfides occurring in the district include covellite and chalcocite with covellite by far the most abundant. Supergene chalcocite was only seen in abundance in polished sections from the Jumbo shaft. Covellite occurred in almost all the polished sections and was seen replacing galena, chalcopyrite, enargite, and tetrahedrite.

The precious metal values are often higher in oxidized outcrops than in the hypogene mineralization below. This is particularly true for gold values which range up to .2 to .3 oz/ton in oxidized rock. Silver is unpredictable but is often as high or higher in oxidized rock than in the hypogene mineralization below. Silver also may be concentrated in the wall rocks adjacent to partially oxidized veins. This is well illustrated by the Cinch prospect vein
where samples of partially oxidized vein material are lower in Ag (and also Pb) than samples of adjacent wall rock which contain no visible mineralization. This relationship may not be due to hypogene processes as less oxidized materials from the Burrus mine do not show the same Ag distribution pattern as the Cinch samples. The vein material (P4a in Table 4) contains 700 ppm. silver whereas the adjacent wall rock (P4) has 0.5 ppm.

Dikes of basalt or basaltic andesite occur near veins in several prospects in the district. The dikes often have Cu and Ag values and the chalcanthite encrustations are usually more common on dikes exposed underground than neighboring rocks. These values are probably due to supergene processes as the dikes are interpreted to be post-ore as will be discussed in a later section.

Hypogene Sulfide Zoning

The distribution of the various hypogene sulfide minerals in the Pyramid district forms a well-developed zoning pattern (Fig. 11). In the central part of the district (Jones-Kincaid, Crown Prince, Good Hope prospects) veins contain only enargite (with intergrown luzonite) and pyrite. A trace of chalcopyrite was seen as inclusions in enargite in one polished section from the Jones-Kincaid and an unknown mineral (arsenopyrite?) was also occasionally seen as inclusions in enargite from the central zone, but no other sulfides were seen in this zone. In the intermediate zone
in the central zone bear enargite, luzonite, and pyrite. Veins in the intermediate zone bear tetrahedrite, galena, sphalerite, chalcopyrite, bornite, chalcocite, and pyrite. Sulfides in the outer zone veins are mostly galena and pyrite.
the veins contain tetrahedrite, chalcopyrite, galena, sphalerite, bornite, chalcocite, and pyrite (e.g. Nevada Dominion, Bluebird, Owl Lode, Wet Adit). In the outer zone, along the periphery of the district (Ruth shaft and nearby prospects), galena and pyrite are the dominant sulfides, but chalcopyrite and sphalerite occur in trace amounts.

Ores from the Burrus and Cinch mines provide examples of the transition from the central enargite-pyrite zone to the polymetallic intermediate zone. These ores contain enargite (with luzonite), tetrahedrite, pyrite, and traces of chalcopyrite, sphalerite, and arsenopyrite (?). The sulfosalts in the transitional ores may occur in complexly intertwined intergrowths and also as isolated crystals. The transition from the intermediate to the outer zone was much more gradational.

Enargite and luzonite have higher sulfur-to-metal ratios than minerals in the intermediate and outer zones. Workers at Butte, Montana (e.g. Meyer and Hemley, 1967) used the term high sulfur-to-metal assemblage for similar enargite-bearing ores at that deposit. Experimental work to be discussed later indicates that high sulfur-to-metal ores are produced by solutions with higher sulfur fugacities than solutions producing the minerals seen in the Pyramid intermediate zone.

The zoning is also reflected in variations in metal ratios across the district. Cu, Pb, Zn, Au, Ag, As, Sb, and Bi values were determined for unoxidized samples or specimens from each of the workings shown on Fig. 12. Values from
Figure 12. Map showing the distribution of workings where unoxidized ores were sampled for zoning studies. Each working is indicated by a numbered circle. The numbers are the same as the sample numbers of the assays from that working used in metal ratio calculations which are listed in Appendix A.
inaccessible shafts were obtained from carefully collected dump samples. There are only 19 workings where unoxidized hypogene sulfides could be sampled and the metal ratios calculated are not statistically valid, however remarkably consistent patterns are seen in the metal ratio maps Cu/Pb+Zn, Cu/Pb, Pb/Zn, Sb/Ag, As/Pb+Zn, Cu/Ag, As/Pb, Sb/Pb (Figs. 13-20) and in other metal ratios.

Au and Bi values were discarded for metal ratio calculations. Au values were non-existent or too small in many of the workings. Bi values were determined by stepwise emission spectrometry and hence were too imprecise to yield meaningful results. Appendix 1 lists the metal values for each working used in the calculations. These analyses were not meant to be representative of ore grade but were used only for metal ratios. Values for Pb were essentially background in the central part of the district, as were those of copper in the peripheral parts. The\(\infty\) and \(<1\) symbols on the metal ratio maps show areas where ratios therefore trended toward very large or very small values.

A comparison of the Pyramid metal ratio patterns to those given by Goodell and Petersen (1974) for the Julcani district in Peru shows similar results, although much more data was available for the Peruvian studies. As shall be discussed later, the Julcani mineralization is very similar to that in the Pyramid district. Goodell and Petersen (1974, and references cited therein) give several generalizations about metal ratio patterns which also apply to the Pyramid
Figure 13. Metal-ratio contour map for Cu/Pb+Zn. On this and the following metal-ratio maps, dashed lines indicate contours whose position is inferred under post-ore cover.
Figure 14. Metal-ratio contour map for Cu/Pb.
Figure 15. Metal-ratio contour map for Pb/Zn.
Figure 16. Metal-ratio contour map for Sb/Ag.
Figure 17. Metal-ratio contour map for As/Pb+Zn.
Figure 18. Metal-ratio contour map for Cu/Ag.
Figure 19. Metal-ratio contour map for As/Pb.
Figure 20. Metai-ratio contour map for Sb/Pb.
district: (1) metal ratio contours are generally convex
toward the source of the solutions, (2) the direction of
solution flow is given by the direction of decrease in Cu/Pb
values, and (3) contours become more strongly distended along
areas of less restricted solution flow (usually areas of more
thorough fracturing). The hydrothermal solutions depositing
the ores in the Pyramid district therefore emanated from
near the head of Perry Canyon (southeastern corner of Figs.
11-20, Pl. 1), perhaps under the post-ore capping, and moved
to the north and east (perhaps more easily to the east, as
shown by the distended contours in Fig. 13, 14, etc).

As/Sb did not yield a consistent pattern although recent
work (Feiss, 1974; Maske and Skinner, 1971) suggests that the
partition of these two elements among the Cu-bearing sulfo-
salts is temperature dependent. The ratios do show a system-
atic decrease toward the periphery of the district if the
values for the intermediate polymetallic zone only are
contoured. Perhaps the change from enargite in the central
zone to tetrahedrite in the intermediate zone is the cause
for the irregular pattern.

Most applications of metal ratio contouring have been in
operating mines where a large number of analyses of more rep-
resentative samples are available (Goodell, 1974). The
delineation of a metal ratio pattern in the Pyramid district
shows that the technique can be a valuable tool in reconnaiss-
sance exploration (even with a limited number of exposures
of unoxidized sulfides) particularly in districts with strong
zoning. Possible causes for the zoning pattern will be discussed in a later section.

**Lead Isotope Analysis**

Zartmann (1974) reports an isotopic analysis of lead from a Nevada Dominion mine specimen. The values are 18.963 for Pb\(^{206}/\text{Pb}^{204}\), 15.628 for Pb\(^{207}/\text{Pb}^{204}\), and 38.678 for Pb\(^{208}/\text{Pb}^{204}\). Zartmann therefore placed the Pyramid district in his zone III of ore deposits of the western United States. This zone is characterized by single-stage, moderately radiogenic lead and includes much of California and also extreme northwestern Nevada. The lead values of the mineral deposits are similar to the lead values of the rocks in this zone and Zartmann suggests that the lead was produced from "eugeosynclinal" or subduction-related sources. It is interesting to note that almost all of the other ore deposits of Nevada belong to Zartmann's Zone II, characterized by lead from "miogeosynclinal" sources.

The analyses given by Zartmann are probably representative of the rest of the lead in the district according to the research of Doe and Stacey (1974), which indicates that Pb isotopes of a mining district can usually be characterized by a single analysis.

**Sequence of Ore Deposition**

New interpretations of the significance of ore textures, particularly replacement textures, cast doubt on the validity
of determinations of the sequence of ore deposition. Many textures originally thought to have been produced by a later phase replacing an earlier phase (providing a basis for the determination of time relationships of mineral deposition) have been reinterpreted by some geologists (for example, Stanton and Gorman, 1968; Stanton and Willey, 1970; and Stanton, 1972) using principles observed by metallurgists in the cold working of metals (Beck, 1954; Smith, 1964; Margolin, 1966). The new work indicates that textures seen in ores do not necessarily reflect the sequence of primary ore deposition, but are produced in the last recrystallization or "healing" of the ores. Laboratory experiments with recrystallization of naturally occurring ore minerals also confirm some of the new interpretations (Stanton and Willey, 1970).

Although the literature is not extensive, "healing" textures are not always restricted to ores that have been metamorphosed but are also common in sulfide ores cutting non-metamorphosed rocks (Stanton, 1972), such as in the Pyramid district. Stanton's work holds that the textures observed in such ores are generally produced subsequent to the initial deposition of the ores, either by annealment as the ores cool from depositional temperatures or by recrystallization produced by deformation. For example, in Figure 6 sphalerite appears brecciated and the fragments have been healed or cemented by quartz and galena. Classically this texture would be interpreted as indicating that deposition of galena followed that of sphalerite. However, the newer
work would support the idea that the relatively "hard" sphalerite fractured in a brittle manner due to directed stress, and the relatively "soft" galena (Stanton, 1972) moved into the open fractures, and that the texture indicated nothing about what was deposited first but only what happened in the last deformation/recrystallization. Figure 10 shows islands of galena enclosed in sphalerite indicating that galena indeed may have formed first in the Pyramid ores. If classical textural interpretation is used, then there must have been two periods of galena deposition in these two ores which occur about 3,000 feet from one another.

Geologists do not agree on which textures, if any, are best for determining the sequence of ore deposition. It is certain, however, that ores with obvious deformation textures may not give correct results. Figure 21 shows the sequence of ore deposition in the Pyramid district using classical textural interpretations of open space filling ores with no obvious deformation, such as those intergrown with euhedral quartz in Figures 9 and 22. For example, in Figure 22 galena is totally surrounded by tetrahedrite and is interpreted to have formed before the tetrahedrite. The results in Figure 21 should be considered tentative however, pending reinterpretations of the significance of ore textures in general. Also, Stanton has pointed out that many deformation textures can only be seen when rather specialized polished section etches are used. These etches were not used in the present study and some deformation textures
Figure 21. Diagram indicating sequence of ore deposition of open-space filling ores.
Figure 22. Photomicrograph of bornite (bn), chalcopyrite (cp), galena (gn), and pyrite (py) enclosed in tetrahedrite (td). Dark areas are quartz and open spaces. Width of field 1.12 mm. Reflected light.
may not have been seen.

Wall Rock Alteration

Propylitic Alteration

Propylitic alteration of the tuffs in the Pyramid district is characterized by the formation of calcite, epidote, montmorillonite, and chlorite. Plagioclase phenocrysts are commonly incompletely replaced by calcite, epidote, montmorillonite, albite, disordered potassium feldspar, sericite or various combinations of these. Biotite is most commonly replaced by pseudomorphs of a mixed-layer intergrowth of sericite and chlorite with rutile and opaque minerals (Mn oxides?) localized along the old biotite cleavages. Pyrite and calcite also occur less commonly after biotite. Oxyhornblende is converted to montmorillonite, sericite, calcite, epidote, or a combination of these minerals. Quartz and sanidine phenocrysts are not affected by the propylitic alteration and cristobalite-sanidine devitrification spherulites also appear to be unaffected. The glassy groundmass materials are replaced by fine-grained quartz with illite, montmorillonite, and unidentified clay minerals; hydrated, but otherwise unaltered glass is sometimes present. The groundmass textures are often well preserved in the propylitized rocks and welded zones are usually less thoroughly altered than the porous lower zones.

The products of the propylitic alteration vary from
place to place. For example, near the Burrus mine, plagioclase is replaced almost exclusively by calcite, but near the Owl Lode plagioclase is replaced by epidote, albite, and montmorillonite with no calcite. No consistent pattern can be shown for this variation, but calcite may be more common near the center of the district. Browne and Ellis (1970) stated that calcite was favored over epidote after plagioclase by a high CO₂ content in the fluid in an active hydrothermal area in New Zealand.

Propylitization is the most voluminous type of alteration exposed in the district. All of the upper unit Hartford Hill rocks south of Mullen Pass are at least propylitized (Pl. 1). The propylitization is less complete in outcrops near the margin of the pass and becomes stronger to the south. Propylitization again becomes weaker in the lower and middle units of the Hartford Hill to the south of the main mineralized area and gradually dies away progressively to the south. It is impossible to draw a sharp line dividing propylitized and non-propylitized rocks in the south because certain of the lower sequence units (more porous?) are still propylitized in areas where units directly above and below are essentially fresh. The quartz-sanidine tuffs of the lower sequence also do not show propylitic alteration as readily in hand sample as the upper unit tuffs, because the phenocrysts are not affected by this alteration. The field mapping of propylitic alteration then becomes difficult. However, no significant mineralization or alteration was observed south of the area
shown in Plate 1.

**Intermediate Argillic Alteration**

No hypogene intermediate argillic alteration was seen in the study. Argillization is quite common in rocks near oxidized vein outcrops but is not present, or is at least very poorly developed, in unoxidized rock. Therefore the argillization is considered supergene in origin.

Montmorillonite commonly forms after plagioclase but either enough calcite is present to indicate the rock should be considered propylitic, or sufficient sericite is present to consider the rock to be sericitically altered. Also, kaolinite was not seen in unoxidized rocks near the boundary of the propylitized and sericitized rocks. Advanced argillic alteration was recognized in the district, but as discussed below, its occurrence and chemical character are distinctly different from intermediate argillic alteration (Meyer and Hemley, 1967).

**Sericitic Alteration**

Propylitic alteration gives way near veins to sericitic alteration which envelopes the veins for widths of 10 to 15 feet. Sericite increases in percentage as the vein is approached and may reach up to 50% of the rock. This is well shown by plagioclase phenocrysts which become progressively more replaced by sericite as the veins are approached (compare Figs. 23 and 24). Small amounts of montmorillonite
Figure 23. Photomicrograph of sericite (se) replacing a partially extinct plagioclase (pl) phenocryst along cleavage in sample taken 12 feet from the Burrus vein. Groundmass is recrystallized quartz and sericite after biotite, amphibole, and plagioclase. Width of field 3.38 mm. Transmitted light, crossed nicols.
Figure 24. Photomicrograph of sericite (se) replacing plagioclase (pl) phenocrysts in sample taken 6 feet away from the Burrus vein. Replacement is much more complete than in Fig. 23. Width of field 3.38 mm. Transmitted light, crossed nicols.

Advanced Argillic Alteration

In the central sericito-pyrite zone (Fig. 11), an advanced argillic assemblage occurs between the veins and the sericitic envelopes. This envelope varies from 1 to 4 feet in width.

In the outer part of this envelope the rocks consist
are present in the very outer part of the sericitized zone. Biotite phenocrysts are replaced by sericite with minor pyrite, rutile, and opaque minerals (Mn oxides?) (Fig. 7). Oxyhornblende phenocrysts are replaced by sericite but an unidentified clay mineral is also present in oxyhornblende in the outer part of the sericitic envelope. Quartz phenocrysts become overgrown by fibrous quartz near the veins. The coarser-grained sericite after biotite is the 2M polytype (M.L. Silberman, oral commun.).

Sericitic alteration is largely confined to the upper unit of the Hartford Hill which has few or no sanidine phenocrysts, but the sanidine-cristobalite spherulitic intergrowths in the unit are partly replaced by sericite (?) and quartz. Their spherulitic structure is well-preserved, however, as is the overall texture of the rock. As with the propylitic alteration, the sericitic alteration is difficult to identify in hand samples of the lower unit tuffs as the quartz and sanidine phenocrysts do not alter readily. In thin section the groundmass of these tuffs and a small portion of the sanidine phenocrysts contain sericite.

Advanced Argillic Alteration

In the central enargite-pyrite zone (Fig. 11), an advanced argillic assemblage occurs between the veins and the sericitic envelopes. This envelope varies from 4 to 8 feet in width. It is significant, composition, and structure is not known. Koalinite also occurs intergrown with pyrophyllite in this.
almost wholly of pyrophyllite, quartz, and pyrite with the pseudomorphs after original phenocrysts, however other original textures and structures are totally destroyed. Rutile occurs in a few of the patches, perhaps indicating they were sites of old biotite phenocrysts, but no other forms could be recognized. The quartz-pyrophyllite-pyrite rock cannot be distinguished from the quartz-sericite-pyrite rock in hand sample or thin section and is only identified by x-ray diffraction or by its very low K$_2$O content. Diaspore occurs in minor quantities intergrown with pyrophyllite in the outer part of the envelope and increases as the veins are approached. In extreme cases the final result of this alteration is quartz-diaspore-pyrite rock with diaspore occurring as disseminations in the recrystallized quartz and as intergrowths with euhedral quartz in veins (Fig. 25).

Topaz occurs as tiny crystals (.01-.1 mm.) intergrown with the pyrophyllite. It is only associated with the rutile-bearing pyrophyllite patches that may be after original biotite. Hydrobiotite occurs in veins along with diaspore but its significance, composition, and structure is not known.

Kaolinite also occurs intergrown with pyrophyllite in this zone (Fig. 26) but has not been seen in unoxidized specimens. The kaolinite is therefore regarded in this study as a product of supergene alteration of pyrophyllite. It should be realized, however, that kaolinite can be a stable hypogene phase in advanced argillic alteration, but
Figure 25. Photomicrograph of a vein of euhedral quartz (qtz), pyrite (opaque or black in the photograph), and diaspore (di). The wall rock along the vein is recrystallized quartz with disseminated diaspore and pyrite. Width of field 3.38 mm. Transmitted light, crossed nicols.

Pyrophyllite undoubtedly forms from sericite (perhaps with intermediate serp) and diasporite may form simultaneously with the pyrophyllite or may form totally from the decomposition of kaolinite. These are seen in the altered area.

Figure 26. Photomicrograph of pyrophyllite (pyl) with intergrown low-birefringent kaolinite (ka). Width of field 3.38 mm. Transmitted light, crossed nicols.

Pyrophyllite undoubtedly forms from sericite (perhaps with intermediate steps) and diaspore may form simultaneously with the pyrophyllite or may form totally from the decomposition of pyrophyllite. Haas and Holdaway (1973) list several reactions involving diaspore and pyrophyllite but the formation of diaspore from pyrophyllite was not investigated. Lovering (1949) suggested that diaspore could form from alunite upon increasing acidity of the hydrothermal solutions. However alunite was not identified in the Pyramid district.

Chemical Changes During Alteration

Table 5 shows major element analyses of samples taken progressively away from the main vein at three feet intervals in the adit level of the Burrus Mine. Sample RC-12a is an unaltered sample for comparison taken from approximately the same stratigraphic horizon in the Rainbow-Mine Canyons area. Figure 27 graphically displays the analyses in Table 5 as the vein is approached as well as the petrographic character of the samples. These trends were confirmed by 8 more analyses at a 5 foot sample interval across minor veins in the Burrus mine.

Calculations of net gains and losses across the zones are not shown because of the incomplete analyses (CO₂, S₂, etc.) and because of uncertainty that RC-12a is actually
TABLE 5: MAJOR ELEMENT CHEMICAL ANALYSES OF ALTERED ROCKS FROM THE BURRUS MINE, ADIT LEVEL AND OF AN UNALTERED UPPER SEQUENCE SAMPLE FROM RAINBOW CANYON.

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<td>0.68</td>
<td>0.016</td>
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Specific gravity

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Table 5: Continued

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<th>wt. %</th>
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<td>0.006</td>
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<td>Total</td>
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<td>Specific gravity</td>
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<td>2.75</td>
<td>2.78</td>
<td>2.78</td>
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1. RC-12a, unaltered cooling unit 6, Hartford Hill Rhyolite, Rainbow Canyon, approximately the same horizon as the altered samples.
<table>
<thead>
<tr>
<th></th>
<th>Sample</th>
<th>Description</th>
<th>Distance from Main Vein</th>
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<tr>
<td>2.</td>
<td>74AW-6</td>
<td>propylitized upper unit Hartford Hill, adit level Burrus mine</td>
<td>15 feet</td>
</tr>
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<td>3.</td>
<td>74AW-5</td>
<td>sericitized upper unit Hartford Hill, adit level Burrus mine</td>
<td>12 feet</td>
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<td>4.</td>
<td>74AW-4</td>
<td>sericitized upper unit Hartford Hill, adit level Burrus mine</td>
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<td>5.</td>
<td>74AW-3</td>
<td>sericitized upper unit Hartford Hill, adit level Burrus mine</td>
<td>6 feet</td>
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<td>6.</td>
<td>74AW-2</td>
<td>advanced argillic alteration of the upper unit Hartford Hill, adit level Burrus mine</td>
<td>3 feet</td>
</tr>
<tr>
<td>7.</td>
<td>74AW-1</td>
<td>advanced argillic alteration of the upper unit Hartford Hill, adit level Burrus mine</td>
<td>bordering main vein</td>
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</table>

* sample recalculated to 100 wt. % with H₂O⁻ removed before calculating gms./cm.³

₁ sample has a high percentage of CO₂ and S₂ which were not determined.
Figure 27. Graph showing chemical variations in samples compared with distance from the main Burrus vein and alteration mineralogy.
Figure 27. Continued
Figure 27. Continued
from the same horizon. However the chemical and mineralogical changes are similar to those reported for the same alteration types in the Eureka district, San Juan Mountains, Colorado (Burbank, 1969) and in the upper levels of Butte, Montana (Meyer, et al., 1968), and at the Chinkuashih mine, Taiwan (Wang, 1973). The most characteristic feature is the extreme leaching of elements from the advanced argillic zone excepting SiO$_2$, Al$_2$O$_3$, and TiO$_2$. Al$_2$O$_3$ and TiO$_2$ are not usually mobile in hydrothermal alteration, and therefore increase in percentage as the other elements are leached. The large SiO$_2$ increase is caused by introduction of SiO$_2$ into the system.

**Alteration Zoning**

Hypogene alteration in the district is crudely zoned (Fig. 28). In Zone 3, sericitic alteration surrounds the veins with propylitic alteration being dominant. In Zone 2, which corresponds to the central enargite-pyrite zone, advanced argillic alteration occurs between the veins and the sericitic envelopes.

In Zone 1 (Plate 1, Fig. 28), there is pervasive sericitic alteration with advanced argillic alteration enveloping the veins. Exposure is poor in this area with almost all the outcrops being silicified ribs along veins. The Hartford Hill could not be differentiated into units in this area with only field criteria so the zone is mapped as “pervasively altered” on Plate 1. The alteration pattern in this zone
argillic alteration along veins. Zona 2 veins have envelopes of advanced argillic and sericitic alteration with propylitic alteration dominant away from veins. Zone 3 has pervasive propylitic alteration with sericitic envelopes bordering veins. Rocks in zone 4 are either propylitized or unaltered (north of Mullen Pass).

Figure 28. Map showing the distribution of alteration zones. Zone 1 has pervasive sericitic alteration with advanced argillic alteration along veins. Zone 2 veins have envelopes of advanced argillic and sericitic alteration with propylitic alteration dominant away from veins. Zone 3 has pervasive propylitic alteration with sericitic envelopes bordering veins. Rocks in zone 4 are either propylitized or unaltered (north of Mullen Pass).
could be produced by closely spaced veins with overlapping sericitic alteration, or it could be simply an area of stronger alteration; it corresponds with the centers of metal ratio and sulfide zoning patterns.

**Alteration in Post-Ore Units**

The dacite intrusives and equivalent lavas are generally propylitically altered and two of the small plugs in Secs. 23 and 24, T. 23 N., R. 21 E. are in part sericitized with minor pyrite. Also, the basaltic dikes often are slightly propylitized. However these units are interpreted to be post-ore by field and K/Ar evidence (these interpretations will be discussed further in a later section on age of the mineralization).

Recent papers (Taylor, 1974; O'Neil and Silberman, 1974; and many others) have emphasized the importance of meteoric water in the alteration process. There is no reason why post-ore units cannot be altered as long as the area they intrude has ground water available for alteration. The dacite units are only slightly post-ore (Table 1) and it is possible that they intruded in the waning stages of the mineralization event.

**Supergene Alteration**

Acid solutions produced during oxidation of the sulfide veins produced opaline silica, chalcedony, hydromicas, kaolinite, and allophane, a clay amorphous to x-rays and optically
isotropic (Meyer and Hemley, 1967), in the wall rocks. Several of the surface outcrops of veins consist of a bold, iron-stained, silicified rib 4 to 15 feet wide which is bordered by a bleached zone of supergene argillic alteration. Although the wall rocks along the veins have a high percentage of silica, such strongly silicified narrow zones are not seen underground below the bold ribs. Therefore the silification is thought to be supergene, and perhaps is caused by the solution and redeposition of silica by the supergene solutions (case hardening) with simultaneous or subsequent leaching of the clay and mica components. Some of the veins, (particularly the west trending veins, (A. Baker, oral commun.)), although partly oxidized, do not have overlying silicified ribs (e.g. Surefire-Jumbo), but the reason for the inconsistency is not known.

Oxidation of the pyrophyllite-bearing advanced argillic assemblages produces a vuggy kaolinite-quartz rock with allophane, minor hydromicas, and unidentified clays. Sericite is sometimes converted to kaolinite but often remains in the oxidized rocks along with clays, allophane, and quartz. Nothing is known about the exact composition of the allophane, nor of the hydromicas as neither could be separated from the rest of the rock for analysis. The hydromica in the supergene alteration could be called hydromuscovite from optical data, whereas the hydromica in the hypogene advanced argillic assemblage is hydrobiotite.

Dikes adjacent to the veins are commonly altered to
clays along their margins (e.g. Cinch mine). This alteration is also interpreted to be supergene as the dikes are thought to be post-ore.

CHEMICAL AND PHYSICAL CONDITIONS DURING ORE FORMATION

The alteration and ore assemblages in the Pyramid district also occur in one of the most studied ore deposits in the world, Butte, Montana, and a large amount of experimental work has been done to determine chemical conditions during alteration and ore deposition (Hemley and Jones, 1964; Meyer and Hemley, 1967; Hemley, et al., 1969). Very similar ore assemblages have been studied in detail in several other ore deposits (Chinkuashih, Taiwan; San Juan Mountains, Colorado; and several Peruvian deposits), allowing some generalizations to be made about temperature and depth of emplacement. The consistent correlation of alteration type with sulfide mineralogy (advanced argillic alteration occurs only in the central enargite-pyrite zone) also provides good evidence that at least the higher grades of alteration were produced by the same hydrothermal solutions that deposited the ore minerals, else no consistent relationship between alteration and sulfide zoning should exist.

Figure 29 shows two experimentally determined stability diagrams which indicate the extreme acidity at which the advanced argillic alteration forms. As the hydrothermal fluid migrates along the vein system and laterally into the wall rocks, it should become less acidic as a result of reaction
Figure 29 (a) and (b). (a) Equilibrium relations in the system $K_2O - Al_2O_3 - SiO_2 - H_2O$ in a chloride electrolyte environment. Total pressure is 15,000 psi and quartz is present. Values for $KCl / HCl$ given on the abscissa constitute the equilibrium quotient of the reactions and correspond to the measured pH of the reactions in experiments involving 1 m. $KCl$. Potassium mica (sericite-muscovite) would become the stable alteration phase instead of pyrophyllite if the solution changed along the path from a to b, that is, became less acidic. Such a change could produce the alteration patterns observed in the Pyramid district. Diagram after Meyer and Hemley (1967). (b) Illustration of stability relations of alunite as a function of the $H_2SO_4$ and $K_2SO_4$ activities. Quartz is present and temperature and pressure are constant. Pyrophyllite should replace kaolinite at temperatures above $350^\circ C$. Abscissa also may be taken to represent decreasing pH to the left. Diagram after Hemley, et al. (1969).
with the wall rocks and enter the stability field of sericite instead of pyrophyllite/kaolinite. This would produce exactly the distribution of alteration minerals seen in the Pyramid district. No alunite was identified in the Pyramid district; the pH and (or) activity of $\text{H}_2\text{SO}_4$ probably did not reach that extreme.

Advanced argillic alteration is thought to form only in relatively near surface environments for three reasons: (1) it dies out with depth in many deposits, for example, at Butte, and in the San Juan Mountains, (2) it is thought that the extremely acid conditions necessary for its formation can only be produced in a near surface environment, and (3) it is forming in shallow volcanic environments today (Yellowstone and Lassen National Parks, Wairakei, New Zealand, Steamboat Springs) (Hemley, et al., 1969). The assemblage may, however, exist to moderate depths (one mile in the Red Mountain district of Colorado). The mineralization in the Pyramid district took place very shortly after deposition of the upper unit ash-flows of the Hartford Hill. The K-Ar ages of the mineralization and upper ash-flows are nearly the same considering the limits of analytical uncertainty and it is therefore doubtful that the Hartford Hill was much thicker at the time of mineralization than at the present. The Hartford Hill section in the mineralized area is already four or five times thicker than most of the Hartford Hill sections in the region. Conclusive data does not exist, but it seems unlikely that the vein ores were
emplaced at depths greater than 1,000 to 1,500 feet. No evidence for the solutions reaching the surface, such as the presence of fossil spring sinters or tufa, was seen.

The reason for the high activity of $H^+$ in the solutions is not clearly known. Hemley, et al, (1969) suggests two sources; (1) near-surface oxidation at $H_2S$ and metal sulfides and (2) the increase in dissociation of $H_2SO_4$ and other strong acids with falling temperature in a migrating, cooling hydrothermal solution.

Meyer and Hemley (1967) present a diagram relating sulfur and oxygen fugacities and pH at 250°C (Fig. 30) which was intended for Butte but can be related to the Pyramid mineralization. Assemblage I represents the high sulfur-to-metal assemblage in equilibrium with advanced argillic alteration at Butte (central zone, main stage). Point II represents the Butte intermediate zone mineralization (a lower sulfur-to-metal assemblage) in equilibrium with sericitic alteration. The relationships shown in the diagram should be applicable to the Pyramid mineralization. Although the Butte central zone has more copper sulfides (particularly digenite and chalcocite) than the Pyramid central zone, both central zones contain abundant enargite associated with advanced argillic alteration and also the intermediate zones have similar vein mineralogy and alteration. According to this work, the sulfide zoning pattern seen at Pyramid could be produced by decreasing $f_{S_2}$ and $f_{O_2}$ along with increasing pH as the solution migrates.
Figure 30. Fugacity-pH diagram showing distribution of some characteristic ore mineral assemblages in the Cu-Fe-S-O system with associated wall rock alteration. Temperature is 250°C and total aqueous sulfur is 0.1 m. Heavy lines mark equilibria between solid sulfide and oxide phases. Light lines are iso-pH contours. I represents the high-sulfur-to-metal assemblage in equilibrium with advanced argillic alteration at Butte, Montana. II represents the lower sulfur-to-metal intermediate zones at Butte which are in equilibrium with zoned sericitic, intermediate argillic, and propylitic alteration. The change from the central zone to the outer zones at Pyramid could have been produced by such a change in the hydrothermal solutions. Diagram after Meyer and Hemley (1967).
No quantitative data for the temperature of ore deposition at Pyramid is available. The work of others on similar ore assemblages in the central zone of Butte (Meyer, 1950; Lange and Cheney, 1971) and at Chinkuashih in Taiwan (Folinsbee, et al., 1972) gives temperatures around 300°C for enargite-bearing ores (with neighboring pyrophyllite-bearing advanced argillic alteration). The enargite-luzonite inversion point, through which the Pyramid ores have passed, lies at about 290°-300°C. (Maske and Skinner, 1971). The effect of impurities on this point have not been fully investigated but the most common impurity, antimony, increases the inversion temperature. Feiss (1974) reports sulfur isotope temperatures from several Peruvian ore deposits that are almost identical in ore mineralogy to the Pyramid district. He reports 325°-250°C. temperatures of ore formation for deposits with enargite associated with tetrahedrite. The presence of topaz, diaspore, and pyrophyllite instead of kaolinite in the Pyramid alteration assemblage also suggests relatively high temperatures. Therefore a reasonable estimate for the temperature of mineralization in the central zone of the district is 300 to 325°C.

ZONING

As already discussed, well-defined zoning patterns are seen in sulfide mineralogy and metal ratios in the Pyramid district. Veins in the central zone bear enargite (luzonite) and pyrite and are copper-rich but lead-poor. Outward from
the central zone, veins in the intermediate zone contain many sulfides including pyrite, tetrahedrite, galena, sphalerite, chalcopyrite, bornite, and a trace of chalcocite. In the outer zone, along Mullen Pass, near the margin of the district, galena and pyrite are the dominant sulfide minerals and the ore is lead-rich and copper-poor. Wall rock alteration also is crudely zoned with advanced argillic alteration bordering the veins in the central high-sulfur-to-metal, enargite-pyrite zone and sericitic alteration bordering the veins in the outer parts of the district.

The experimental work in Figures 29 and 30 provides some possible reasons for the zoning. The central zone ore was probably deposited by a very acidic hydrothermal solution with relatively high sulfur and oxygen fugacities. As this solution migrated along the channelways and laterally into the wall rocks, the pH would be expected to increase with increasing interchange with wall rocks, and sericite becomes the dominant alteration product instead of pyrophyllite. With a concomitant decrease in sulfur fugacity and oxygen fugacity (although less decrease than in sulfur), experimental work (Fig. 30) suggests that a lower sulfur-to-metal ore assemblage, as is seen in the outer parts of the district, would become stable. The increase in pH and the decrease in sulfur and oxygen fugacities could also have been produced by increasing interchange with large quantities of meteoric water along the migration path. It is also reasonable to assume the temperature of the solutions de-
crease as they migrated from the center of the system, but it is not known if lower temperature alone could stabilize the sulfide and alteration assemblage seen in the outer parts of the district.

CONTROLS OF MINERALIZATION

Regional Controls

Several factors probably contribute to the localization of a mineral deposit such as the Pyramid district in its regional setting. The exact mechanisms of this localization are not well known but, by correlation of areas with similar geologic development and similar ore deposits, a few patterns can be seen.

The Pyramid district is among many ore deposits of the Circum-Pacific region which are hosted by or originated from calc-alkaline (subduction related?) igneous rocks (Pereira and Dixon, 1971; Sawkins, 1972; Sillitoe, 1972) and are localized by the occurrence of such rocks. The upper unit ash-flows of the Hartford Hill, which intimately associated with the ore in time and space, are petrographically and chemically calc-alkaline. The Fe/Mg ration of 2.2 at 66% SiO₂ (Table 2, analysis 3) plots well into the calc-alkaline field of an Fe/Mg versus SiO₂ diagram, which can be used to delineate the chemical affinity of an igneous rock (Miyashiro, 1974). The highly-siliceous, lower ash-flows are not as obviously calc-alkaline in chemistry, but several workers
have presented evidence that they are of "andesitic affinity" or subduction-related (M. L. Silberman, oral commun.; E. H. McKee, oral commun.; Noble, 1972).

Most of the larger ore deposits in western Nevada occur along the Walker Lane structural zone and the Pyramid district lies along its northern extension. Although the origin and mechanics of the Walker Lane and other similar zones such as the Texas Lineament, are not known, the importance of such structures in the localization of ore deposits and igneous activity has long been emphasized (Schmitt, 1966; Lowell, 1974; Silberman and McKee, 1974). The northeast trending discontinuity extending from Mullen Pass to near Midas discussed earlier is not well understood but also may have had some influence in the localization of the district.

Several ore deposits in Washoe County and eastern California are along the margins of the large circular feature of unknown origin discussed earlier (e.g. Peavine, Pyramid, Olinghouse). The feature is a structural high but until its origin is better understood it will not be known if ore deposits are preferentially localized along its marginal structures. It is possible that the ore deposits only appear to be localized around the margins because they are hosted by Tertiary volcanic rocks which are not nearly as common in the central area of the feature.

Some authors have suggested that the rich western United States metal province was localized because of an anomalously metal-rich underlying mantle (Noble, 1974) and
that favorable regional structural development is of little or no importance. This school of thought receives little attention from most American geologists (for example, Lowell, 1974). In my opinion, structural features were probably the main influence in the localization of the district. The intersection of the Walker Lane and the northeast trending structure lying on the circumference of the circular feature would provide excellent pathways for ascending igneous rocks and/or mineralizing solutions (perhaps produced by subduction-related processes).

Local Controls

Alteration and mineralization does not extend to the north across the Mullen Pass structural zone. The southern limit of the alteration is somewhere in the lower and middle Hartford Hill outcrops along the southern boundary of Plate 1, but exposed sulfide mineralization is confined to the tuffs north of the boundary. The eastern limit of mineralization is not known as part of the district is covered by post-ore lavas and landslide deposits (Plate 1, Fig. 2). The first place to the east where Hartford Hill rocks emerge from under post-ore cover is near the Guanomi pluton and they are also pervasively altered in that area.

The Pyramid district veins are controlled along north-west or west trending fracture zones (Pl. 1). Some of the fracture zones show very little or no recognizable displace-
ment but are parallel to fault zones with displacement but no known mineralization. Some of the main faults were probably closed with gouge or, at any rate, too "tight" to permit entrance of mineralizing fluids as most have only minor or no alteration. Many of the main faults may be mineralized at depth but no indications of mineralization were seen along the surface outcrops. Many of the mineralized fracture and fault zones extend for considerable distance (e.g. Nevada Dominion-Burrus-Jones Kincaid vein system) but are only irregularly mineralized along strike. Physical controls appear to be the dominant localizing force for these "ore shoots" and each is probably slightly different. An intersection of two fracture zones appears to localize a shoot at the Cinch mine and cymoidal loop structures (at deflections in strike and dip of the structure) are thought to be important in the Wet adit prospect and at the Burrus mine (Gibbons, 1972; Ivosevic, 1970).

Most of the veins are confined to the more mafic upper unit tuffs although faults and fractures of the same trend and, apparently, of the same type mineralized in the upper unit, cut the lower unit tuffs in many places south of the main area of mineralization. The only area where lower units are mineralized to any extent is in the highly altered zone in the central parts of the district (Pl. 1) where poorly exposed veins cut sericitized rock of the lower unit (The distribution of the tuff units in that area is not well
known due to poor exposure and alteration, but from thin section analyses, the lower unit is present in at least some of the southern part of the area. Several factors could have caused the preference for the upper unit tuff. The upper unit may be more chemically favorable for ore deposition with the lower unit only being mineralized near the very center of the system. Intermediate igneous rocks are preferred over rhyolites for ore deposition at Comstock, Tonopah, Olinghouse, Wedekind and other vein districts in the western United States. Silberman and McKee also point out that mineralization in western and central Nevada is often hosted in volcanic units closely related to the mineralization in age, and the mineralization is only slightly younger than the upper unit tuffs (Table 1). Several physical controls, such as manner of fracturing or permeability, could have made the upper unit more favorable for ore deposition. However, the lower units could well be mineralized at depth and, by happenstance, not exposed in the mineralized area.

**AGE OF MINERALIZATION**

Alteration sericite (2M muscovite) from the Nevada Dominion adit yielded an age of $21.3 \pm 0.6$ m.y.. This date is only slightly younger than the upper unit Hartford Hill (22.1 \pm 0.5) and is older than the other Tertiary volcanic and intrusive units in the area excepting the Guanomi pluton (Table 1).
The K/Ar data is compatible with the field evidence. The tuff-breccia and basaltic lavas of the Pyramid Sequence unconformably overlie mineralized and altered rock and are interpreted to be post-ore because they are unmineralized and unaltered. An excellent area to examine this relationship is in the NW 1/4 of Sec. 14, T. 23 N., R. 21 E. near the tuff-breccia cone where highly altered Hartford Hill is beneath very porous but fresh tuff-breccia and basalt lavas. The altered dacite intrusives and lavas are also interpreted to be post-ore from field evidence. Veins trend toward the stock in Sec. 17, T. 23 N., R. 21 E. but do not enter it. Also the veins in the Ruth shaft area are vertical but in the adit just to the north where the wall rocks have been tilted up, the vein dips into the intrusive. The change in dip of the veins is about the same as the tilt of the wall rocks, implying both beds and vein were upturned by forcible intrusion. Minor radial faults associated with this intrusive appear to offset the veins although these exposures (between the north Ruth shaft and the adit to the north) are poor and can be interpreted in other ways. The dacite lavas near the Burrus mine in places overlie one of the strongest vein systems in the district but are unmineralized. The K/Ar age date on the intrusive supports the post-ore interpretation but the lava date overlaps that of the mineralization when the analytical precision is considered.

The basalt and basaltic andesite dikes, which may show propylitic or supergene argillic alteration, are also inter-
interpreted to be post-ore for several reasons: (1) they intrude the dacite stock in Sec. 17, T. 23 N., R. 21 E. (Plate 1) which is thought to be post-ore, (2) the dikes are only propylitized or, in places, are fresh where they cut Hartford Hill ash-flows which show extreme hydrothermal alteration, such as along the Cinch vein, (3) the dikes are interpreted to be feeders for the post-ore Pyramid Sequence.

The similar ages of the upper Hartford Hill volcanism and the mineralization fits the data of Silberman (Silberman and McKee, 1974 and references cited therein) who show that mineralization and volcanism are intimately related in many epithermal camps in western and central Nevada. A similar close association with volcanism is seen for ore deposits in the San Juan Mountains of Colorado, Peru, Taiwan, and Japan, which are quite similar in ore mineralogy and alteration to the Pyramid district (Steven, et al 1974; D. C. Noble, oral commun.; Wang, 1973; Nakamura, 1970).

An interesting feature of the Pyramid mineralization is that it is probably older than the other districts whose ore is hosted by Tertiary volcanic rocks in Washoe and Storey counties. Most of the others have not been radiometrically dated but are enclosed in wall rocks such as the Chloropagus Formation (approx. 15 m.y.), the Alta Andesite (at least 15 m.y. and perhaps up to 19 m.y.), and the Kate Peak Formation (12-13 m.y.) that are younger than the Pyramid mineralization (Bonham, 1969). This younger group of mineral deposits includes the Jumbo, Olinghouse, Peavine, Wedekind,
and Comstock districts. The only deposit which has been dated radiometrically is the Comstock which yields dates of about 13 m.y.

URANIUM DEPOSITS

The Hartford Hill tuffs host uranium deposits in several areas of Washoe County including Peterson Mountain, Dogskin Mountain, the Virginia Mountains, and the Pah Rah Range. In the Pyramid district and vicinity uranium deposits occur at the Armstrong claims, Secs. 31 and 32, T. 24 N., R. 21 E.; the Lowary (Maue-McCray) mine and the DeLongchamps prospect (Red Bluff Mine) in Sec. 36, T. 24 N., R. 20 E.; Sec. 1, T. 23 N., R. 20 E., and Sec. 31, T. 24 N., R. 21 E.; the Thunderbird claims in Sec. 35, T. 23 N., R. 21 E.; the Bing claims in Sec. 28, T. 23 N., R. 21 E.; the Lost Pardner mine, Sec. 24, T. 23 N., R. 20 E.; the Hopeless claims in Sec. 9, T. 24 N., R. 20 E. (Bonham, 1969). Most have been explored by shallow adits and bulldozer cuts, but have produced very little, if any, uranium.

The uranium occurs in the basal poorly welded zone of several Hartford Hill cooling units and is localized by carbonaceous material and dikes (Holmes, 1972). The uranium mineralization is not considered to be part of the Pyramid base metal mineralization for several reasons. The same types of uranium deposits are distributed throughout the region and are not just localized near the Pyramid district or other base metal mineralization. Uranium mineralization
in the vicinity of the Pyramid district is not zoned with respect to the base metal deposits but occurs throughout the district and in areas well outside of the district (P. Holmes, oral commun.). Many of the uranium deposits are hosted in tuffs that are not hydrothermally altered (Holmes, 1972).

At the DeLongchamps prospect, uranium is associated with a pyroxene basalt or basaltic andesite dike of the same type that is thought to be post-ore in the Pyramid district.

GUANOMI MINE AREA

The Guanomi mine is in an outlier of the Guanomi quartz monzonite intrusive in the SE 1/4, Sec. 24, T. 23 N., R 22 E. (Fig. 2). Walter Schmelzer and T. W. Foster developed the mine in the 1930's. The workings are now caved but reportedly consist of a 400 foot adit with 800 feet of lateral development, three shallow shafts, and a few prospect pits (Prochnau, 1973).

Similar mineralization also exists in the main body of the Guanomi pluton in Secs. 23, 25, 26, T. 23 N., R. 22 E. In 1971 and 1972 American Selco, Inc. performed geologic mapping (1:6000), geochemical and geophysical surveys, and 5230 feet of rotary and diamond drilling in 9 drill holes in the pluton and wall rocks. Much of the following discussion is taken from a report prepared in 1973 by J. Prochnau, a geologist employed by American Selco. The report is on file with the Nevada Bureau of Mines and Geology, Mackay School of Mines, University of Nevada.
The mineralized pluton (herein called the Guanomi quartz monzonite) intrudes tuffs of the Hartford Hill and is overlain unconformably by post-mineralization lavas and tuffs of the Pyramid Sequence. The pluton is thoroughly propylitized in the central portions and becomes sericitized near its margins. Ribs of pyrophyllite- and diaspore-bearing advanced argillic alteration and silicification were noted in the present study but their extent and relation to the sericitized rock is not known. Prochnau (1973) reports quartz-feldspar-gypsum veinlets in drill core from about 1,000 feet deep in the center of the pluton, but no potassium silicate alteration could be found on the surface.

The better copper and molybdenum values are disseminated in the sericitized and pyritized rock along the margins of the pluton. The drilling confirmed extensive but very low grade mineralization (average .003% Mo and .05% Cu). Sulfide minerals include molybdenite, chalcopyrite, and pyrite (W. Kemp, oral commun.) and little or no supergene enrichment is present. The contact of the pluton and the sericitized Hartford Hill is sometimes difficult to recognize. Prochnau mapped essentially all the sericitized rocks as Hartford Hill, but much of the sericitization and mineralization is in the porphyritic outer zone of the pluton.

Table 1 presents a K/Ar age of sericitized and silicified intrusive rock from the Guanomi mine dump. The age, 23.4±0.7 m.y., confirms the geologic interpretations that the intrusive body is younger than at least some of the
Hartford Hill and older than the Pyramid Sequence if the alteration age is representative of the age of emplacement of the pluton. The 23.4 m.y. age also makes the Guanomi area the youngest known occurrence of disseminated Cu-Mo mineralization in Nevada.

The relation of the Guanomi mineralization to the Pyramid district is an intriguing question. The Guanomi pluton itself is probably not the source of the Pyramid ores as it is too far from the central enargite-pyrite zone of the district. The enargite-pyrite zone is thought to be in or near the actual center of the partly covered district as this type of relatively high-sulfur assemblage is near the center or overlies the center of other quite similar deposits (several Peruvian districts, Butte, and Chinkuashih, Taiwan) to be discussed later. However the possibility exists that a similar pluton may underlie the central zone of the district. As shall be discussed in more detail in a later section, mineralized plutons (Cu-Mo) underlie similar assemblages in other, better explored districts.

The age of the Guanomi alteration is slightly older than the age of the Pyramid alteration but that does not rule out the possibility that the two are related. Silberman has shown in several studies of Great Basin epithermal districts that the duration of the mineralizing event is often 1 or 1.5 m.y. and the disparity in ages is near these values when analytical uncertainty is considered. Also sparse literature suggests that the duration of the mineralizing event may be
longer for some of the higher temperature porphyry copper type systems than for the epithermal camps (Moore and Lanphere, 1971; Page, 1971) although this is not true for all the porphyry coppers (Damon and Mauger, 1966; Theodore, et al., 1973; Eyzaguirre, et al., 1975). No research has been reported for the duration of the mineralizing event for porphyry copper systems with related veins in the wall rocks.

COMPARISONS WITH OTHER ORE DEPOSITS

There are many vein deposits in young volcanic rocks (less than 30 m.y.) in western and central Nevada and along the Walker Lane (e.g. Tonopah, Goldfield, the Comstock Lode). These districts have been grouped by many authors into an epithermal category. To many exploration geologists deposits of this category lack base metal potential and these districts are often rather disparagingly called the "epithermal-precious metal districts." Although the Pyramid district is similar to these districts in that its mineralization occurs as open-space filling veins in young volcanic rocks with widespread propylitization, however the Pyramid veins differ in several important ways from those of typical epithermal districts:

1. The veins have dominantly base metal sulfides and precious metal values are low.
2. The district is strongly zoned in respect to the base metals. Several of the epithermal camps show slight increases in base metals
If the inferred 300-325°C. temperature of formation is correct, then the Pyramid veins formed at higher temperatures than those of many of the epithermal districts. Many of these districts are inferred to have intrusives at depth which may have acted as heat sources or perhaps as sources for the metals. The Pyramid district, however, is the only one known to me with an exposed intrusive nearby which is nearly the same age as the vein mineralization and is itself heavily altered and mineralized, although low-grade. The Guanomi intrusive may not be the source area for the Pyramid mineralization but its existence implies that other similar bodies may exist in the area, perhaps at depth in the district. It does not appear to be related to the Pyramid mineralization.

The Pyramid mineralization is strikingly similar to some of the deposits in the San Juan Mountains of Colorado, particularly the breccia pipe deposits along the western side of the Silverton caldera such as Red Mountain (Burbank, 1947; Burbank and Luedke, 1968; Fisher and Leedy, 1973) and deposits in and near the Summitville-Platoro calderas (Steven and Ratte', 1960; Steven, 1968; Lipman and Steven, 1970; Mehnert, et al., 1973; and Steven, et al., 1974). Similar
or identical mineralization is also seen in several of the Peruvian polymetallic vein or pipe deposits, particularly Huaron, Julcani, Yauricocha, Cerro de Pasco, and Morococha (Lacey and Hosmer, 1956; Ward, 1959, 1961; Nagell, 1960; and Petersen, 1965; Goodell and Petersen, 1974). The Chinkuashih deposit in Taiwan (Huang, 1963; Folinsbee, et al., 1972; Wang, 1973) and several of the Japanese polymetallic veins, such as Ashio (Nakamura, 1970) are also very similar. The main stage mineralization at Butte, Montana also has many similarities to the Pyramid district (Meyer, et al., 1968).

The main points that these mineral deposits have in common are:

1. Most of the mineralization in the districts is intimately associated with calc-alkaline volcanism. The deposits are either located in or near volcanic vent structures or they can be shown to be in near-surface, sub-volcanic intrusives. The exception is Butte, Montana which does not appear to be related to volcanism.

2. All the districts have advanced argillic alteration in association with high sulfur-to-metal ores. Many have alunite as the dominant alteration mineral in this assemblage rather than pyrophyllite (Cerro de Pasco, Platoro). The zoning is particularly strongly displayed by the base metals and is characterized by high
sulfur-to-metal sulfide assemblages grading outward into lower sulfur-to-metal assemblages.

(4) Most of the deposits have similar ore mineralogy with enargite very common in or dominating the high sulfur-to-metal ores. The lower sulfur-to-metal assemblages usually contain tetrahedrite-tennantite, chalcoprite, bornite, galena, and sphalerite, and become more Pb-Zn rich in the outer zones. Some of the camps are rich in precious metals (e.g. Red Mountain, Chinkuashih) and Butte has abundant copper sulfides (especially chalcocite and digenite) in its central zone. Tungsten, molybdenum, and tin minerals may appear in the central zones of the deposits (Ashio, Julcani) or the ores may be anomalous in these elements. Pyrite is always very common in the deposits.

(5) The gangue mineralogy is almost always quartz and barite. The only other common gangue minerals are phases of the advanced argillic alteration (alunite, pyrophyllite, etc.) which often occur intergrown with the ores.

(6) Several of the deposits are associated with porphyry copper type mineralization at depth. The deep level chalcoprite and molybdenite zone at Butte could be considered more like a
porphyry copper deposit than the upper levels. Recent exploration at Morococha has revealed an exploitable porphyry copper ore body (Hollister, 1974; Eyzaguirre, et al., 1975) and disseminated Cu-Mo mineralization occurs in intrusives at several places in the San Juan Mountains (Lipman and Steven, 1970; Steven, et al., 1974).

EXPLORATION RECOMMENDATIONS

Mineralization in the Pyramid district has not been adequately explored. The veins should persist to considerable depths (1500-2000 feet and more) judging by the behaviour of similar ones at Chinkuashih, Red Mountain, and Butte. Wider ore shoots may exist but their positions are difficult to predict. Structural intersections such as where the Crown Prince west trending zone intersects the Jones-Kincaid northwest trending zone are good targets for wider ore shoots. Another such intersection is in the NW 1/4, SW 1/4, Sec. 15, T. 23 N., R. 21. E. where a northwest trending zone intersects the west trending Cinch zone.

High grade pods of supergene enriched ore may exist along some of the veins. These are more likely nearer Mullen Pass as oxidation becomes less deep to the south, especially near the head of Perry Canyon in Sec. 24, T. 23 N., R. 21 E. where pyrite can occasionally be found in outcrop. The lack of the deep oxidation, so common in Nevada ore deposits
may have been caused by a very shallow water table. The thickest section of lake sediments seen at the base of the Pyramid Sequence lavas (approximately 75 feet) is exposed in the NE 1/4 of Sec. 24 near where the oxidation is least deep. The water table would intersect the surface at a lake and prevent supergene enrichment. Oxidation and supergene enrichment is not taking place today and the time interval in which the lake existed (sometime between 20 and 15 m.y. ago) is thought by many to be the period in which conditions were best for supergene enrichment (A. L. Payne, oral commun.).

Based on the similarity of the Pyramid system to deposits overlying or related to porphyry copper mineralization such as Butte, Morococha, and perhaps the San Juan deposits, it is reasonable to think that large disseminated deposits in intrusive rock may exist at depth in the district. Breccia pipe deposits such as those at Red Mountain and Cerro de Pasco may also be present. The best target area is in Secs. 13, 14, 23, and 24 where the sulfide, metal ratio, and alteration zoning is centered. It is not known how far this central zone extends to the east and southeast under the post-ore capping, but a target could conceivably be totally covered there.

The depth to such a deposit is difficult to predict. At Morococha part of the disseminated mineralization crops out along with the zoned vein deposits. The deep chalcopyrite and molybdenite zones are about 3000 feet below the surface at Butte and the central zone high sulfur-to-metal
ores occur up to the surface. Disseminated mineralization in intrusive rock crops out in the San Juan Mountains but large bulk-mineable ore bodies have not yet been found. The upper part of the Guanomi quartz monzonite is at an elevation of about 5800 feet and the central zone in Perry Canyon is a few hundred feet less in elevation but the effects of post-mineralization tectonics are not known, nor is the original relative elevations of these two exposures of mineralization now separated by 6 miles.

The conditions are unfortunately poor for narrowing the target area by geophysical methods. The terrain is steep in the central zone and post-ore basalts cap part of the area. Oxidation is not deep in the central zone and electrical methods such as induced polarization may be best if the target is relatively shallow (less than 1,000 feet).
SUMMARY AND GEOLOGIC HISTORY

In the Mesozoic, granodiorites and quartz monzonites of the Sierra Nevada batholith were emplaced in metasediments of the Nightingale Sequence and metavolcanics of the Peavine Sequence. There is no geologic record in the area between this event and 28 m.y. ago when silicic ash-flow volcanism began. The ash-flow volcanism of the Hartford Hill Rhyolite progressively became more mafic and ceased about 21-22 m.y. ago. Minor mudflows and rhyolite lavas are interbedded with the tuffs and the northeast trending Mullen Pass structure localized the emplacement of the lavas.

Mineralization began with the emplacement of the Guanomi quartz monzonite stock which hosts disseminated copper and molybdenum mineralization along its margins. The upper ash-flow tuffs of the Hartford Hill which are similar in age to the Guanomi stock, were broken by west and northwest trending faults soon after their emplacement and these faults acted as channelways for the hydrothermal solutions that deposited the Pyramid district veins. Zoning patterns in the veins and associated alteration center near the southern part of Perry Canyon where an intrusive body similar to the Guanomi may lie at depth. Based on comparisons with similar mineral deposits, the intrusive may be mineralized and provides the main exploration potential in the district.

Dacite stocks and lavas were emplaced slightly after the ore with the larger stocks being localized along the Mullen Pass structure. Post-ore lacustrine sediments, basaltic
tuff breccias, basaltic lavas, and intermediate ash-flow tuffs of the Pyramid Sequence were deposited unconformably over the mineralized Hartford Hill tuffs. Movement on north trending faults of the Basin and Range type followed emplace-
ment of the basaltic lavas. All of the fault sets show evidence of reactivation at various times and age relation-
ships are sometimes difficult to determine.
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**APPENDIX A:** Assay values listed below were used for metal ratio calculations. Assays are not to be taken as representative of grade. The sample locations are numbered as they are on the map in Figure 11. All section numbers listed below are T. 23 N., R. 21 E. All values are reported in parts per million.

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Au</th>
<th>Ag</th>
<th>As</th>
<th>Sb</th>
<th>Bi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wet prospect</td>
<td>4400</td>
<td>670</td>
<td>33,500</td>
<td>0.61</td>
<td>137.8</td>
<td>900</td>
<td>1880</td>
<td>100</td>
</tr>
<tr>
<td>2. Owl prospect</td>
<td>1270</td>
<td>23,000</td>
<td>13,500</td>
<td>0.61</td>
<td>99.2</td>
<td>200</td>
<td>240</td>
<td>&lt;10</td>
</tr>
<tr>
<td>3. Bluebird</td>
<td>71,500</td>
<td>4,710</td>
<td>1,480</td>
<td>0.31</td>
<td>321.4</td>
<td>26,000</td>
<td>3,500</td>
<td>30</td>
</tr>
<tr>
<td>4. Jones-Kincaid adit</td>
<td>11,050</td>
<td>7</td>
<td>490</td>
<td>0.31</td>
<td>202.3</td>
<td>2,600</td>
<td>5,000</td>
<td>15</td>
</tr>
<tr>
<td>5. Cinch</td>
<td>5,700</td>
<td>300</td>
<td>510</td>
<td>0.31</td>
<td>74.7</td>
<td>2,300</td>
<td>1,250</td>
<td>50</td>
</tr>
<tr>
<td>6. Jumbo</td>
<td>28,000</td>
<td>2,200</td>
<td>1,000</td>
<td>0.61</td>
<td>619.6</td>
<td>350</td>
<td>1,250</td>
<td>1,000</td>
</tr>
<tr>
<td>7. Nevada Dominion shaft</td>
<td>2,950</td>
<td>4,900</td>
<td>7,300</td>
<td>-</td>
<td>79.6</td>
<td>1900</td>
<td>840</td>
<td>30</td>
</tr>
<tr>
<td>8. Shaft dump in SE1/4, SE1/4, sec. 17</td>
<td>120</td>
<td>1,000</td>
<td>660</td>
<td>-</td>
<td>40.4</td>
<td>250</td>
<td>42</td>
<td>&lt;10</td>
</tr>
<tr>
<td>9. South Ruth shaft dump</td>
<td>450</td>
<td>1,500</td>
<td>1,420</td>
<td>-</td>
<td>201.4</td>
<td>140</td>
<td>55</td>
<td>&lt;10</td>
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<tr>
<td>10. Shaft dump in NW1/4, SW1/4, sec. 11</td>
<td>120</td>
<td>280</td>
<td>60</td>
<td>-</td>
<td>12.9</td>
<td>100</td>
<td>16</td>
<td>20</td>
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<tr>
<td>SAMPLE LOCATION</td>
<td>Cu</td>
<td>Pb</td>
<td>Zn</td>
<td>Au</td>
<td>Ag</td>
<td>As</td>
<td>Sb</td>
<td>Bi</td>
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</tr>
<tr>
<td>11. Adit dump in NW1/4, SW1/4, sec. 23</td>
<td>30</td>
<td>30</td>
<td>28</td>
<td>–</td>
<td>–</td>
<td>10</td>
<td>4</td>
<td>&lt;10</td>
</tr>
<tr>
<td>12. Crown Prince</td>
<td>30</td>
<td>60</td>
<td>–</td>
<td>–</td>
<td>2,900</td>
<td>410</td>
<td>10</td>
<td></td>
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<tr>
<td>13. Shaft dump in SW1/4, SW1/4, sec. 16</td>
<td>380</td>
<td>1,020</td>
<td>1,260</td>
<td>0.31</td>
<td>75.9</td>
<td>850</td>
<td>55</td>
<td>20</td>
</tr>
<tr>
<td>14. Shaft dump in NE1/4, SE1/4 sec. 10</td>
<td>390</td>
<td>220</td>
<td>80</td>
<td>–</td>
<td>77.1</td>
<td>200</td>
<td>150</td>
<td>30</td>
</tr>
<tr>
<td>15. Jones Kincaid shaft dump</td>
<td>1,370</td>
<td>40</td>
<td>40</td>
<td>–</td>
<td>27.6</td>
<td>500</td>
<td>550</td>
<td>10</td>
</tr>
<tr>
<td>16. Ruth north shaft dump</td>
<td>120</td>
<td>2,070</td>
<td>30</td>
<td>0.31</td>
<td>137.8</td>
<td>350</td>
<td>55</td>
<td>&lt;10</td>
</tr>
<tr>
<td>17. Burrus</td>
<td>35,500</td>
<td>40</td>
<td>2,440</td>
<td>0.61</td>
<td>549.8</td>
<td>10,800</td>
<td>6,000</td>
<td>N.D.</td>
</tr>
<tr>
<td>18. Nevada Dominion adit</td>
<td>2,900</td>
<td>300</td>
<td>730</td>
<td>–</td>
<td>0.31</td>
<td>400</td>
<td>39</td>
<td>N.D.</td>
</tr>
<tr>
<td>19. Good Hope</td>
<td>1,150</td>
<td>43</td>
<td>39</td>
<td>–</td>
<td>0.61</td>
<td>610</td>
<td>98</td>
<td>10</td>
</tr>
</tbody>
</table>

* sample not used for metal ratio calculation due to background values.

N.D. not determined

Background values (estimated) are Cu 10, Pb 40, Zn 50, Au less than 0.31, Ag less than 1, As 5, Sb 1, and Bi .3 – .5 ppm.