University of Nevada
Reno

The Geology of the Bovard Mining District, Gabbs Valley Range, Mineral County, Nevada

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

by

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I would like to acknowledge the strong support of Dr. Miles Silberman to this project. Dr. Silberman suggested the project, provided the K-Ar age dates, and generally provided much encouragement and discussion about the area. The U.S. Geological Survey provided the air photos, field support, and had the thin sections made. Finally, I would like to acknowledge my fiance, Deborah Alvarez, for her constant support in the final stages of this project.
Abstract

The Bovard Mining District, located in the Gabbs Valley Range, Mineral County, Nevada produced about $360,000.00 in gold and silver. The mineralization is of the epithermal vein type. The district is underlain by a thick sequence of Tertiary ashflow tuffs, which have been highly faulted by movements of the Walker Lane, a regional northwest-trending lineament of significant right lateral strike-slip movement. Two major strike-slip faults, as well as numerous secondary oblique-slip and normal faults pass through the area. These faults have allowed the passage of hydrothermal fluids which were the source of the mineralization and widespread hydrothermal alteration of the Tertiary volcanics. Alteration is sericitic along the faults and propylitic away from the faults. The primary sericitic alteration has been dated at 22.6 ± 0.7 m.y. by the K-Ar method. Alunite, dated at 4.7 ± 0.9 m.y. found in the Golden Pen Mine is considered to be a supergene alteration mineral formed by oxidizing/weathering of the area.
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The Bovard Mining District is located in the central part of the Gabbs Valley Range, Mineral County, Nevada, about 50 kilometers north-northwest of the town of Hawthorne and 75 kilometers south of Mackay (Fig. 1). Most of this part of the central Gabbs Valley Range lies within the Copper Mountain study area. In about 70% the urgent Wash on the Horse Canyon which runs just north of the range to the west, detailed examination of the alteration and mineralization in the area, and central the alteration and mineralization in the area. To carry this out, mapping was undertaken at a scale of 1:20,000 (Plate I). Mapping was done on color aerial photos taken by the U.S. Geological Survey (C. E. Intersearch, and then transferred to a topographic sheet map. The alteration patterns in the district were consistent with the idea of approximately 150 thin sections and study of heavy metal whole rock analyses.

Old Mining Districts Never Die!

(Frontispiece)
Introduction

The Bovard Mining District is located in the central part of the Gabbs Valley Range, Mineral County, Nevada, about 50 kilometers northeast of the town of Hawthorne and 17 kilometers south of Rawhide (Fig. 1). Most of this part of the central Gabbs Valley Range lies within the Copper Mountain and Poinsettia Springs, 7/5' quadrangles. The study area includes approximately 60 square kilometers of which about 70% is exposed bedrock. The study area is bounded by Nugent Wash to the north, Gabbs Valley to east-northeast, Wildhorse Canyon to the south, and a high internal alluvial valley which separates the Gabbs Valley Range from the Gillis Range to the west. Figure 1 is a location map of the area.

Purpose and Scope of Study

The purpose of this thesis was to initiate a detailed study of the geology of the Bovard Mining District, concentrating on the alteration patterns in the area and the structural imprint (i.e., faults) created by the "Walker Lane", which control the alteration and mineralization in the area. To carry this out, mapping was undertaken at a scale of 1:24,000 (Plate I). Mapping was done on color air photos obtained by the U.S. Geological Survey from Intrasearch, Denver, Colorado, and then transferred to a topographic base map. The alteration patterns in the district were delineated with the aid of approximately 160 thin sections and about 60 x-ray diffraction whole rock analyses.
A secondary purpose of the project was to evaluate the amount and distribution of the alteration mineral, alunite, which is present in the Golden Pop vein. Alunite, which is a hydrated potassium aluminum sulphate, and a characteristic member of the advanced argillic suite of alteration minerals (Neger and Hesley, 1967), is a possible future source of aluminum.

Figure 1. Location map of study area.
A secondary purpose of the project was to evaluate the amount and distribution of the alteration mineral, alunite, which is present in the Golden Pen vein. Alunite, which is a hydrated potassium aluminum sulphate, and a characteristic member of the advanced argillic suite of alteration minerals (Meyer and Hemley, 1967), is a possible future source of aluminum.
Geologic Setting

The Gabbs Valley Range is composed primarily of a thick section of Tertiary volcanic rocks which overlie the Mesozoic basement of Triassic-Jurassic marine sediment and volcanic rocks of the Excelsior formation and sediments of the Luning formation. These sediments and volcanics were deformed into tight folds during the Jurassic (Ferguson and Muller, 1949) and intruded by Mesozoic batholithic rocks ranging in composition from diorite to granite. Potassium Argon dating of the granodiorite exposed at Copper Mountain in the northern Gabbs Valley Range yield a late Middle or early Late Jurassic age of 158 ± 4 m.y. to 155 ± 7 m.y. (Ekren, et al., 1980).

The Tertiary volcanic section is up to 2000 meters thick in the Gabbs Valley and neighboring Gillis Range and is composed largely of ashflow tuffs with some flow and hypabyssal intrusive rocks. These rocks range in age from Oligocene to Late Miocene.

The Gabbs Valley Range lies within the "Walker Lane", a regional northwest-trending lineament originally defined by Locke, Billingsly and Mayo (1940 [Fig. 2]). Subsequent work by many others (Ferguson and Muller, 1949; Moody and Hill, 1956; Bonham and Slemmons, 1966; Albers, 1967; Shawe, 1965; Nielson, 1965; Hardyman, et al., 1975; Hardyman, 1978; Ekren, et al., 1980) has demonstrated the "Walker Lane" to be a zone of significant right lateral strike-slip faulting. The Gabbs Valley and Gillis ranges are cut by five northwest-trending
Figure 2. The approximate position of the Walker Lane (after Silberman, 1979).
right lateral strike-slip faults which have a combined displacement of at least 32 kilometers (Hardyman, 1978; Ekren, et al., 1980). These major strike-slip faults are accompanied by many moderate to high angle normal and oblique slip faults which add greatly to the structural complexity of the area. In some areas, such as in the Bovard Mining District, these faults provided conduits for hydrothermal solutions which created widespread areas of hydrothermal alteration.

Previous Work

Most of the previous work in the Gabbs Valley Range has been reconnaissance in nature. Investigations by Muller and Ferguson (1939), Ferguson and Muller (1949), Silbering and Roberts (1962, and Nielson (1965) concentrated primarily on the structure and stratigraphy of the Mesozoic sedimentary and intrusive rocks. D. C. Ross of the U.S. Geological Survey did reconnaissance mapping of the region for the Nevada Bureau of Mines Mineral County report (Ross, 1961). The Tertiary volcanic section was divided into four broad units at this time. Further reconnaissance mapping was carried out in the late 1960's and early 1970's by F. J. Kleinhampl, M. L. Silberman, and R. Kopf for inclusion in the Nevada State geologic map project (Stewart and Carlson, 1978). R. F. Hardyman's (1978) Ph.D. dissertation included detailed geologic mapping of the Gillis Canyon 15' quad which is located just north-northwest of the study area.
Ekren and others (1980) have divided the Tertiary volcanic section into the present units used in this work and have completed mapping at a scale of 1:48,000 of the Luning quadrangle (U.S.G.S. open file report). Until this present study, no detailed work has been done on the Bovard Mining District and its surrounding geology. F. C. Schrader (1947), within the context of the U.S. Geological Survey open file report on the Carson Sink area, discusses some of the mineralization, alteration and production of the Bovard District up to that time.
Stratigraphy

The greatest volume of bedrock exposed in the Bovard Mining District consists of a thick sequence of Tertiary ashflow tuffs, ranging in age from Middle Oligocene to Middle Miocene. Several of these ashflow tuffs are regionally extensive and can be recognized throughout west-central Nevada, being originally assigned to the Hartford Hill rhyolite (Gianella, 1936; Bonham, 1969; Moore, 1969). Recent work by Proffet and Proffet (1976) in the Yerington area, Bingler (1978) in the Carson Canyon region, and Ekren and others (1980) in the Gillis-Gabbs Valley Range has redefined and subdivided the "Hartford Hill Rhyolite" into several formations which have been formally or informally named. Bingler (1978) has suggested abandonment of the name "Hartford Hill" and the use of the now accepted terminology for the individual ashflow units as standard formation rank. The Tertiary stratigraphy as described by Ekren and others (1980) is shown in Table 1. Only those units which are exposed in the Bovard District are discussed in this report. Because of the highly altered and faulted nature of the study area, fresh and complete sections of most of the units were not available for examination. For this reason some of the basic descriptive material on the units has been taken from Hardyman (1978) and Ekren, and others (1980).

Pre-Tertiary Rocks: (Luning limestone)

The only pre-Tertiary rocks exposed in the study area are a few small windows of Triassic Luning limestone. The
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exposures consist of nondescript massive dark grey limestone that in most cases has been recrystallized. In one exposure, in a wash on the southwest side of the study area, interbeds of fine-grained quartzite were present. Most of the exposures are in high angle fault contact with the Tertiary extrusive rocks. However, low angle depositional contacts are present in the window southeast of the Blue Sphinx monolith and on some sides of the exposures in the southwest part of the area.

**Tertiary Extrusive Rocks:**

**Singatse Tuff**

The Singatse Tuff is the oldest Tertiary extrusive unit exposed in the study area and is stratigraphically the middle unit of the Benton Springs group, which consist of the Mickey Pass Tuff, the Singatse Tuff, and the Petrified Springs Tuff. These three units are considered a group because of their similar age, petrographic composition, and areal distribution (Ekren, et al., 1980). Only the Singatse Tuff is exposed in the study area. At the type locality on Singatse Peak in the Singatse Range, described by Proffet and Proffet (1976), the Singatse Tuff consists of a multiple ashflow simple cooling unit 240-410 meters thick. At Calvada Summit in the southern Gabbs Valley Range, the Singatse Tuff is a compound cooling unit and shows well developed welding zonation (Ekren, et al., 1980). Fresh complete sections of the Singatse Tuff in the Gabbs Valley-Gillis Range area commonly consist of a black basal vitrophyre 1-4 meters thick which grades upward into densely welded light red or reddish grey devitrified tuff.
(Ekren, et al., 1980). Compositionally, the unit grades from a rhyodacite at the base to quartz latite in the upper sections. Mineralogically, it contains abundant phenocrysts of quartz, plagioclase, sanidine, biotite, and hornblende. It also commonly contains abundant lithic fragments of intermediate volcanic rocks, Mesozoic granitic rocks, and carbonate and clastic rocks (Ekren, et al., 1980). The Singatse Tuff has been dated at 26.2 ± 1.1 m.y. (biotite) and 31.7 ± 1.8 m.y. (hornblende) by K-Ar (Proffet and Proffet, 1976) at its type locality.

In the study area the Singatse Tuff (Tbs in Plate I) is well exposed on the southwest side of the Golden Pen fault where it makes up the base of the prominent ridge southwest of the Golden Pen Mine. The Singatse Tuff can easily be recognized in the field by the abundant fresh quartz phenocrysts which often have a bipyramidal crystal shape. Alteration has destroyed the ferromagnesian minerals throughout much of the Singatse Tuff's exposure in the mapped area, which in most outcrops appears as bleached white densely welded tuff with abundant quartz and remnant feldspar phenocrysts. Remnant pumice fragments are sometimes visible on hand sample scale, and in thin sections these can be seen to have been replaced by fine-grained secondary quartz. In exposures where the Singatse has only undergone propylitic alteration, remnant biotite or hornblende can be seen altering to chlorite, epidote, and iron oxides. The groundmass in most thin sections examined has been recrystallized and has had fine-grained secondary quartz added.
Tuff of Gabbs Valley

Overlying the Singatse Tuff in many areas of the Gabbs Valley-Gillis Range are the tuffs of Gabbs Valley. This informally named formation is composed of three or four thin ashflow cooling units of rhyolite to quartz latite tuff (Ekren, et al., 1980). It has been dated in the Gillis Range at 25.0 ± 1.0 m.y. to 26.1 ± 8 m.y. In the study area the Gabbs Valley Tuff (Tgv in Plate I) is found in two locations. The least altered exposures are found in the northeast part of the mapped area, just south of Nugent Wash where it is in depositional context with the Singatse Tuff. Here, the Gabbs Valley Tuff is a distinctly crystal poor white to cream colored densely welded tuff, with thinly bedded compaction foliation which gives it a distinct platy appearance (Fig. 3).

Occasional small fragments of apheric rocks are present along with small flattened pumice fragments which have been recrystallized and replaced by silica. Phenocrysts make up 10-15% of the rock and are primarily alkali feldspar with occasional small quartz and altered ferromagnesian minerals.

The other exposures of the Gabbs Valley Tuff are found on the high ridge southwest of the Golden Pen Mine where it again is in depositional contact with the Singatse Tuff. The tuff in this area thins markedly to the northwest until eventually the overlying Blue Sphinx Tuff lies directly on the Singatse. Intense alteration gives the Gabbs Valley a bleached and recrystallized appearance in most of this area, however, it is easily recognized by its crystal poor nature.
Blue Sphinx Tuff

The Blue Sphinx Tuff which overlies the tuff of Gabbs Valley is found over a wide area of the Gillie and Gabbs Valley Ranges in the Howard District at Hidden Pen Mine, where an Egyptian Sphinx Tuff is also exposed because of persisive hilly terrain.

Figure 3. Thinly bedded compaction foliation in the Gabbs Valley Tuff.
Blue Sphinx Tuff

The Blue Sphinx Tuff which overlies the tuff of Gabbs Valley is found over a wide area of the Gillis and Gabbs Valley Range. Its type locality is located in the Bovard District about one-half mile south of the Golden Pen Mine, where an outcrop of the tuff closely resembles an Egyptian Sphinx (Fig. 4). The tuff was named the Blue Sphinx Tuff because of its pale blue color which was produced by pervasive mild hydrothermal alteration.

The Blue Sphinx Tuff is a multiple flow, simple cooling unit of quartz latite which typically contains lithic fragments of apheric intermediate lava and highly altered tuff. Phenocrysts of quartz, alkali feldspar, hornblende and biotite make up 30-40% of the rock. Alkali feldspars dominate up to 35% of the phenocrysts followed by quartz, up to 15%. The quartz phenocrysts are typically large (up to 6 mm) and exhibit extreme resorption embayments (Fig. 5). In hand sample these highly resorbed quartz phenocrysts take on a wormy or sieve appearance which allows easy field recognition of the Blue Sphinx Tuff. Alkali feldspar phenocrysts also show some resorption, however, not to the extent of the quartz phenocrysts. Noble (1970) suggests that highly resorbed phenocrysts are indicative of pressure reduction in a magma which is under-saturated with respect to water. Thus, it is possible that tuffs which contain highly resorbed phenocrysts were erupted from deep magma chambers which would be under-saturated in water (Ekren, et al., 1980).
Figure 4. The Blue Sphinx monolith at the type locality of the Blue Sphinx Tuff.
Figure 5. Highly resorbed quartz phenocrysts in the Blue Sphinx Tuff.
The Blue Sphinx Tuff (Tsp in Plate I) is well exposed in the vicinity of the Golden Pen Mine, where it is in fault contact with the Singatse Tuff. The Blue Sphinx is highly altered and bleached in this area and is only recognizable by the presence of the resorbed quartz phenocrysts which have not been disturbed by the alteration. The less altered Blue Sphinx is found near the top of the ridge southwest of the Golden Pen Mine, where it depositionally overlies the Gabbs Valley Tuff. It is also found in the northeast section of the area just south of Nugent Wash, where it again overlies the Gabbs Valley Tuff.

Intermediate Lavas of Nugent Wash

The Intermediate Lavas of Nugent Wash is an informal name given to a group of hornblende rich lavas which overlie the Blue Sphinx Tuff in areas northwest and southeast of Nugent Wash (Ekren, et al., 1980). The most widespread lavas of this group are flows of light grey to greenish grey weathering, dark to medium grey, porphyritic hornblende bearing lavas, and are named the Nugent Wash Hornblende Latite. The hornblende phenocrysts, which attain sizes of up to 6 mm, are oxidized and exhibit rims of iron oxides, the most visible dehydration reaction products of hornblende. The hornblende phenocrysts along with small plagioclase laths are set in a pilotaxitic glassy though often devitrified groundmass of small plagioclase laths and Fe-Ti oxide grains. Phenocryst content is about 30% with 60% of that being hornblende. This unit (Tla in Plate I) is well exposed near the Blue Sphinx.
monolith and on the high ridge to the southwest where it caps 
the Blue Sphinx Tuff on several prominent knobs.

Another unit which has been grouped in the Intermediate 
lavas of Nugent Wash is a massive dark black to purple aphan-
itic clinopyroxene and plagioclase bearing lava, which often 
contains cognate and accidental inclusions of massive fine-
grained lava fragments. The Nugent Wash Andesite (Tln in 
Plate I) appears to grade upward into an agglomeratic breccia 
containing both fragments of fine-grained lava and porphyryi-
tic lava set in a vesiculated matrix containing numerous phen-
ocrys of plagioclase, pyroxene, hornblende and biotite. The 
lava fragments attain sizes up to 2 meters in diameter and the 
phenocrysts in the matrix are highly fractured. Outcrops of 
this agglomeratic breccia are well exposed in a subsidiary 
wash of Nugent Wash in the northeastern section of the mapped 
area (Fig. 6). The aphanitic clinopyroxene bearing lavas are 
exposed near the Nevada Rand Mine along the southwestern side 
of the Golden Pen fault zone.

**Hu-Pwi Rhyodacite**

The Hu-Pwi rhyodacite is a thick sequence of rhyodacite 
tuff lava which is rich in ferromagnesia minerals. The unit 
is divided into three formal members and one informal member: 
the Nugent Tuff member, Ghost Dance Lava member; Intermediate 
Lavas of the Poinsettia Springs area, and the Poinsettia Tuff 
member which together total at least 1000 meters in thickness 
(Ekren, et al., 1980). Only the Nugent Tuff member and the 
Poinsettia Tuff member are exposed in the study area.
Figure 6. Large lava block in the agglomeratic breccia of the Nugent Wash Andesite.
Nugent Tuff

The oldest member of Hu-Pwi rhyodacite is the Nugent Tuff member (Thn in Plate I) which is named for exposures around Nugent Wash, the northern boundary of the study area. The Nugent Tuff makes up almost 50% of the exposed rock within the mapped area of Plate I having been greatly extended by several north-northwest striking normal faults. The Nugent Tuff is typically densely welded and contains up to 40-50% phenocrysts, the most striking of which are large plagioclase grains, making up to 80% of the phenocryst content. These plagioclase phenocrysts attain sizes up to eight millimeters. In fresh Nugent Tuff, ferromagnesian minerals make up from 15-30% of the phenocrysts mineralogy. Biotite and clinopyroxene are most abundant with some hornblende and orthopyroxene also present. In the study area the Nugent Tuff is pervasively altered to at least a propylitic assemblage, hence, most of the ferromagnesian minerals have been transformed to chlorite, epidote, iron oxide, and calcite. Primary quartz was not present in any samples examined petrographically and minor alkali feldspar was noted. The groundmass is devitrified, however, and secondary quartz has been added in some areas particularly replacing highly flattened pumice fragments. Lithic fragments of both apheric lava and porphyritic lavas which often display a pilotaxitic groundmass are commonly present. Outcrops commonly show distinct compaction foliation striking NW and dipping NE, and sometimes shows a crude columnar jointing.
The Nugent Tuff has been dated at 22.8 ± 0.5 m.y. in the Gillis Range (Ekren, et al., 1980).

**Poinsettia Tuff**

The Poinsettia Tuff member of the Hu-Pwi rhyodacite (Tp in Plate I) is well exposed along the northeast flanks of the study area extending out into Gabbs Valley. The Poinsettia Tuff is the least altered of all the tuffs exposed in the area, being only mildly propylitized near its western fault contact with the Nugent Tuff and quite fresh out along the eastern range front road. It consists of moderately welded light to medium grey crystal rich tuff. Plagioclase is the most abundant phenocryst followed by euhedral phenocrysts of biotite. Clinopyroxene is also present as is minor quartz and alkali feldspar. Pumice fragments usually exhibit spherulitic devitrification.

**Intermediate Rocks of Mount Ferguson**

Overlying the Poinsettia Tuff in the eastern margin of the study area are a series of intermediate lava flows exposed in low fault raised hills in the northeastern part of the mapped area. These rocks are grouped together and called the Intermediate Lavas of Mount Ferguson (Tlf in Plate I). They do not appear to be genetically related to the ashflow tuffs described previously (Ekren, et al., 1980) and have not been hydrothermally altered.

The dominant unit of the Mount Ferguson lavas is a dark brown to black phryritic two pyroxene andesite which weathers into blocky talus slopes. The unit contains abundant
phenocrysts of hypersthene and augite, often as glomeroporphyritic clumps set in a pilotaxitic groundmass of small plagioclase laths. Plagioclase phenocrysts are also present, along with minor hornblende phenocrysts.

The other flow exposed in the area is porphyritic hornblende rich latite. The red-brown weathering unit overlies the two pyroxene andesite and contains abundant large oxyhornblende phenocrysts with well developed dehydration reaction rims of magnetite, pyroxene, and plagioclase. The hornblende exhibits a characteristic deep red to red orange pleochroism. Plagioclase phenocrysts are also present and the groundmass is typically pilotaxitic. Flow banding is often present on an outcrop scale, defined by phenocryst orientation.

Tertiary Intrusive Rocks

Diorite

Exposed in a belt roughly parallel to the Golden Pen fault zone are several small intrusive bodies of medium grey to grey green hornblende diorite (Tdi in Plate I). This unit contains abundant plagioclase and hornblende laths often exhibiting a medium to fine-grained texture. Small biotite and clinopyroxene grains are present as well as minor amounts of intergranular quartz and alkali feldspar. Some outcrops exhibit a distinct porphyritic texture with larger plagioclase and hornblende phenocrysts (Fig. 7). This variation in grain size is due to different cooling rates throughout the intrusion and possibly also to phenocryst accumulation. The diorite has been pervasively propylitically altered, with epidote and chlorite
Figure 7. Photomicrograph of typical porphyritic diorite (Tdi) (Cross nicols, 10x).
replacing hornblende. Fine-grained feathery secondary biotite is also present.

Present in the diorite body which is cut by the Golden Pen fault (Plate I) are several exotic blocks of Luning limestone and Mesozoic granite. The Luning block is about 11 meters in diameter and contains a typical skarn mineralogy of green subhedral to euhedral garnets, diopside, and tremolite. The granitic block is about 15 meters in diameter giving an outcrop appearance of numerous spheroidally weathered boulders. Quartz and orthoclase feldspar are the mineral constituents of the granite which displays medium grained hydroidomorphic granular texture. Strain textures are evident with the feldspar being fractured and the quartz exhibiting undulatory extinction.

The diorite intrudes the Nugent Tuff and is most likely genetically related to it as evidenced by distinctly similar mineralogy. Both units contain abundant ferromagnesian minerals including hornblende, clinopyroxene and biotite in similar modal percentages. Plagioclase makes up the greatest percentage of minerals in both units and phenocryst morphology is also similar. Whole rock chemical analyses along with electron microprobe analyses of the phenocryst mineralogy of both units would prove or disprove a genetic relation.

Hornblende Latite

A small plug of black fine-grained porphyritic hornblende latite (Thl in Plate I) is exposed near one of the faults which cuts the Nugent Tuff in the northeast section.
of the area. This unit is fresh and is composed of abundant (25-30%) euhedral hornblende phenocrysts up to 10 mm in length set in fine-grained felty groundmass. The hornblende phenocrysts exhibit excellent dehydration reaction rims. Small plagioclase phenocrysts are present (15%), often exhibiting corroded rims.

**Latite**

The youngest igneous rock exposed in the area is dense black apheric latite which is intruded along the Gum Drop Hills strike-slip fault into a Tertiary fanglomerate. The unit (T1 in Plate I) is exposed along the top of the ridge of this fanglomerate and appears to intertongue with the gravels. The latite is composed of small microphenocryst laths of plagioclase and minor orthopyroxene set in a hyalopilitic groundmass. Abundant microphenocryst cubes of iron-titanium oxides are also present. The glassy matrix is partially devitrified.

Ekren and others (1980) obtained a K-Ar age date of 5.8 ± 0.2 m.y. for this unit.

**Alluvial Deposits**

**Tertiary Alluvium**

Exposed in the southwest part of the study area is a large area of Tertiary fanglomerate deposits. These fanglomerates (Tfg in Plate I) are composed of a large variety of subrounded to angular boulders, cobbles, and pebbles of Mesozoic and Tertiary rocks set in loosely consolidated
sands and silts. The Gum Drop Hills strike-slip fault has cut this unit with 1.8 kilometers of right lateral offset. The black apheric latite intertongues with the fanglomerate, having intruded along the Gum Drop Hills fault.

**Quaternary Alluvium**

Quaternary alluvial fan deposits (Qfa in Plate I) are found along the eastern range front and consist of subangular boulders, cobbles, and pebbles of Tertiary and Mesozoic rocks set in unconsolidated sands and silts. Alluvium found in the washes of the area consist of loose unconsolidated silt and sand with associated boulders, cobbles, and pebbles (Qa in Plate I).
Structural Geology

Walker Lane Strike-Slip Faults

The structural geology of the Bovard District is dominated by faulting which is primarily related to the Walker Lane, a regional northwest-trending lineament originally defined by Locke, Billingsly, and Mayo (1940 [Fig. 2]). Mapping in the Gabbs Valley and Gillis ranges by Hardyman (1978) and Ekren and others (1980) has defined the Walker Lane in this region as a northwest-trending shear zone that is about 30 kilometers wide. Five major strike-slip faults make up this shear zone, with a combined apparent right lateral displacement of about 48 kilometers (Ekren, et al., 1980). Two of these strike-slip faults are present in the Bovard District. They are, as named by Hardyman (1978), the Gum Drop Hills fault and the Red Ridge fault. The Gum Drop Hills fault offsets the Tertiary fanglomerates in the western part of the area, and the Red Ridge fault passes just to the east of the mountain front in Gabbs Valley (Plate I).

Gum Drop Hills Fault

The Gum Drop Hills fault is the most sharply defined right lateral strike-slip fault in the Bovard area, and it is conspicuous on aerial photographs. The trace extends for about 90 kilometers (Hardyman, 1978). In the Bovard area it does not offset bedrock, but displaces the Tertiary fanglomerate exposed in the western region of the study area (Plate I). Right lateral displacement of two kilometers is present
in the fanglomerate just south of Nugent Wash and is readily visible on aerial photography. Exposure of the fault is difficult to find on the ground due to the poorly consolidated nature of the fanglomerate. The apheric latite dated at 5.8 million years (Ekren, et al., 1980) appears to intrude along the trace of the fault in some places. The fault does not appear to cut the latite, although exposures are generally poor.

**Red Ridge Fault**

The Red Ridge fault is the second major Walker Lane structure which passes through the area of Plate I. The trace of the fault is more than 90 kilometers long, and is coincident with the fault bounding the southwest side of the Pilot Mountains in Soda Springs Valley (Hardyman, 1978).

The Red Ridge fault in the study area is obscured by recent alluvium, however, it is defined by the displacement of two flows of the lavas of Mount Ferguson. Just south of Nugent Wash an exposure of porphyritic two pyroxene andesite of Mount Ferguson which is overlain by a flow of the porphyritic hornblende latite of Mount Ferguson, has been offset 6 kilometers southeast from a similar exposure near Nugent Wash (Plate I). The sense of movement is clearly right lateral.

**Normal and Oblique-Slip Faults**

Most of the other faults present in the study area are a series of normal and oblique slip faults which trend northwest and are subparallel to the Walker Lane strike-slip faults.
These faults are most likely secondary structures which formed in direct response to the tectonic movement of the Walker Lane.

**Golden Pen Fault**

The Golden Pen fault is a major oblique-slip fault named for the Golden Pen Mine through which it passes. Its seven kilometer trace is defined by conspicuous hydrothermal alteration and brecciated bedrock. To the southeast the fault disappears under the alluvium of Gabbs Valley. To the northwest it splits or splays into three branches in the vicinity of the Lone Star Mine (see Plate I). All of the major mines in the district are located along this fault system. In the vicinity of the Golden Pen Mine it has served as a conduit for fluids which created the only major advanced argillic alteration present in the area and it is also the major locus of precious metal mineralization in the area.

Movement on the Golden Pen fault has been varied. Slickensides exposed in the fault zone in the Golden Pen Mine illustrates pure strike-slip, normal and oblique-slip movement. Approximately 150 meters of normal component movement is visible in displacement of the Blue Sphinx Tuff at the Golden Pen area. A right lateral strike-slip component of about 100 meters is seen in displacement of the intrusive diorite just north of the Golden Pen Mine. The fault has evidently had a complex history of movement. The latest movement may have been oblique or strike-slip as evidenced by the majority of slickensides present in the Golden Pen Mine.
Other Normal and Oblique-Slip Faults

The study area is cut by numerous other normal and oblique-slip faults, some of which are connected splays off the Golden Pen fault. Others appear to be distinct though most likely related to the stresses created by Walker Lane movement. The evidence for these faults in the field is usually manifested as a linear band or more highly altered bedrock often shattered and brecciated. Prospect pits are often located along these faults (Fig. 8) and when present, slickensides show a dominant normal component of movement. Because of the lack of distinct marker horizons and the highly altered nature of the rock units involved, it is difficult if not impossible to gain an insight into the amount and direction of movement of these faults. The primary significance of these faults to this study is that they have provided the pathways for hydrothermal fluids in the area. Thus, they play a direct role in the alteration and mineralization of the Bovard District.

Time Constraints of Fault Movement

The various isotopic age determinations which have been performed on the rock units and alteration in the Bovard District allows time constraints to be placed on the faulting in the area. Since the Golden Pen fault cuts the 27 million year old Singatse Tuff (Ekren, et al., 1980), the oldest tuff exposed in the area, faulting could not have occurred before that time. It had to have occurred before the 22½ million
Figure 8. Fault exposed in prospect pit.
sericitic alteration in the Golden Pen Mine (Silberman, written communication) if we assume the hydrothermal fluid traveled through the fault. Movement occurred at least till about 5 million years ago as evidenced by 5 million old alunite (Silberman, written communication) in the Golden Pen Mine which has been stretched, deformed and exhibits numerous slickensides. The Mount Ferguson andesites dated at about 21.5 m.y. in the area (Ekren, et al., 1980) are displaced by the Red Ridge fault, evidence for its movement after that time. Finally, movement on the Gum Drop Hills fault appears to have stopped by 5.8 m.y. because the apheric latite of that age which was intruded along it does not appear to be displaced.

From the above discussion it can be stated that fault movement in the Bovard District occurred from sometime prior to 22½ million years ago till at least around 5 million years ago.

**Regional Stresses**

The stresses which acted on the small region of the Bovard District to form the pattern of faulting present today can be directly related to stresses which produce the Walker Lane strike-slip zone which in turn can be related to stresses which created the structures of the entire Basin and Range Province. Studies by Moody and Hill (1956), Shawe (1965), Hill and Troxel (1966), and Wright (1976) propose that Basin and Range structure is related to conjugate faulting and shearing that developed
in response to approximately north-south oriented compressive forces. The north-south compressive force is postulated in reference to Anderson's (1951) analysis of principal stress orientations which lead to different types of faulting (Fig. 9). The structures resulting from this north-south compression include the northwest trending right lateral strike-slip faulting of the Walker Lane (Locke, et al., 1940), northeasterly trending left lateral strike-slip faults extending eastward from the southern end of the Walker Lane to the edge of the Colorado Plateau (Anderson, 1973), and the innumerable north-south to northeast-southeast trending normal faults throughout the Basin and Range. Figure 10 is schematic of the development of such features. The patterns of faulting present in the mapped area (Plate I) can be generally related to those in Figure 10.
Figure 9. Principal stress directions for normal, reverse, and strike slip faults (after Anderson, 1951).
Figure 10. Probable stress orientation responsible for Basin and Range faulting (after Wright, 1976).
Description of Mines and Prospects

The Bovard Mining District was established in 1908 when Albert J. Bovard discovered the Bovard deposit in the northeastern Gabbs Valley range. Subsequent discoveries at the Golden Pen, Nevada Rand, and Lone Star mines followed with a total district production of about $360,000.00 (Vanderburg, 1937). Gold was the major commodity mined along with some silver, primarily from the Golden Pen, Nevada Rand and Lone Star mines. Most of the production occurred from about 1912 to the late 1920's. All of the mines are located along the Golden Pen fault. A discussion of the most important mines follows.

Bovard Mine

The Bovard Mine was the first deposit in the area to be discovered and although its production was very limited, it was important because it focused attention on the Golden Pen fault/vein system. It is located in the SW1/4 of Section 33, T11N, R32E about one-half mile southeast of the Golden Pen Mine (Plate II), and was developed to a depth of 450 feet on four levels. The deposits consisted of highly crushed and altered wall rock cemented by quartz and stained with iron and manganese oxides. Alunite is also present (Schrader, 1947). Very minor amounts of pyrite and chalcopyrite with some microscopic free gold were present. The author was not able to view the mine due to the poor quality of the shaft.
Golden Pen Mine

The Golden Pen Mine, located in the SE\(^{1/4}\) of Section 33, T11N, R32E (Plate II) (Fig. 11), is the most important deposit in the Bovard Mining District, having produced about $250,000 in gold ore (Schrader, 1947). The mine has more than 5,000 feet of workings distributed on six levels. Access is provided by an adit and a 258 foot deep vertical shaft.

Schrader (1947) gives an excellent account of the Golden Pen's interesting history. He writes:

Closely following the discovery of the Bovard mine in 1907, the deposit of the Golden Pen Mine was discovered and located in April, 1908 by Bert Knap, Charles Trailkill, and Charles Deadman, who soon found rich ore in it, since then, under several different managements, it has produced more than $250,000 in gold ore.

In 1908 it was bonded to Tex Ricard, who is reported to have made a down payment of $24,000, and soon produced $80,000 in high-grade surface ore from the glory hole and then relinquished it.

Later it was leased to Dr. Garnard who mined and shipped to the Weiss mill at Alkali Flat below Rawhide $5,000 worth of ore.

The property was next incorporated by Knap and Judge Glen as the Golden Pen Mining Company which working it for 6 months, started the Lucky Strike winze no. 1, and shipped $2,000 worth of ore.

In December 1912, P. Saturno and J. D. Farreto became the principal owners of the mine and worked it till 1915 when it was sold for $130,000 under a 2 year bond. They found a high grade ore shoot in the east drift from which in 1913-14 they shipped $55,000 worth of $500 ore and had remaining about $30,000 worth of high-grade ore in sight in the mine. Ten sacks of the ore shipped weighing 963 pounds averaged more than $7,000 to the ton. About this time some of the ore was hauled to the railroad station at Luning.
In December 1915 the mine was leased to J. H. Miller and associates, who, after doing about 600 feet of underground work and making two shipments which netted them $7,500, relinquished it with good showings on the third and fourth levels.

About this time (1916) the mine contained 1,800 feet of development work and about $25,000 worth of ore lay on the dump, of which 2,000 tons was said to be $1.00 mill ore. The property consisted of a group of 15 claims including several fractional, or a total of about 200 acres of ground to consider for.

Also about this time the Barrett Brothers, Joe and John, became owners of the mine and soon made several shipments aggregating about $41,000 in high-grade ore. The mine at that time was called the Idlewild or Dead Horse well, since no previous ores were used by the company.

In 1923 the mine was acquired by the Forest mines and worked intermittently by the four men on the mine with a crew of 10 men, and was producing some of the ore shipped being very rich ore found in new ground.

In 1927 it was incorporated by the Barrett brothers as the Golden Pen Mines Company which still owns it. In 1927 the ore reserves were estimated at 41,000 tons of 62% ore, mostly in an ore shoot 90 feet long by 5 feet wide. It was opened mainly by a 220-foot deep shaft and a 500-foot tunnel and contained more than 5,000 feet of workings.

Figure 11. The Golden Pen Mine.
In December 1915 the mine was leased to J. H. Miller and associates, who, after doing about 600 feet of underground work and making two shipments which netted them $7,500, relinquished it with good showings on the third and fourth levels.

About this time (1916) the mine contained 1,500 feet of development work and about $36,000 worth of ore lay on the dump, of which 2,000 tons was said to be $11 mill ore. The property comprised a group of 15 claims including several fractions, or a total of about 200 acres of ground in compact form.

Also about this time the Farreto brothers, Joe and John, became owners of the mine and soon made several shipments aggregating about $41,000 in high-grade gold ore.

In 1919 the Golden Pen Mines Company organized by Los Angeles interests and incorporated for $500,000 as the Golden Pen Mines Company, acquired the mine, did 3,000 feet of development work in it, and made a $100,000-production, of which $15,000 was high-grade shipping ore and $85,000 bullion. It also materially increased the surface equipment but finally, owing to financial difficulties, lost the mine by sheriff's sale in April 1921, whereupon it reverted to its former owners, the Farreto brothers.

The improvements made by the Company included erection of substantial mine buildings, installation of a new hoist and a Kinkaid 20-ton amalgamating mill on the mountain side about 400 feet below the mine, and procurement of a permanent water supply by sinking a 112-foot deep well towards the south edge of Alkali Flat, about 4 miles from the mine. The water of this well is said to be of better quality than that of Dead Horse well, which had hitherto been used by the Company.

In 1922 to 1927 the mine was being worked intermittently by the owners, part of the time with a crew of 10 men, and was producing; some of the ore shipped being very rich ore found in new ground.

In 1927 it was incorporated by the Farreto brothers as the Golden Pen Mines Company which still owns it. In 1927 its ore reserved were estimated at 41,000 tons of $20 ore, mostly in an ore shoot 90 feet long by 5 feet wide. It was opened mainly by a 260-foot deep shaft and a 500-foot tunnel and contained more than 5,000 feet of workings.
The cost of ore shipped to Nolan was $7 per ton and that of ore treatment $4.60 per ton. A few hundred tons of the medium-grade ore was shipped to the Thompson Smelter of the Mason Valley Mines Company. The building of a mill at the Company well and the conveyance of the ore to it by aerial tram was contemplated by the Company.

From 1927 to the present, the mine seems to have been quiet.

The recent construction of a road to the mine is evidence of renewed interest in the property.

The deposits which occurred in the Golden Pen were composed of highly sheared wall rock replaced by quartz and fine grained pods of alunite. Fine grained disseminated free gold was present along with minor microscopic disseminated argentite. The ore carried two thirds of an ounce of silver to one ounce of gold (Schrader, 1947). Local occurrence of galena and sphalerite were also reported (Schrader, 1947).

Nevada Rand Mine

The Nevada Rand Mine (Plate II) is located about two miles northwest of the Golden Pen Mine on the Golden Pen fault. It lies on the northeast side of Lone Star Wash (SE1/4 of Section 30, T11N, R32E), which joins Nugent Wash about a mile northwest of the mine. As of 1925 the mine had produced about $100,000 in high grade ore (Schrader, 1947). About 5,000 feet of workings are present on six levels. Because access is provided by 250 foot vertical shaft in poor condition, the author was not able to examine the mine.

The deposits were found in quartz veins emplaced in
highly sheared and altered Nugent Tuff. Sericitic alteration is seen in surface outcrops in the fault zone, which at the mine is about 100 feet wide. The ore was mostly brown oxidized manganese-iron stained silicified Nugent Tuff and coarse quartz containing free gold, electrum, cerargyrite, and argentite. The cerargyrite is an oxidation product of argentite. The silver to gold ratio of the ore was 34:1 (Schrader, 1947). Some extremely high grade lenses were discovered, with values to $8,000 to the ton.

Lone Star Mine

The Lone Star Mine is located in the SW\(1/4\) of Section 29, T11N, R32E about 1500 feet southeast of the Nevada Rand Mine on the Colden Pen fault/vein system. The fault cuts Nugent Tuff in the upper levels of the mine with Singatse Tuff being present at a depth of about 200 feet. The development consists of three shafts which give access to 3,000 feet of workings. The deepest shaft is 550 feet deep. The deposits were again dominately gold-silver and occurred as brecciated quartz and wall rock with calcite, jarosite, manganese oxides, and gypsum. Galena, pyrite, chalcopyrite, sphalerite and argentite were the ore minerals present (Schrader, 1947). Galena and pyrite in quartz is present on the dumps.
Hydrothermal Alteration

Most of the rocks of the Bovard Mining District have been hydrothermally altered. Hydrothermal alteration results from hot ion charged fluids passing through rocks and converting the initial assembly of minerals to new minerals which are stable under the hydrothermal conditions of temperature, pressure, and fluid composition that exist in the presence of the fluids. Hydrothermal alteration is often intimately associated with many types of ore epigenetic deposits, hence, careful study of wall rock alteration can lead to greater understanding of such ore deposits and may provide useful exploration criteria.

Hydrothermal alteration is usually classified by the dominant mineral or mineral assemblage present in the altered rock. The classification scheme used in the study area was put forth by Meyer and Hemley (1967) for alteration of aluminosilicate rocks. The classification divides altered rocks into propylitic, intermediate argillic, advanced argillic, sericitic, and potassic alteration. Essential characteristics of this classification are given below.

Propylitic -- Presence of epidote and/or chlorite, and a lack of appreciable cation metasomatism or leaching of alkalis or alkaline earths; \( \text{H}_2\text{O}, \text{CO}_2 \), and sulphur may be added.

Intermediate argillic -- Presence of important amounts of kaolinite, montmorillonite, or amorphous clays,
principally replacing plagioclase; sericite may accompany clays; potassium-feldspar unaltered or argillized, appreciable leaching of calcium, sodium, and magnesium.

Advanced Argillic -- All feldspar is converted to dickite, kaolinite, pyrophyllite, diaspore, alunite, or other aluminum-rich phases.

Sericitic -- Both potassium-feldspar and plagioclase are converted to sericite, minor kaolinite may be present.

Potassic -- Potassium feldspar and/or biotite found as an alteration of plagioclase or mafic minerals.

The degree of alteration is not only dependent on temperature and ionic strength of the hydrothermal fluid, but also on the composition, pressure setting, and degree of porosity of the material that the fluid is altering. Hydrothermally altered terrains often exhibit zoning where the highest degree of alteration is located along structures such as joint or faults, which are areas of high porosity and permeability and form channels for fluid migration. The successively less altered rocks are found at greater distances from the structure. This is well exhibited in the study area.

Regional Alteration

Significant amounts of the Gabbs Valley Range have been subjected to hydrothermal alteration ranging from advanced argillic to propylitic grade. Large white bleached zones indicating the alteration are quite evident in aerial and ERTS photography throughout the region. These zones are
often linear in pattern and define structural discontinuities. The structural framework imprinted on the region by Walker Lane strike-slip faulting provided excellent ground preparation for the passage of hydrothermal fluids. The major strike-slip faults acted as natural conduits for the rise of hydrothermal fluids driven perhaps by magma sources at depth and for the passage of descending meteoric waters which often make up a large component of hydrothermal systems (Taylor, 1974). The highly faulted and fractured bedrock of the region facilitated the passage of hydrothermal fluids, resulting in widespread alteration effects. The most intense areas of alteration are located along the major strike-slip faults. Since these faults are deep pervasive structures, circulating fluids would likely be channeled through these larger faults before spreading out into more shallow secondary faults.

Perhaps the most striking regional example of this fault controlled alteration is present along a 15 mile segment of the Soda Springs Valley fault northwest of the Gabbs-Luning road. The bleached appearance of the fault zone is readily apparent on aerial photography. The rocks located along the fault trace have been highly altered to a white soft and friable consistency. Outcrops of leached and silicified material are also scattered along the altered zone. Much of the alteration is of advanced argillic type characterized by kaolinite and alunite. Outcrops at the Siskon silver prospect contain excellent examples of alkali feldspar phenocrysts which have been replaced by coarse grained pink
Alunite. The coarse grained replacement nature of the alunite suggests a primary hypogene origin. This alunite has been dated 19 m.y. (Morton et al., 1977) by the K-Ar method, a date concordant with the age of a rhyolite dike located 6.4 km east of Wildhorse Canyon in the Gabbs Valley Range (Ekren, et al., 1980).

Although it is not a part of the Gabbs Valley Range, the Rawhide Mining District, located about 17 km north of the Bovard District on the northwest side of Gabbs Valley, is another highly altered area which should not be overlooked in a review of regional hydrothermal alteration. It seems surprising that so little detailed geologic work has been completed in a district that produced 1.5 million dollars in gold and silver. Schrader (1947) describes the area as being a complex assemblage of Tertiary volcanic rocks including rhyolite, dacite, andesite, and basalt as flow tuffs, and small plugs. The ore deposits are found in a rhyolite as replacement veins along faults and joints. Hydrothermal alteration is well developed in the wall rocks throughout the area. Schrader (1947) identified adularia, alunite, jarosite, kaolinite, pyrite, pyrrohitite, quartz, and calcite as the major alteration minerals present. Limited isotopic dating by Silberman, Bonham, and Osborne (1975) establishes an interval age of 14.5 to 15.5 m.y. for alteration and mineralization in the Rawhide District. Further work is needed to better characterize the alteration and mineralization which could possibly be related to mineralization and alteration in the Gabbs Valley Range.
It should be noted that the Rawhide District is on strike with the northwestern most strike-slip fault of the Walker Lane. The trace of this fault disappears under Gabbs Valley but if continued it would pass through Rawhide. A detailed study might serve to link the alteration and mineralization to Walker Lane structure.

Reconnaissance of the Gabbs Valley Range area by the author has shown that fresh totally unaltered rocks are rare. Broad areas of the region exhibit low grade propylitic alteration and the more intensely altered areas are located in the more highly faulted areas. With such a vast area affected, it seems likely that large amounts of hydrothermal fluids probably over a long time period passed through the area, fueled by magmas which were the sources of the thick sequence of volcanic rocks present in the region.

**Alteration in the Bovard District**

Alteration in the Bovard Mining District is widespread and associated with the numerous fault structures which cut the area. Propylitic alteration is pervasive through units away from major structures, while sericitic alteration is found close to and along structures. Advanced argillic alteration, primarily defined by the presence of alunite, is found in some areas particularly along the Golden Pen fault. Intense silicification has also occurred along many of the faults. Plate II shows the distribution of hydrothermal alteration assemblages in the area.
Propylitic Alteration

Propylitic alteration is the most widely distributed alteration type in the area and is particularly evident in the Nugent Tuff. Even the freshest appearing outcrops of Nugent Tuff contain abundant epidote and chlorite occurring often as pseudomorphs after biotite or hornblende. Calcite is usually present both as discrete autonomous grains which were most likely directly precipitated and as alteration of plagioclase. Figure 12 is a particularly striking example of a plagioclase phenocryst which has almost completely altered to calcite and fine euhedral prisms of epidote. Only the most sodic rim of the plagioclase remains intact. Some plagioclase grains also have sparse fine grains of sericite included along cleavage. Extremely fine-grained amorphous clays and minor montmorillonite are present in some areas of the Nugent particularly close to major structures. The groundmass of much of the Nugent Tuff has been recrystallized with the probable addition of secondary silica again particularly evident near the major structures.

Blue Sphinx Tuff, Gabbs Valley Tuff, and Singatse Tuff when propylitized contain characteristic chlorite and epidote replacing the ferromagnesian minerals. Calcite is present although not to the degree as in the Nugent, probably because of the lower percentage of plagioclase due to the more felsic nature of these units. Alkali feldspars often appear to be dusted with minor sericite and clays.

The intrusive diorite is pervasively propylitized.
Figure 12. Photomicrograph of plagioclase phenocryst (pl) altered to calcite (c) and epidote (ep) in the zone of propylitic alteration. (Cross nicols, 10x).
exhibiting fine-grained chlorite and epidote pseudomorphs after hornblende and biotite. Fine-grained feathery brown secondary biotite is also present along with plagioclase dusted by clays, sericite and occasional calcite.

**Intermediate Argillic Alteration**

Intermediate argillic alteration is not widespread in the area, being present only on the southwest side of the Golden Pen fault. The footwall of the Golden Pen fault in the Golden Pen Mine is densely welded Singatse Tuff containing alkali feldspar phenocrysts which have been altered to montmorillonite or amorphous clays. Only minor sericite or kaolinite are present. Distinct areas of intermediate argillic alteration are not present between propylitized rock and the more highly altered sericite, quartz alteration near faults in the remainder of the area. A similar lack of intermediate argillic alteration has been noted by Wallace (1975) in the Pyramid District, Washoe County, Nevada.

**Advanced Argillic Alteration**

Advanced argillic alteration is present primarily along the Golden Pen fault zone, being characterized by massive white fine-grained alunite and quartz. Minerals that often are associated with advanced argillic alteration such as pyrophyllite, diaspore, kaolinite are not present. In some areas along the Golden Pen fault tabular veins of fine-grained alunite up to several inches thick cut the rocks of the hanging wall and foot wall. Alunite was also found in some of the highly silicified
zones of faults cutting the Nugent Tuff, however, this was not common. Advanced argillic alteration will be discussed in greater detail in the following section on the Golden Pen Mine.

**Sericitic Alteration**

Sericitic alteration is the next most widespread alteration type after propylitic alteration, being closely associated with numerous faults which cut the area. In all units the ferromagnesian minerals have been destroyed, producing a light colored appearance. The feldspars are in various stages of conversion to sericite (Fig. 13). Large grains of sericite appear to be pseudomorphs after biotite. Green tourmaline rosettes are also present in sericitically altered Blue Sphinx and Singatse Tuff.

Silicification is closely associated with sericitic alteration particularly in fault traces. Massive quartz flooding has occurred along most of the faults producing vein zones of massive quartz. In addition, much recrystallization and addition of silica has occurred in tuffs at large distances away from some main faults. Crystal faces at 120°, polygonal mosaics, are characteristic of recrystallized minerals and are present in some areas (Fig. 14). Since much of this recrystallized fabric is present in the Nugent Tuff in close proximity to the diorite, it could be a direct function of the intrusion and be considered metamorphic recrystallization. Figure 15 shows a typically sericitically altered fault zone.
Figure 13. Photomicrograph of K-feldspar replaced by sericite. (Cross nicols, 10x).
Figure 14. Photomicrograph of recrystallized quartz in the sericitically altered and silicified Nugent Tuff. (Cross nicols, 10x).
The Golden Pan Mine provides an excellent opportunity for
a closer look at alteration zoning as related to a mineralized
structure. A 219. (74 m) fault cut across an essential cross-
section across the Golden Pan Mine zone. These faults are de-
scribed geologic and alteration work of one unit of the ophi-
ite, dipping at other levels can not shown due to the narrow
nature of these zones.

Figure 15. Sericitically altered fault zone.
Alteration in the Golden Pen Mine

The Golden Pen Mine provides an excellent opportunity for a closer look at alteration zoning as related to a mineralized structure. A 219 (74 m) foot adit provides an excellent cross section across the Golden Pen fault/vein. Plate III is a detailed geologic and alteration map of this level of the mine. Mapping at other levels was not done due to the hazardous nature of those areas.

The Golden Pen vein is located along a major oblique-slip fault which extends for about seven kilometers from Lone Star Wash to the eastern front of the Gabbs Valley Range about 3.1 kilometers southeast of the Golden Pen Mine. Most of the mines which produced precious metals are on or close to this fault.

The vein in the Golden Pen Mine ranges from eight to ten feet thick and is composed of highly sheared and brecciated wall rock almost totally replaced by large pods of quartz and thick tabular sheet of fine-grained alunite. The vein appears to dip almost vertically although individual fault planes located within it dip 60-85° to the northwest. The vein was mined for a length of 174 meters along its N35W strike. Blue Sphinx Tuff is exposed on the northeast down dropped hanging wall side and Singatse Tuff is exposed on the southwest footwall side, making the fault the contact between the two units.

Samples were taken at three meter intervals along the main adit through the Blue Sphinx Tuff, across the vein, and into the Singatse Tuff. Thin sections were examined and x-ray
diffraction analyses were made to identify the alteration mineralogy.

The alteration in the Golden Pen Mine is shown in Plate III. The Blue Sphinx Tuff on the hanging wall side of the fault has been pervasively sericitized, the rocks being highly bleached and all feldspars altered to sericite. No ferromagnesian minerals remain. Sericite appears as pseudomorphs after biotite and is also disseminated throughout the groundmass which is often silicified. Green rosettes of tourmaline are present in some samples. Sericite concentrated from a sample located 14 meters from the vein has been dated by the K-Ar method at 22.6 ± 0.7 m.y. by the U.S. Geological Survey (Silberman, written communication, 1981) (see Table 2).

Alteration of the Singatse Tuff on the footwall side of the vein is sericitic to intermediate argillic and is characterized by lesser amounts of sericite along with montmorillonite, kaolinite, and amorphous clays. In general the feldspars are much less altered when compared with the feldspars of the Blue Sphinx Tuff on the hanging wall side of the fault. The difference in alteration of the two units at similar distances from the vein could be due to several factors. One reason for the differences in the type of alteration seen in the rocks on either side of the Golden Pen fault could simply be due to differences in the whole rock chemical composition of the tuffs as well as different mineral contents. Also, and probably most important, differences in welding and consequent differences
Table 2. Potassium-Argon Age Dates for Alteration Minerals in the Golden Pen Mine

<table>
<thead>
<tr>
<th>Rock</th>
<th>Mineral</th>
<th>Percent K$_2$O</th>
<th>$\text{Ar}^{40}$ rad (moles/Sr m$^{-1}$)</th>
<th>$\frac{\text{Ar}^{40}}{\text{Ar total}}$</th>
<th>Apparent Age (millions of years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Sphinx altered tuff</td>
<td>sericite</td>
<td>6.37</td>
<td>2.085 x 10^{-10}</td>
<td>0.61</td>
<td>22.6 ± 0.7</td>
</tr>
<tr>
<td>Golden Pen vein material</td>
<td>alunite</td>
<td>7.44</td>
<td>0.5064 x 10^{-10}</td>
<td>0.07</td>
<td>4.7 ± 0.9</td>
</tr>
</tbody>
</table>
in porosities could have had an effect on the intensity and
type of alteration of the two tuffs. The more densely welded
Singatse Tuff would not be altered to the same degree as the
moderately welded and more porous Blue Sphinx Tuff. This is
supported by the fact that the most heavily sericitized Sin­
gatse Tuff is found in or near joints and fractures.

As previously mentioned the vein itself is composed of
highly sheared and brecciated wall rock cemented by quartz
and tabular sheets of alunite (Fig. 16). This alunite, which
was found to be potassium rich by the x-ray diffraction method
of Cunningham and Hall (1976), is extremely fine-grained and
massive and often exhibits a porcelaneous surface texture. In
thin sections the alunite appears as a nondescript amorphous
fine-grained material with low birefringence (Fig. 17). Re­
placement of discrete mineral grains by the alunite is not
seen. Fine-grained pods of strained quartz are scattered
through the alunite. Much of the quartz shows evidence of
being stretched apart, evidence for the formation of the
alteration in the fault being penecontemporaneous with its
movement. Veins of alunite cut both the Blue Sphinx Tuff
and the Singatse Tuff at substantial distances away from
the main vein (Fig. 18), but no alunite replacement of
feldspars was noted in either unit even within centimeters
of the vein contacts.

Potassium Argon age dating of the alunite by the U.S.
Geological Survey yields an age of $4.7 \pm 0.9$ m.y. (Silber­
man, written communication, 1981) (Table 2). This fact
Figure 16. Alunite in the Golden Pen fault in the Golden Pen Mine.
Figure 17. Photomicrograph of alunite in the Golden Pen fault. (Cross nicols, 10x).
Figure 18. Vein of alunite cutting altered Singatse Tuff in the Golden Pen Mine.
along with the fine-grained vein only occurrence of the alunite points to a supergene origin of advanced argillic alteration present in the Golden Pen Mine. Other facts which support this idea include the presence of the secondary iron sulphate, jarosite, in some of the alunite filled veins and fractures, the presence of gypsum on some joint planes, and the general absence of unoxidized sulphides in the Golden Pen Mine.

Similar occurrences of alunite are found at Goldfield, Nevada (Jensen, et al., 1971), where tabular vein-like bodies of fine-grained alunite were determined to be supergene in origin by the use of sulphur isotopic analysis. During the conditions of hypogene alunite formation, sulphur isotope fractionation occurs greatly enriching the sulphate alunite in $^{34}S$ relative to the sulphides forming at the same time (Jensen, et al., 1971 and Field, 1966). Such enrichment of $^{34}S$ in alunite does not occur during formation in supergene conditions. Consequently the $^{34}S$ values of supergene alunites and coexistent sulphides are very low.

Sulphur isotopic analysis of the alunite and coexisting, but rare sulphides in the Golden Pen would be very helpful in confirming its supergene origin, but at present it is beyond the scope of this study.
Alteration and Mineralization -- The Geologic and Economic Significance

The geologic events which took place to form the alteration and epithermal vein mineralization of the Bovard Mining District area appear to have been complex and occurred over a large span of time. The limited isotopic age determinations of alteration minerals in the Golden Pen Mine clearly point to two stages of alteration events.

Primary Alteration and Mineralization

The primary event occurred about 22 m.y. ago with the passage of large amounts of hydrothermal fluids through the faults created by the tectonics of Walker Lane. This event was responsible for the widespread propylitic alteration of the ashflow tuff units present, the sericitic alteration in the heavily faulted areas, and the primary gold and silver mineralization along the Golden Pen fault. As suggested by stable isotope investigations of other similar epithermal vein type deposits along the Walker Lane (Taylor, 1973; Taylor, 1974; O'Neil and Silberman, 1974), the source of the hydrothermal fluids was most likely meteoric waters passing down through the faults and coming into contact with magmas at depth. The large volume of ashflow tuffs erupted over a time period of more than 5 million years is evidence enough for the existence of magmas at depth to fuel those fluids. Although the exact age of the intrusive diorite is not known, it or its parent is a likely candidate for a heat and magmatic
fluid source (i.e., metal ions) of the primary alteration and mineralization. Other speculated sources of alteration in the Gabbs Valley Range are rhyolitic intrusions (Silberman, personal communication), one of which has been dated at 19.2 ± 0.7 m.y. (Ekren, et al., 1980), a date concurrent with the 19.5 m.y. alunite at the Siskon Silver prospect.

Although the chemistry of the hydrothermal fluid may appear to be the most important factor in what kind of alteration is being produced, it is in fact the geologic environment which plays an equal if not more important role in the production of different types of alteration. For example, hydrothermal fluids existing at depths below the water table tend to have pH's which are neutral to weakly alkaline, which in felsic rocks produce feldspars, micas, zeolites, silica minerals, and montmorillonite as alteration products (Rose and Burt, 1979). As such fluids rise, cooling may take place resulting in supersaturation and possible precipitation of quartz along with alteration of feldspars to k-mica (sericite) at temperatures below 300°C as shown by the equation:

$$\frac{1}{2} KAlSi_3O_8 + H^+ \rightarrow KAl_3Si_3O_10(OH)_2 + 3SiO_2 + K^+$$

(Rose and Burt, 1979)

Gold and silver carried in the hydrothermal solution as sulphide complexes would tend to be deposited as sulphides on cooling at temperatures below 300°C (Barnes, 1979). Given the presence of sericitic alteration, quartz veining and silicification, and gold-silver mineralization in the Bovard
Mining District, it seems logical that we are dealing with the conditions and type of alteration/mineralization discussed above. Limited fluid inclusion studies on quartz vein material from the Nevada Rand Mine place quartz deposition at about 220°C (Clifton, personal communication, 1979), but no samples from the Golden Pen have yet been analyzed.

As hydrothermal fluids rise above the water table oxidizing conditions are met resulting in sharp decreases in pH. This strong increase in acidity is usually caused by the oxidation of $\text{H}_2\text{S}$ to $\text{H}_2\text{SO}_4$ and results in advanced argillic alteration. Alunite and clays are often formed with the surface expression of the system being an acid hot spring. The strong acid sulphate environment often intensely leaches the country rock leaving only fine-grained opaline silica at the surface with alunite deposited just above and at the water table. An excellent example of this acid hot spring alteration is present at Steamboat Springs, Nevada (Schoen, et al., 1974), where alunite is forming today at the water table in an acid hot spring environment. Below the alunite zone at Steamboat, kaolinite becomes the dominate alteration mineral which in turn gives way at depth to argillic and sericitic alteration.

In the Gabbs Valley Range advanced argillic alteration is widely present along the Soda Springs Valley fault system. As previously discussed in the regional alteration section, large amounts of kaolinite and replacement alunite are present along with a high percentage of leached siliceous rock. With this alteration dated at 19.5 m.y. (Morton, et al., 1977)
at the Siskon Silver prospect being possibly genetically related to the same hydrothermal system which created the 22 m.y. old primary alteration at Bovard, we could hypothesize the presence of acid hot spring alteration at levels above the now exposed Bovard District which have been removed by erosion. It has been demonstrated that large hydrothermal systems can remain active for time spans of nearly three million years (Silberman, et al., 1979).

**Secondary Alteration**

The second phase of alteration in the Bovard District is of a secondary or supergene nature typified by the presence of alunite in the Golden Pen Mine. Its age of about 5 m.y. negates any relationship to the earlier 22-19 m.y. alteration/mineralization event in the area. Faced with the problem of the origin of the alunite in the Golden Pen we can turn to two possible environments of deposition. These environments are the acid hot spring environment and a weathering environment of strong oxidizing conditions. In the hot spring environment the high activity of $H^+$ and $SO_4^{2-}$ necessary for alunite formation comes from the dissociation of $H_2SO_4$ and other strong acids with falling temperature in a cooling migrating hydrothermal fluid (Hemley, et al., 1969). In a weathering environment the oxidation of metal sulphides in aqueous media provides the $H^+$ and $SO_4^{2-}$ with meteoric waters providing the transport and alteration medium. Figure 19 illustrates the stability relations of alunite as a function of $H_2SO_4$ and $K_2SO_4$ activities. The pertinent reaction applying to the
Figure 19. Stability of relations of alunite as a function of $\text{H}_2\text{SO}_4$ and $\text{K}_2\text{SO}_4$ activities. Pressure is constant and quartz is present (after Hemley and others, 1969).
Golden Pen Mine would be the conversion of sericite (muscovite) to alunite and quartz:

\[ \text{KAl}_3\text{Si}_3\text{O}_{10} (\text{OH})_2 + 4 \text{H}^+ + 2 \text{SO}_4^{2-} = \text{KAl}_3(\text{SO}_4)_2(\text{OH})_6 + 3 \text{SiO}_2 \]

Pyrite, deposited with the primary sericitic alteration, was oxidized producing the sulphuric acid necessary to produce the high \( \text{H}^+ \) and \( \text{SO}_4^{2-} \) concentrations. The question remains whether the solutions which produced this secondary alteration were associated with a hot spring system or were merely ground waters in a weathering environment. The best evidence to support a hot spring system is the fact that the alunite is localized along a short segment of the Golden Pen fault. If the alunite were formed by weathering oxidation it might be expected to be more widespread than it is. However, original pyrite deposition may have been high only in the area of the Golden Pen Mine. Evidence against a hot spring system is the lack of highly leached rock with large amounts of opaline silica in the immediate area. Surficial hot spring deposits could have been removed by erosion but this same erosion could accentuate weathering and create the observed alteration. It is possible that both mechanisms were active but the author prefers the weathering environment creating the present alteration and mineralization in the Golden Pen Mine for reasons discussed below.

Another question to be addressed is why gold is primarily found in the Golden Pen and silver in the Rand area. Mineralization in the Golden Pen could have been primarily pyritic with gold being fixed within the structure of the pyrite.
The strong oxidizing conditions which led to the formation of the alunite released the gold which was redeposited in association with quartz and alunite. The relatively small amount of gold present in the area along with its disseminated microscopic "free" nature (Schrader, 1947) supports this idea. Any silver present could have been mobilized and transported out of the area, perhaps downwards as a supergene enrichment zone. Mineralization in the Nevada Rand and adjoining Lone Star Mine was primarily silver as the sulphide mineral argentite, now oxidized to cerargyrite. Gold is not as abundant in the Rand area possibly because the pyrite present is much less oxidized than in the Golden Pen. Fresh pyrite and other sulphides are found on the dumps of the Rand and Lone Star possibly indicating a lesser degree of oxidation along the Rand segment of the Golden Pen fault. This could be related to the areas position relative to the paleosurface which ultimately effects oxidizing-weathering conditions, which in turn could be related to the fault movements in the area. Movement on the Golden Pen fault occurred in the Golden Pen Mine at the time of alunite formation as evidenced by stretched and pulled apart quartz stringers within the alunite. This movement could have promoted flow of ground water through the fault, ultimately creating the conditions for the secondary alteration to form.

An equally possible explanation for the differences in mineralization between the Golden Pen and the Rand area could simply have been different pulses of hydrothermal fluids with
different metal concentrations. The existence of the hydrothermal alteration in this region for three million years has been documented. It is highly probable that conditions of fluid composition, temperature, etc. would change even over much shorter time periods. Also, the host rocks in the two areas are different, the Rand area being much more mafic than the Golden Pen, and this could affect deposition of alteration and ore minerals by providing different elements for combination by reaction with the ore fluid.

The best explanation for the differences in mineralization between the Golden Pen and the Rand area is a vertical zoning of mineralization controlled by depth of boiling in the system. Buchanan (1981) has proposed a model (Fig. 20) to explain the apparent vertical zonation of mineralization in many epithermal vein systems. Within any particular vein system the base metals would be deposited at depths below the point of boiling of the hydrothermal fluid while silver would be deposited at and above the boiling point. Gold is deposited at even higher levels because it is carried by thio complexes which require higher oxygen fugacities to break them down to sulphates (Buchanan, 1981). The point of boiling in the system is controlled by the hydrostatic pressure and the density of the solution. Evidence of boiling is best documented by fluid inclusion studies.

With this model in mind it is likely that the gold mineralization in the Golden Pen Mine is representative of mineralization nearer to the paleosurface then the
Figure 20. Schematic of model of vertical zoning of mineralization as related to point of boiling of the hydrothermal fluid (after Buchanan, 1981).
silver and minor base metal mineralization of the Rand area. Fluid inclusion studies would help to substantiate this idea.

The present geology of the Bovard Mining District were a long series of geologic processes, many interrelated, which when viewed collectively suggest a highly faulted sequence of volcanic rocks with a superimposed hydrothermal system displaying alteration and mineralization of the epithermal vein type. The proposed simplified sequence of events can be summarized as follows:

1. Eruption of large quantities of ashflow tuffs and lava flow units started in the middle Oligocene with the Singatoa Tuff and ended with the Nugent Tuff about 23 million years ago in the middle Miocene (volcanism did continue but subsequent units were unaffected by alteration).

2. Stresses from Walker Lane tectonics started to create a pattern of faulting typical of lateral shear fault zones. These stresses operate until recent times and would have been in existence pre-Tertiary (Albers, 1967).

3. Possible emplacement of an unknown intrusive complex below or within the covolcanic pile. The intrusive diorite could represent a phase of such an intrusion.

4. Corresponding primary hydrothermal alteration and mineralization caused by upwelling of magmas from depth along the Walker Lane fault system. Hydrothermal fluids were most probably dominantly of meteoric origin with the alteration occurring in environments below the water table at an
Summary of Geologic Events

In summary we can see that the events that formed the present geology of the Bovard Mining District were a long series of geologic processes, many interrelated, which when viewed collectively suggest a highly faulted sequence of volcanic rocks with a superimposed hydrothermal system displaying alteration and mineralization of the epithermal vein type. The proposed simplified sequence of events can be summarized as follows:

1. Eruption of large quantities of ashflow tuffs and lava flow units started in the middle Oligocene with the Singatse Tuff and ended with the Nugent Tuff about 23 million years ago in the middle Miocene (volcanism did continue but subsequent units were unaffected by alteration).

2. Stresses from Walker Lane tectonics started to create a pattern of faulting typical of lateral shear fault zones. (These stresses operate until recent times and would have been in existence pre-Tertiary (Albers, 1967).

3. Possible emplacement of an unknown intrusive complex below or within the covolcanic pile. The intrusive diorite could represent a phase of such an intrusion.

4. Corresponding primary hydrothermal alteration and mineralization caused by upwelling of magmas from depth along the Walker Lane fault system. Hydrothermal fluids were most probably dominantly of meteoric origin with the alteration occurring in environments below the water table at an
unknown depth. Alteration is sericitic with quartz along faults and fractures and propylitic in surrounding less permeable units. Sulphide mineralization occurred in the veins with silver as argentite at Rand and gold fixed in pyrite at the Golden Pen. Very minor copper and lead sulphides are also deposited. The age of this event is about 22 m.y. ago.

5. Volcanism and faulting along the Walker Lane continues with subsequent uplift and erosion of the region.

6. Oxidizing weathering conditions and groundwater circulation created the secondary advanced argillic alteration from the primary sericitic alteration present in the Golden Pen Mine and released gold from pyrite which was deposited with the alunite and quartz in the Golden Pen vein about 5 m.y. ago. Oxidation affected the Rand area of the Golden Pen fault but possibly not to the extent of the Golden Pen. Silver as argentite was oxidized to cerargyrite.

7. Erosion, weathering, and possibly fault movement have continued till the geomorphology of the present area is reached.

Such detailed work needed to further define characteristics of vein ore deposits in the Bovard District is beyond the scope of this study. If applied, such studies would likely discover new deposits along the Golden Pen vein and its related faults; however, given the past limited production...
Discussion and Conclusion

Economic Potential

Since the Bovard District is characterized by epithermal precious metal vein deposits of at least two types, it would be logical to look for additional such deposits. Exploration for additional precious metal vein deposits in the Oatman, Arizona District by the Fischer-Watt Mining Company utilized four basic procedures to define the characteristics of past productive areas (Clifton, Buchanan and Durning, 1980). These include vein contouring, detailed alteration mapping, temperature determinations of fluid inclusion, and geochemical sampling. Characteristics of known deposits are determined by the above methods and then exploration to find similar characteristics in other parts of the same or similar vein systems is carried out.

All the known deposits at Oatman were found to be located at particular points of curvature on the veins and all irrespective of level exposed in the hydrothermal system exhibited a distinctive and predictable alteration signature. Fluid inclusion studies indicated boiling or non-boiling conditions during deposition, temperature of deposition at the sample point, level of exposure relative to the boiling interface and, by establishing a paleogeothermal gradient to the ore horizon, a depth control for drilling (Clifton, Buchanan and Durning, 1980).

Such detailed work needed to further define characteristics of vein ore deposits in the Bovard District is beyond the scope of this study. If applied, such studies would likely discover new deposits along the Golden Pen vein and its related faults; however, given the past limited production...
of the district, such deposits would most likely be too small and thus be uneconomical even at today's high gold/silver prices.

It is in the author's opinion, that the primary economic potential of the Bovard District is the possibility of a buried porphyry copper deposit being present at depth. Sillitoe (1973) was one of the first geologists to address the vertical expression of porphyry copper systems. He states that porphyry copper deposits are normally located beneath a comagmatic volcanic pile which is transected by a column of hydrothermal alteration expressing the upper part of the porphyry system. The characteristics of mineralization and alteration associated with porphyry copper systems tend to change with time and space, a statement which is supported by studies of many porphyry copper deposits, including Butte, Montana (Meyer et al., 1968), Red Mountain, Arizona (Corn, 1975) and El Salvador in Chile (Gustafson and Hunt, 1975). A general genetic model for the emplacement and deposition of porphyry copper deposits has been given by Gustafson and Hunt (1975) based on their detailed studies of the deposit at El Salvador, Chile. Their model is based on three essential elements which are:

1. Shallow emplacement of a usually complex series of porphyritic dikes or stocks in and above the cupola zone of calc-alkaline batholith;
2. Separation of magmatic fluids and simultaneous metasomatic introduction of copper, other metals, sulphur, and alkalies into both the porphyries and wall rocks; and
3. The establishment and inward collapse...
of a convective groundwater system, which reacts with the cooling mineralized rocks. Initial alteration and mineralization is of a primary magmatic origin with disseminated copper sulphide mineralization and potassium-silicate alteration in the core area and propylitic alteration spreading out into the outer fringes and upper levels of the wall rocks, with the influx of meteoric water into the system the alteration changes from alkali to hydrogen ion metasomatism. This K-feldspar destructive alteration occurs at levels above the intrusive complex and may gradually encroach downward overprinting the earlier mineralization/alteration with sericite and strong pyritic mineralization. This alteration/mineralization is often fracture controlled. With time an acid hot spring environment may develop at the surface and upper levels of the hydrothermal system creating significant amounts of advanced argillic alteration above the mineralized porphyry (Gustafson and Hunt, 1975). Gustafson and Hunt (1975) state that similarities of porphyry copper deposits around the world are variations on a common theme; the differences and unique features exhibited by individual deposits reflect the imprint of local variables on the basic model. Such variables can include depth of emplacement, availability of groundwater, volume and timing of successive magma advances, and concentration of metals, sulphur, and other volatiles in magmas.

Estimation of depth to a potential mineralized porphyry below a favorable surface alteration pattern is difficult due to the variable nature of the geologic environment and the
complexities of such systems as discussed in the preceding paragraph. Wallace (1979), in a discussion of signatures of buried porphyry copper deposits, states that estimating depth by alteration zoning sequences may be complicated by telescoping due to changes in fluid flow patterns and repositioning of the heat sources by faulting and erosion. This can be a problem when the hydrothermal system is active for a long time period. Supergene effects tend also to complicate the picture.

Sillitoe (1973) estimates that, at the time of mineralization, the surface may be 3 - 4 km above the porphyry body. The advanced argillic alteration he estimates is present to a depth of about 1 km above the porphyry body. Gold, silver, lead, and zinc veins form between the surface and the porphyry and also laterally to the porphyry (Sillitoe, 1973). Wallace (1979) suggests that metal suites found more closely to a mineralized porphyry copper deposit are high sulfidation copper rich assemblages which include abundant enargite and corellite/digenite. None of those minerals are present in the Bovard District.

With the preceding discussion in mind, the reader can see that the area of the Bovard District could represent the upper levels of alteration associated with typical porphyry copper systems. If it is assumed that any primary advanced argillic alteration was present above the now exposed sericite-quartz-pyrite zone in the area, a mineralized prophyry could be present at a depth on the order of 1 km below the present
surface. However, the likelihood of this is significantly decreased by the fact that very little copper is present in the area. Although minor secondary copper minerals are present in one area of the Golden Pen Mine (Plate III) and adjacent to the diorite intrusion and small amounts of chalcopyrite occur at Rand, preliminary reconnaissance geochemistry (to be published in a U.S.G.S. open file report) shows no significant copper anomalies in the area. The precious metal vein deposits along with the alteration present tends to support the idea that if the hydrothermal system which created the alteration/mineralization of Bovard is related to a mineralized porphyry, the district was developed at upper levels and laterally to that mineralized porphyry. Such a porphyry might logically be located at depth southeast of the district in closer proximity to the well developed acid hot spring alteration along the Soda Springs Valley fault.

Alunite as a Potential Source of Aluminum

The major economic significance of alunite is its potential as a source of aluminum. The other major components, sulphur and potassium, are also marketable commodities. At the present time, the USSR is the only country producing significant amounts of aluminum from alunite ore (Minerals Yearbook, v. 3, 1974). The mining of alunite in the U.S. has primarily been restricted to the Marysville, Utah area. During WW I, when German imports were cut off, alunite was mined to produce potash. This accounted for 4-7% of the
U.S. production of potash at that time (Callaghan, 1938). Production stopped when imports resumed in 1920. Alunite was again mined at Marysville during WW II, when it was recognized as a significant source of alumina. A process was developed to recover alunima and potassium sulphate from alunite (Fleischer, 1944) and a plant was built in Salt Lake City to process Marysville ore. About 37,000 tons were mined for testing purposes (Parker, 1964). After the war interest again declined and currently only small amounts of alunite are mined for use in fertilizer. With the increased demand for aluminum in the future and decreasing supplies of bauxite, domestic reserves are approximately 40 million tons and we import 87% of bauxite used to manufacture aluminum (Patterson and Dyni, 1973), alunite must again be considered as an important source of alumina.

Initial estimates of the amount of alunite in the Bovard District proved to be far greater than reality. Significant alunitization of tuffs on either side of the Golden Pen vein did not occur, which severely reduces the estimates of 4.9 x 10^6 metric tons calculated before the study began. Since this figure was itself a marginal number with respect to mineable alunite reserves, it is unlikely that the alunite in the Bovard District will become an important future source of aluminum.
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Appendix A.

Plates:
I, Ia, II, and III
(in pocket)