THE GEOLOGY AND MINERAL DEPOSITS OF THE SILVER DISTRICT, TRIGO MOUNTAINS, YUMA COUNTY, ARIZONA

A Thesis
Presented to the
Faculty of
San Diego State College

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
in
Geology

by
Frank Z. Parker

August, 1966
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[Signatures]
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INTRODUCTION

Location and Accessibility

The Silver mining district (Figs. 1 and 2) is located in the southern part of the Trigo Mountains of Yuma County, Arizona, and can be reached by way of U.S. highway 95 north from Yuma. The approximate traveling distance from Yuma is fifty-five miles. Access to the district from Cibola, Arizona, is possible with four-wheel drive vehicles, but roads are only jeep trails along dry washes and impassable after severe rainstorms. Travel is restricted along the eastern border of the district due to the proximity of the Yuma Proving Grounds of the U.S. Army.

The area of the district is approximately thirty-six square miles, although the line dividing the Silver and Eureka districts is indefinite (Wilson, 1933). In some past reports the two districts have been considered as one district. In this thesis longitude 114° 37' 30" west, and latitude 33° 02' 30" north, were used as the western and southern borders of the district.

Topography

The Silver district lies within the portion of the Sonoran Desert known as the Yuman Desert
FIGURE 1

INDEX MAP OF YUMA COUNTY, ARIZONA, SHOWING THE LOCATION OF THE SILVER DISTRICT
FIG. 2. LOCATION OF THESIS AREA, SILVER DISTRICT, YUMA COUNTY, ARIZONA
(Jaeger, 1957) or sometimes called the Colorado Desert (Blake, 1853). The district lies wholly within the Basin and Range Province (Thornbury, 1965) and is characterized by individual low, rugged, linear mountain ranges that rise abruptly from the valley plains. The Trigo Mountains have a linear north-south trend, similar to the ranges of southeastern Arizona. The lower slopes of the Trigo Mountains are covered with erosional debris forming nearly uniform slopes from the peaks to the valley floor. Peaks rise to elevations of 1200 to 1300 feet above sea level in the Trigo Range while elevations of 300 to 400 feet are found in the larger drainages such as the Red Cloud Wash. All of the present drainage in the district is to the west into the Colorado River. Running water is apparently the dominant erosional agent in the area with sheetflood erosion common.

The district is further characterized by an advanced stage of arid land pedimentation, prominent faulting, igneous intrusive rocks, volcanic eruptive rocks, and minor folding. Wilson and Moore (1959) have placed the western portion of Arizona into the Basin and Range Structural Province which corresponds with the physiographic Basin and Range Province. However, the
structural province is based only on structural criteria.

**Climate**

The western part of Yuma County, Arizona, is one of the most arid areas of the southwestern United States and has recorded some of the highest summer temperatures. Parker and Fort Mohave, Arizona, have recorded temperatures of 127°F. (Green and Sellers, 1964). However, average July reading for Yuma County is 90°F. The average January temperature is 50°F. with occasional overnight freezing temperatures. Precipitation is generally less than 5 inches for the yearly total (Green and Sellers, 1964) with heaviest and most damaging rains occurring in the summer and early fall. Average relative humidity for the summer is 29% with clear skies and south or southeast surface winds of 5 to 10 miles per hour (Green and Sellers, 1964).

Elevations found in the Silver district are 350 to 1150 feet higher than the elevation at Yuma so considerable variation in temperature and precipitation is to be expected from one part of the district to another. The vegetation of the district is diverse and consists of typical Sonoran Desert flora (Jaeger, 1957).
Previous Work

Very little geologic literature related to the Silver mining district has been published, although it has been an area of mining interest since it was discovered in 1865. There are undoubtedly reports and maps of the district in the files of mining companies and interested individuals, but these were not available to the writer.

One of the few investigators of the geology of Yuma County to include a study of the geology of the district was E. D. Wilson (1933, 1951) in which he summarized the general geology. A reconnaissance geological map of the district was included in his 1933 report and later incorporated into the Yuma County geologic map (Wilson, 1960) at a scale of 1:375,000. Since the original work of Wilson, little has been published about the district. Other mining districts in Yuma County, and Imperial County, California, do not have much published work available for study. Henshaw's (1942) report on the geology and mineral deposits of the Cargo Muchacho Mountains, Imperial County, California; Lee's (1908) reconnaissance of the geology of western Arizona; and Bancroft's (1911) reconnaissance of the ore deposits of northern Yuma County are some of the few references
available that are concerned with the geology and ore deposits adjacent to the Colorado River.

**Terminology**

The terms used to describe fault displacements are those suggested by Hill, (1959). The plutonic and metamorphic rock names follow the classification of Williams, Turner, and Gilbert (1954) and Heinrich (1956). Fragmental volcanic rocks are classified using the classification of Smith (1964). A diagram was prepared to aid classification of the fragmental volcanic rocks and is illustrated in Figure 3. Volcanic rocks too fine-grained for mineral study using petrographic means were tentatively classified using the fused bead index of refraction methods of Kittleman (1963) and Huber and Rinehart (1966).

**Purpose and Methods**

The purpose of this study was to make a detailed survey of a relatively old but unknown mining district, in order to determine the types and distribution of igneous and metamorphic rocks and the types and control of mineralization.

A total of eight weeks was spent in the field during the months of October, November, and December,
OTHER TERMS

Volcanic breccia = Tuff breccia
                   Lappi breccia
                   Flow breccia
                   Rubble breccia

Flow breccia = Volcanic rubble in a lava matrix

Flow conglomerate = Rounded volcanic fragments in lava matrix

FIGURE 3

FRAGMENTAL VOLCANIC ROCK TERMS USED, TERMS APPLIED ON THE BASIS OF THE VOLUME PER CENT OF COMPONENTS IN THE ROCK (FROM SMITH, 1964)
1965, and January, 1966. The geology was mapped either on U.S. Geological Survey aerial photographs (1:20,000 scale) and transferred to enlarged U.S. Geological Survey 7 1/2' Picacho and Hidden Valley, Arizona, quadrangle maps, or mapped directly on the enlarged maps (1:18,000 scale) where photo coverage was lacking or poor. A base map at 1:12,000 scale was used in areas where greatest detail was needed. Mapping methods using aerial photographs supplemented with enlarged topographic maps were found to be particularly suitable because of the abundant rock exposures and distinctive lithologic units identifiable on the aerial photographs, and good base maps with distinctive topography facilitating the transfer from photographs to base maps.

Detailed mapping around areas of mineralization at scales of 1 inch to 200 or 300 feet was accomplished using a combination of pacing, hand-held compass bearings, and altimeter readings at predetermined stations. Most of the underground workings did not warrant remapping since accurate maps of the major mines of the district are available.

Particular emphasis was placed on a petrographic study of the rocks of the district when it became evident early in this study that much of the history of the
area could be obtained through petrographic study. Nearly one hundred thin sections of igneous and metamorphic rocks were examined. Mineral percentages for each specimen were estimated when possible. Heavy liquid separations of a few samples were made using bromoform as the separating media. Many of the igneous rock samples not thin sectioned were selectively stained to facilitate classification. The study of volcanic rocks was supplemented, after microscopic textural studies, with oil immersion index determinations of fused rock beads.

Ore samples were obtained from most of the prospects and mines of the district, and when possible, polished sections were made. The polished sections were studied for paragenesis and alteration in association with thin sections of wall rocks. Ore samples that were badly oxidized were qualitatively analyzed using X-ray fluorescence for element identification.

X-ray fluorescence was also used as a technique to determine trace elements in silicate and carbonate minerals associated with silver-lead-zinc mineralization. Unexplored areas along fault zones were sampled for silicate and carbonate minerals and later analyzed for trace elements in order to determine areas favorable for future exploration of silver-lead-zinc mineralization.
The major metamorphic rock units of the district are quartz-feldspar schists, calc-schists, quartz-mica schists, argillite, calcareous sericite phyllite, quartz-feldspar gneiss, and gneissoid biotite granite. The metamorphic complex of regionally (?) metamorphosed sediments is limited to the southern part of the district. The principal mineral assemblage that composes the metamorphic rocks is typical of the greenschist facies of Fyfe, Turner, and Verhoogen (1958). The common mineral assemblage of the pelitic and quartzofeldspathic schists is chlorite, albite, quartz, muscovite, epidote, and microcline.

The metamorphic complex exhibits a gradual change to porphyroblastic schists, quartzofeldspathic hornfels, and calc-silicate hornfels toward the intrusive area. These rocks are typical of the albite-epidote-hornfels facies of Fyfe, Turner, and Verhoogen (1958) and constitute a zone of contact metamorphic rocks. Although the mineral assemblage is similar to the greenschist facies mineral assemblage of the regionally metamorphosed rocks, gradations to hornblende-hornfels facies near the intrusive contact area are found.
Metasomatic replacement in the regionally (?) metamorphosed complex is exhibited by a gradational change in the schists to porphyroblastic textured schists as the intrusive contact zone is approached. Apparently reactions between the constituent minerals of the schists and chemically active solutions or gases from the intrusive rocks, moving through the pores of the schists, due to a possible pressure gradient, effected the metasomatism. Turner and Verhoogen (1960) note that a metasomatic front of "granitization" is common in areas of granitic bodies due to the effects of the last aqueous residues. Goldschmidt (1922) noted several types of metasomatic replacement. One type, alkali metasomatism, in which there is a fixation of alkali minerals by excess Al₂O₃ in the precipitating rock agrees well with the type of metasomatism exhibited in the thin sections examined from rocks of the Silver district.

Foliation in the schistose rocks has apparently facilitated an inward diffusion of the late aqueous residues of the intrusive rock as porphyroblasts are oriented parallel to the relict schistosity. The presence of the large potash feldspar porphyroblasts in the schists indicates that the chemical composition within
the space occupied by the porphyroblasts changed during recrystallization. The porphyroblastic schists are found to show gradational contacts to gneissic granite and migmatite. The passage from pelitic mica schists, through porphyroblastic potash feldspar schists, to gneissic granite, in which potash feldspar is common, is not uncommon near intrusive zones and has been noted by Turner and Verhoogen (1960), who also reasoned that the prolonged reaction between the intruding magma and the intruded rocks produce complex and gradational contacts and a variation in chemical composition. A thermal or chemical gradient between the intruding rock and the intruded schists was probably present and responsible for the long distance of alkali metasomatism from the intrusive rock.

Petrographic evidence was used in a limited way to indicate the presence of metasomatic processes in the rocks of the district. The feldspar metacrysts in the schists were found to have a similar composition to the feldspar of the intrusive rock, and patchy streaks and shreds of micaceous material or plagioclase-biotite were found. Moorehouse (1959) used similar criteria to indicate the texture and mineralogy of metasomatized rocks. However, the petrographic evidence observed in the
Silver district rocks is well supported by the field relationships, and there can be little doubt that metasomatic processes were operative during the intrusion of granitic rock.

The intrusive rock of the district is limited to a granodiorite stock with diorite and quartz diorite marginal facies. The granodiorite has apparently been contaminated along marginal areas by the assimilation of more basic rock since dark, pod-like zones or xenoliths of amphibole-rich rocks are common along the marginal areas. Petrographic study of basic rock along the marginal areas of the intrusive, the intermediate ring of less basic rock, and the central granodiorite intrusive, exhibits gradational contacts from basic to less basic rock. The hornblende-rich rocks represent the hornblende-hornfels metamorphic facies of the contact aureole of Fyfe, Turner, and Verhoogen (1958). A typical mineral assemblage of andesine and hornblende is found. Basification, a term originally proposed by Ramberg (1952) is used in this study to indicate the process of metasomatism in which salic elements are removed from a rock, producing a basic rock such as amphibolite. The granodiorite shows the reciprocal effects of basification in areas near the basic rocks and becomes richer in biotite and oligoclase, and poorer
in potash feldspars and quartz, approaching the composition of either diorite or quartz diorite. The granodiorite intrusive of the Silver district was apparently modified by the basification of the intruded rock which was probably the metamorphic complex of schists. No evidence is found to indicate that the intruded rock was schist, but field relationships in the district indicate that there is no other rock that the granodiorite might have intruded. The basification is presently limited to marginal areas of the intrusive, but possibly has been removed by erosion from the higher elevations, indicating a localization of basification to the probable crustal zone of the granodiorite. This agrees well with geochemical evidence that the basic elements (Fe, Mg, and Ca) are less mobile in ordinary rocks than are the normal granitic elements and would tend to be concentrated along the crustal and marginal areas of intrusive rocks and not diffuse inward and mix with the granitic elements.

Migmatites are common near the intrusive stock and locally grade into granodiorite. Migmatites are defined in the manner of Turner and Verhoogen (1960) as mixed or hybrid rocks consisting of the schistose country rock, altered by contact metamorphism or
metasomatism, and the intrusive granodiorite. Gradational contacts between schists and granodiorite are commonly displayed. Migmatites of the district can be further classified in the field according to the diadysite-embrechite-anatextite classification of Raguin (1965) depending upon the degree of relict schistosity visible. The migmatites of the Silver district would be necessarily classified as embrechites since the foliation of the metamorphic rocks is still distinct but somewhat encroached upon by pods of igneous material. The migmatites were formed through metasomatic replacement of schists by granodiorite, but in some areas evidence of granodiorite injection along the foliation of schistose rocks is displayed. In both cases of alteration of schistose rocks, the foliation of the schists apparently became pathways for aqueous residues of the intrusive rock or injected magma.

The contact metamorphic rocks closest to the granodiorite are found to be either basified or migmatized while further from the contact hornfels and porphyroblastic schists are found. The contact metamorphic effects of the intrusive rock on the schistose rocks of the district are clearly displayed in the field, but whether the granodiorite intrusion was totally responsible for all of the metamorphism of the
district is not known; nevertheless, the heat imported to the crustal layer of rocks in the rest of the district is a possible mechanism for altering argillaceous and arenaceous sediments. If the intrusion is responsible for all the metamorphism of the district, then possibly granodiorite underlies most of the area where metamorphic rocks are exposed.

Overlying the intrusive rocks and metamorphosed sediments and limited to the northern part of the district, are several hundred feet of Tertiary volcanic flows, breccias, agglomerates, and other pyroclastic rocks. The composition of the volcanic rocks range from rhyolite to andesite. Andesitic lava was one of the earlier volcanic rocks extruded in the district and is found beneath more acidic lava flows and pyroclastic rocks. Rhyolitic to dacitic tuffs and lapilli tuffs and associated pyroclastic rocks are found in most areas of the district.

Pliocene or Pleistocene vesicular basalt flows overlie the Tertiary volcanic series of dikes, plugs, related intrusive masses or flows, and pyroclastic rocks. The basalt flows are limited to the northeast corner of the district and are associated with rhyolitic ash and tuff.
Pleistocene and Recent alluvial material constituting stream and stream terrace deposits, alluvial fans, valley fill, and slope wash deposits, is the youngest geological unit found in the Silver district.
PRE-TERTIARY ROCKS

Undifferentiated Schists, Gneiss, Phyllite, Argillite, and Granite

The oldest rocks in the district are a complex of schists, gneisses, phyllites, argillites, and gneissoid granite.

The foliated rocks of the greenschist metamorphic facies occur mainly in the southern part of the district. Very good exposures are found in Arrastra Wash. The typical exposure is a light gray to dark gray, lineated, fine-grained rock, exhibiting visible foliation when coarser grained. Both planar schistosity and lineation are common in the schistose rocks. There is a pronounced northeast-trending parallelism of the foliation in the metamorphic rocks which is clearly displayed on aerial photographs. Dip of the foliation is variable to the southeast or northwest. The schistosity is generally parallel to the original stratification. Contacts between beds appear to be conformable and commonly show gradational contacts within a few feet. Sedimentary facies changes are probably exhibited in the metamorphic rocks since beds that are continuously traced along their strike show an increase in calcareous content to the south. It would be
difficult to identify metamorphic rocks in one part of the district as belonging to the same unit of another part of the district were it not for the good exposures which permit a unit to be traced continuously along the strike. There are no obvious color differences or lithologic differences visible in the thin-bedded metamorphic units, but petrographic study indicates that the mineral assemblage varies along the strike of a particular unit. Dikes and apophyses of aplite or pegmatite are abundant in areas near intrusive rock exposures. Rhyolite porphyry dikes, intrusive to the metamorphic complex, can usually be traced along the surface for some distance because of the marked difference in color and lithology between the metamorphic rocks and the dikes. The schists, phyllites, and argillites were a series of sediments composed of clay, sand, and sandy clay prior to consolidation and metamorphism. The total thickness of the metamorphic complex is difficult to measure due to folding and the presence of an intrusive gneissoid granite in the central portion of the section. A minimum of 3500 feet of schist, argillite, phyllite, and gneiss is present. Brief petrographic descriptions of rock types in the metamorphic complex are given in the following sections.
Quartz-Feldspar Schist

Gray to pink, weakly foliated, quartz-feldspar schist is a less common schistose rock found grading into hornfelsic rocks near the intrusive contact area. Further from the contact the quartz-feldspar schist grades into the more common micaceous schists. Lineated segregation layering of quartz and feldspar is well developed.

Microscopic examination of thin sections shows a weakly developed schistose texture with a tendency toward a porphyroblastic texture. The schist consists predominantly of slightly strained anhedral quartz, euhedral microcline and orthoclase, and anhedral albite (An 10). Accessory minerals are chlorite, brown biotite, muscovite, magnetite, kaolinite, hematite, and apatite. Mineral grain size ranges from 0.05 mm to 3.0 mm. Sutured quartz grains constitute the largest percentage of minerals and are found as elongated, porphyroblastic, parallel-arranged grains, in lensoid stringers or as interstitial small grains intermixed with orthoclase. Sericitized porphyroblasts of albite, poorly twinned, average 2.0 mm in length.

This schist represents a high grade foliated rock in which quartz and feldspar of relatively coarse size
predominate with the exclusion of most mica (Heinrich, 1956). The quartz-feldspar schists are less platey and less regularly schistose because of the sparsity of mica; however, petrofabric examination of the quartz optic axes indicates a weak preferred orientation parallel to the segregation layering.

**Quartz-Mica-Feldspar Schist**

Schistosity is prominent in the gray to dark-gray, foliated, quartz-mica-feldspar schist common to the southern part of the district.

Thin sections of the schist show a fine-grained, equigranular schistose textured rock. The schistosity is well exhibited by the parallel alignment of abundant reddish-brown biotite, muscovite, and chlorite. Mica flakes average 4.0 mm in length. Essential minerals, quartz, orthoclase, and albite (An 10), range in size from 0.25 mm to 1.0 mm. Accessory minerals include almandine garnet, magnetite, hornblende, zircon, and apatite. Secondary minerals found are: calcite, sericite, hematite, limonite, and chloritoid (?).

Biotite, muscovite, and chlorite form continuous to partially continuous trains of well-oriented flakes alternating with granular quartz-feldspar layers. Anhedral quartz is elongated, usually showing undulatory
extinction, and forms sutured aggregates. Zircon inclusions in individual quartz grains are frequently observed. Subhedral orthoclase occasionally shows twinning according to the Carlsbad law. Anhedral albite is poikiloblastic with quartz inclusions and generally exhibits ragged crystal borders.

The quartz-mica-feldspar schists represent the major schistose rock found in the district and constitute a large part of the metamorphic rock complex. Variations in thickness of beds and degree of schistosity developed are evident in the field, but the probable pre-metamorphic sedimentary facies changes producing differing mineral assemblages are not evident without petrographic examination.

Quartz-Plagioclase Schist

Some schistose rocks show lateral gradation into alkali-feldspar-free schists containing more calcic plagioclase. Labradorite (An 54) associated with brown-green biotite and chloritoid is common. The labradorite is sericitized and forms porphyroblastic clusters and knots of plagioclase averaging 0.25 mm in length. With the exception of the more calcic feldspar and the lack of alkali feldspar, the schist is very much similar to the quartz-mica-feldspar schist described in the
previous section. It is thought that this schist represents a sedimentary facies change in the pre-
metamorphic quartz-mica-feldspar schist sediments.

**Calc Schist**

Weakly foliated, banded, carbonaceous calc schist generally occurs only in the southern part of the dis-
trict. Exposures are common along the drainages into Arrastra Wash. Fine-grained, dark-gray bands typically alternate with coarse-grained white bands.

Thin section examination of the schist shows fine carbonate grains arranged in parallel, elongated lenses alternating with coarser, crystalline calcite. Calcite is inequigranular with grain sizes ranging from 0.05 mm to 1.0 mm. The texture is granoblastic, but foliation is weakly developed resulting from the parallelism of alternating carbonate layers.

Calcite grain borders are denticulated when in contact with other minerals, creating subhedral, sutured aggregates of wavely, leticular, white bands. Alternating with the white bands are dark-gray to black bands consisting of quartz, fine-grained granular calcite, sericite, chlorite, iron oxides, epidote, and carbonaceous particles. Twinning lamellae and rhombohedral cleavage is well exhibited in the coarser
calcite grains. Minor granulation and apparent recrystallization of calcite is conspicuously displayed in the coarser euhedral calcite grains. Epidote and quartz intergrowths in sub-graphic aggregates are common and occur with thin platey to tabular chlorite and sericite. Dusty or flakey disseminated carbonaceous particles are usually limited to the finer granular calcite layers, imparting a dark color. The carbonaceous material has not been subjected to temperatures high enough to form graphite and indicates that the sediment prior to metamorphism was probably a calcareous and carbonaceous clay or possibly a carbonaceous and argillaceous carbonate.

**Feldspathic Chlorite-Quartz Schist**

Greenish-gray, feldspathic, chlorite-quartz schist, containing visible disseminated magnetite grains, occurs interbedded with less chloritic schists.

Under the microscope the schist is observed to consist predominantly of quartz, chlorite, epidote, and orthoclase. Sizes of minerals range from 0.05 mm to 2.0 mm. The texture is inequigranular with a weak development of sub-schistose texture due to the elongation of quartz grains and segregation layering of chlorite with other minerals. Kaolinitized, anhedral
orthoclase porphyroblasts, averaging 2.0 mm in length, occur in a matrix of anhedral quartz clusters, microcline, granular epidote, and sericite. The chlorite occurs as isolated individual flakes. Accessory minerals include magnetite, zircon, and apatite. Secondary limonite is frequently observed in the schist matrix.

The schist probably represents a pre-metamorphic sediment not related through facies changes to the other schists. Field relationships indicate that the chlorite-quartz schists overlie the previously described schists and do not grade into them through facies changes.

**Quartz-Muscovite Schist (Fuchsite)**

Weakly foliated, green, quartz-muscovite schist, displaying monomineralic segregation banding of quartz and green muscovite, is generally found near the intrusive contact area. Quartzose layers, 1 cm. in width, alternating with green mica layers show a definite parallelism under the microscope.

The texture, as seen under magnification, is granoblastic grading into schistose texture. The schist consists of anhedral, unstrained, elongated quartz grains occurring in well sutured parallel stringers, and
flakey, somewhat curved, muscovite. Grains range in size from 0.25 mm to 0.50 mm. Minor andesine (An 40), albite (An 8), microcline, calcite, hematite, apatite, zircon, magnetite, sphene, clinozoisite, sericite, myrmekite, and chromite (?) occur in the schist.

X-ray fluorescence of the schist indicated the presence of chromium, although no attempt was made to eliminate heavy mineral contaminants such as chromite that could possibly account for the chromium. However, a strong peak was recorded for chromium and it is doubtful that a small amount of chromite could account for all of the chromium present in the schist. It is thought that the muscovite contains chromium. A rock of this composition (quartz and chromium muscovite) is customarily called a Fuchsite schist (Heinrich, 1956) and belongs to the greenschist facies.

**Calcareous Sericite Phyllite**

Gray sericite phyllite, exhibiting well-developed foliation and a silky sheen on cleavage surfaces is closely associated with calc schists. Pyrite molds are common.

Under the microscope, the phyllite is a finely foliated, fine-grained, granoblastic rock containing sericite, chlorite, anhedral quartz, and labradorite
Segregated bands containing sericite and chlorite alternate with bands of quartz and labradorite. Sizes of mineral grains average less than 0.10 mm. Fine-grained porphyroblastic calcite lenticles and veinlets are ordinary constituents of the phyllite. Areas of former pyrite (?) cubes, averaging 1.0 mm, are partially filled with introduced quartz and hydrous iron oxides. A suggestion of former eye-shaped pressure shadows around pyrite (?) molds is present. Quartz grains are elongated and occur in parallel, aggregated lenses and stringers with sericite and chlorite. Accessory minerals include apatite, zircon, magnetite, hematite, and limonite.

**Siliceous Argillite**

Siliceous argillite layers found between schistose rocks of the district generally average a few feet in thickness. Colors are dominantly black. The argillites grade into thinly laminated, fine-grained shale with occasional siliceous interlayers. They are easily distinguishable from the schists by their abundance of biotite and more strongly altered condition. When the argillites are cleaved, the long axes of the biotite flakes are found to lie in the cleavage planes.
Thin section examination of the argillite shows a nearly monomineralic, schistose textured rock, containing biotite flakes averaging 1.0 mm in size. Quartz occurs in granular aggregates between biotite flakes.

**Quartz-Feldspar Gneiss**

Quartz-feldspar gneiss constitutes a small part of the metamorphic complex of the district and is typically a well-banded, pink to greenish-gray, quartz-feldspathic rock containing alternating layers of biotite-epidote and quartz-feldspar. The segregated bimineralic bands average 1.0 cm. in width.

Microscopically, the gneiss consists of quartz, albite (An 10), biotite, epidote and accessory apatite, zircon, hematite, and magnetite. The fabric is inequigranular with anhedral quartz constituting 45 percent of the rock. Quartz grains are elongated and usually granulated around the crystal borders. Broken grains and undulatory extinction are frequently present in the quartz. Normally zoned plagioclase (An 50-10) occurs with sericitized subhedral albite (An 10) and andesine (An 30). Poikiloblastic plagioclase containing rounded quartz inclusions is limited to the zoned crystals. Twinning is generally obscure in the plagioclases. Epidote is usually associated with the
plagioclases, and probably represents an alteration product of the more calcic andesine. Grain size ranges from 0.05 mm to 0.50 mm.

The gneiss represents a somewhat thicker-foliated metamorphic rock of the district and locally intergrades with thinner foliated schists. It is probably a metamorphosed sediment similar to those that formed the schists of the district, but thicker bedded. Heinrich (1956) lists such criteria as grain size variation, thin banding, plagioclase composition variation and zoning, and excess quartz content as diagnostic of a metamorphic sedimentary rock.

Gneissoid Biotite Granite

Pink, gneissoid biotite granite occurs within the complex of schists and apparently is not intrusive into the schists and other metamorphic rocks of the district; but rather is a much older rock, partially buried by the metasediments. Field relationships do not indicate intrusion of the granite into the overlying rocks. Exposures are small and discontinuous and not mappable on the scale used in this project. The granite is similar to granite described by Johannsen, in Lee (1908), Bancroft (1911), and Moore (1958). Possibly it
represents the exposed portion of the Precambrian basement complex.

Thin section examination of the granite shows essential pink orthoclase, andesine (An 48), quartz, and biotite, in an equigranular, medium-grained, hypidiomorphic-granular texture with sub-parallel mafic minerals. Anhedral microperthitic orthoclase and microcline, altered to kaolinite along cleavages, are the major potash feldspar constituents. Bent cleavages and twin lamellae in the potash feldspars are not unusual. Subhedral andesine shows nearly complete alteration to sericite. Albite and Carlsbad twinning in the andesine is frequently present. Occasional normally zoned plagioclase is present, but not well exhibited. Borders of andesine are usually corroded by potash feldspar crystals. Interstitial granular quartz containing abundant apatite inclusions generally shows undulatory extinction. Frequently chloritized brown biotite with zircon inclusions is intergrown with magnetite in sub-parallel strings. Accessory minerals include brown-green, subhedral hornblende, zircon, magnetite, and apatite. Secondary chlorite, calcite, kaolinite, sericite, and hematite are sparingly present.
UPPER CRETACEOUS-LOWER TERTIARY

CONTACT METAMORPHIC ROCKS

Gradational changes from typical schistose rocks to "spotted" or porphyroblastic schists, calc silicate hornfels, quartzo-feldspathic hornfels, migmatites, and amphibolites occur near the granodiorite intrusive rocks.

"Spotted" schists are common near the igneous rock areas and are conspicuous due to the contrast of the lighter-colored ellipsoidal potash feldspar porphyroblasts to the dark-gray host rock. The long axes of the feldspar porphyroblasts statistically parallel the foliation of the host rock. The "spotted" schists were probably originally schists, prior to igneous intrusion into the area, similar to schists found in the southern part of the district, but through metasomatic replacement became enriched in potash feldspar porphyroblasts. The schists form a relatively large unit of several hundred feet thickness and extend along the intrusive periphery in the southern part of the district.

Siliceous hornfelses are limited to areas close to the intrusive contact and frequently are finely laminated. These rocks have the gross appearance of a
quartzite, but upon closer hand sample or petrographic study, typical hornfelsic texture is evident. A variety of colors from white to gray, and occasionally red to green, are found in the hornfels. Megascopically the rocks appear structureless, but thin sections show well-defined planar mica orientations. In the field, the two common hornfels, calc silicate hornfels and quartzofeldspathic hornfels, cannot be easily distinguished.

Amphibolites and hornblende schists occur generally as small, lensoidal, black, massive units at the intrusive contact. They are irregular basified bodies ranging in size from a few feet to nearly 100 feet occurring in the intrusive rock. The hornblende-rich rocks locally intergrade with the granodioritic intrusive and occasionally with schistose metamorphic rocks. The two general types of amphibole-bearing rocks are not easily distinguished from one another, but when apparent foliation is present and thin section study indicates the presence of more quartz, a distinction can be made between amphibolite and hornblende schist. They are distinctive units due to their darker color, but usually were too small to be mapped in the field at the scale used. Larger bodies of hornblende-bearing rocks were mapped on the larger scale base maps and later
transferred to the map included in this study.

Schistose rock complexly intermixed with intrusive rock, or rocks exhibiting apparent metasomatic replacement of schistose texture and compositions for "granitic" textures and composition were differentiated during the field mapping and classified as migmatites. Generally, the apparently metasomatized rocks retain relict foliation and have the appearance of schistose rocks. Closer hand sample examination readily indicates that the rocks are not true schists nor are they typical in texture or composition to the intrusive rock of the district, but rather they are hybrid rocks retaining some characteristics of the schistose rocks and gaining some characteristics of igneous rocks. They are typically white to pink or gray rocks. Thicknesses of several hundred feet are exposed in several parts of the district. Frequently they are complexly intermixed with intrusive rock and show gradational contacts from migmatite to granodiorite. In some areas of the district the migmatites constitute zones of intermixed schists and intrusive rock. These zones represent forceful injection of granodiorite into the overlying schistose rocks rather than metasomatic replacement in the schists. In the following sections brief
petrographic descriptions will be given of the contact metamorphic rocks.

**Porphyroblastic Quartz-Chlorite-Feldspar Schist**

Foliated, gray, quartz-chlorite-feldspar schist containing white orthoclase porphyroblasts occurs near the intrusive contact. Porphyroblasts range in size from 1.0 millimeter to several centimeters.

Thin sections show porphyroblasts of anhedral orthoclase in a medium-grained matrix of quartz, oligoclase (An 24), and prochlorite. The orthoclase exhibits weakly developed Carlsbad twinning and generally shows a strong alteration to sericite. Green prochlorite is formed around the porphyroblasts producing a semi-phacoidal texture.

Granular quartz grains average 0.25 mm in size and occur as sutured monomineralic aggregates. Boehm lamellae in the quartz grains are usually present. Oligoclase shows very faint polysynthetic Albite twinning and is usually closely associated with graphic-granite (quartz-orthoclase intergrowth). Magnetite, sphene, tremolite, epidote, chloritoid, biotite, and hornblende are the usual accessory minerals. Secondary calcite fracture fillings, hematite, limonite, and talc constitute the lesser secondary minerals.
The porphyroblasts of orthoclase apparently formed under conditions favorable to the introduction of potash feldspar solutions along the foliation planes of the schists, probably at the time of igneous intrusion. During growth of the potash feldspar crystals, prochlorite was crystallizing around the orthoclase and forced aside as the porphyroblasts increased in size. The schist was probably a quartz-mica-feldspar schist prior to igneous intrusion into the district. The obvious mineralogical changes in the porphyroblastic schist are the change from albite (An 10) composition to oligoclase (An 24), the alteration of biotite to prochlorite, and the increase in potash feldspar. Schistosity is less well exhibited in the porphyroblastic schists.

**Calc-Silicate Hornfels**

The calc-silicate hornfels is a light green, banded, nearly bimineralic rock containing green, granular epidote and colorless quartz.

Thin sections of the hornfelses show an equigranular, fine-grained, granoblastic textured rock composed essentially of quartz and epidote, ranging in size from 0.25 mm to 0.50 mm with minor amounts of subhedral sphene, ilmenite, magnetite, and leucoxene.
Quartz grains are well sutured, elongated, and generally occur in lenticular aggregates alternating with bands of green, granular aggregates of epidote. Banding in the rock is probably due to relict stratification developed prior to metamorphism or intrusion of granodiorite.

Quartz-Feldspathic Hornfels

The other hornfels found in the contact area of the district is a quartzo-feldspathic hornfels. It is typically a white or light-gray color, but red to green varieties do occasionally occur. The hornfels consists predominantly of quartz, feldspar, and minor accessory minerals.

Thin sections of several quartzo-feldspathic hornfelses exhibit a fine-grained, equigranular, granoblastic texture. Grain size ranges from 0.05 mm to 0.25 mm. Rarely, some of the thin sections examined of the hornfels show a porphyroblastic texture. Mineral grains are usually found to be slightly interlocked in phacoidal textured hornfels where lensoidal aggregates of quartz occur. Apparent relict bedding of pre-metamorphic sediments is shown in some varieties containing mineralogical banding.
Anhedral quartz is the most abundant constituent of the hornfels and is generally found as clear, unstrained, anhedral crystals, containing deformation lamellae and somewhat elongated along a preferred direction. Minor border suturing of quartz grains is present.

Feldspar composition is usually represented by subhedral microcline, orthoclase, and albite (An 10). Porphyroblasts of feldspar are occasionally observed. Alteration to kaolinite or sericite is abundant, with sericite alteration being the more common.

Minor accessory minerals frequently contained in the hornfels include biotite, perthite, magnetite, and zircon. Secondary minerals kaolinite and sericite are abundant; chlorite and limonite are sparse in the quartzo-feldspathic hornfels.

**Amphibolite and Hornblende Schist**

Dark-gray to black amphibolite and hornblende schist forms zones along the marginal areas of the intrusive rock of the district and occurs in lensoidal bodies of irregular extent. They intergrade with intrusive rocks but are distinguishable from the lighter-colored, crystalline intrusive rock. Hornblende schist is described with amphibolite because they are similar
rocks and difficult to distinguish in the field without close hand sample or petrographic study. Quartz content and schistosity are the features used to distinguish these similar-appearing rocks.

Amphibolite is the more common of the two basic contact metamorphic rocks and microscopically appears as a medium-grained rock with textural variations from idioblastic to xenoblastic or porphyroblastic textures. Grain size ranges from 2.0 mm to 5.00 mm. The rock is composed essentially of hornblende and plagioclase with accessory microcline, biotite, quartz, magnetite, apatite, garnet, and sphene-ilmenite intergrowths. Alteration minerals include: Chlorite, epidote, sericite, calcite, hematite, and limonite.

Hornblende is the most abundant essential mineral of the amphibolites and hornblende schists and occurs as green, prismatic crystals with a rugged or straight termination. Usually the hornblende forms twins with (100) as the twin plane. The crystals are frequently arranged in a decussate fashion and commonly show various stages of alteration to chlorite. Sieve structure in hornblende crystals is not uncommon and inclusions in different crystals may be either quartz, plagioclase, or rarely, hercynite.
The plagioclase composition is usually andesine (An 40-50), occurring as equant xenoblasts and showing alteration to sericite along twinning planes. Polysynthetic Albite twinning and Pericline twinning on the andesine b-axis is abundant. Occasional Carlsbad twins are observed in the andesine.

Quartz tends to occur as a granular, unstrained, interstitial mineral in minor amounts in the amphibolite, but becomes an essential mineral in the schistose amphibolites. In the hornblende schists, quartz ranges in size from 0.25 mm to 1.50 mm. Undulatory extinction in quartz is more common in the hornblende schists than in the amphibolites.

The amphibolites and hornblende schists probably represent metasomatized or basified schistose rocks formed through contact with intrusive granodiorite magma.

**Migmatites**

Contact metamorphic rocks exhibiting the dual characteristics of granitic composition and texture with metamorphic relict foliation are perhaps incorrectly placed in a migmatite classification. In all probability they should be called anatexites. Other rocks of the district are clearly foliated metamorphic rocks.
intermixed with granodiorite or its derivative intrusive rocks and should be called embrechites according to Raguin (1965). However, for convenience in mapping rocks with dual metamorphic-igneous characteristics, both the anatextites and embrechites were tentatively identified as "migmatite." There is a zonal relationship of migmatite displayed in the field where embrechites grade into anatextites and finally into granodiorite, but contacts are not clear or not exposed in all areas. No attempt was made in the field mapping to separate zones of migmatite.

The migmatites are generally white to pink, or less frequently, dark gray, inequigranular rocks. Weakly developed gneissic or schistose structures are sometimes discernible. In general, three differing mineral compositions can be recognized in the thin sections of the district migmatite suite: those high in potash feldspar constituents, those high in albite, and those containing segregations of potash feldspar in sodic plagioclase matrices.

Thin sections of migmatite high in potash feldspar are generally found to contain inequigranular-xenoblastic textures, broken mineral grains, and bent feldspar lamellae. Grain sizes range from 0.05 mm to 2.0 mm. Contacts between mineral grains are frequently
indistinct. Mineral composition usually includes microcline, microperthite, strained monomineralic quartz segregations, unstrained granular quartz, green-brown biotite intergrown with magnetite, and plagioclase of varying composition (An 4, An 10, An 40-54). Secondary minerals include calcite, chlorite, hematite, sericite, and kaolinite. Accessory minerals include myrmekite, apatite, epidote, and orthoclase. An indistinct banding or parallel arrangement of biotite and microcline is occasionally observed.

Thin sections of migmatites with high albite (An 8) composition have a tendency to contain porphyroblastic textures and dark colors. Porphyroblasts of anhedral feldspars containing curved twin lamellae, embayed and corroded crystal borders, and strong alteration to sericite, are ordinarily present. Mortar texture is sometimes present in primary quartz grains usually showing undulatory extinction. Some secondary unstrained, sutured segregations of quartz are observed. Andesine (An 40) is sometimes present in the same rock with albite, but always in subordinate amounts. Other minerals usually found in this type of migmatite include epidote, chlorite, magnetite, pleonaste, biotite, sericite, hornblende, kaolinite, hematite, apatite,
myrmekite, and leucoxene. Relict schistosity is displayed by the parallel arrangement of mica and quartz monomineralic stringers.

Thin sections of migmatites containing segregations of potash feldspar in sodic plagioclase matrices appear granoblastic textured. Schistose texture is exhibited in some of the migmatites. Anhedral and poikiloblastic crystals are usually present. Two generations of quartz crystallization are found, one relatively unstrained, the other strained and containing mortar structures. The potash feldspar occurs as aggregated clusters of microcline, micrographic microcline, and microperthite in a matrix of sericitized albite (An 8) and andesine (An 40), green-brown biotite intergrown with magnetite, and quartz. Albite and andesine are frequently Albite and Carlsbad twinned with abundant quartz inclusions. Biotite—magnetite intergrowths generally occur in parallely segregated, porphyroblastic clusters. Other minerals present in this type of migmatite include epidote, sericite, augite, hematite, calcite, chlorite, muscovite, and leucoxene.

Apparently the differences in mineral composition of migmatite varieties is a reflection of the original composition of the intruded schistose rock and the distance or gradients to the intrusive rock. Migmatites
closest to the intrusive rock are more similar in texture and composition to granodiorite than migmatites further from the contact.
A small stock-like mass of granodiorite and its derivative rocks occupying an area of about five to six square miles in the central part of the district, is the major intrusive. The migmatites probably formed through metasomatic processes of the intruding granodiorite reacting with overlying schistose rocks, and represent contact metamorphic zones. If granodiorite underlies most of the migmatites, then the stock is probably much larger than the present exposures seem to indicate. Excellent exposures of granodiorite are readily accessible to the east or west of the Red Cloud mine area.

The granodiorite weathers to a friable material and unweathered exposures are usually found to be covered with several inches of grus formed by weathering. Contacts of granodiorite with other rocks of the district are usually sharp fault contacts, but some gradational contacts to migmatite or basified rocks are occasionally present. Light-gray to dark-gray colors predominate. Jointing is not conspicuous due to weathering, but where unweathered exposures are found, jointing sets generally strike northeast or nearly west, with dips to the south.
Three units were distinguished for mapping purposes on the basis of mineral composition; but this criterion becomes unreliable for field differentiation due to the general similarity of textures, grain size, and color indices of the units. Contacts between units are always gradational and not easily traceable from weathered surface exposures. Close to the contact with metamorphic rocks, the granodiorite assumes a quartz dioritic or dioritic composition, as a result of the possible reciprocal effects of basification. Xenoliths of amphibolite and hornblende schist are common along the marginal areas of the stock. Ordinarily, porphyritic and fine-grained facies of granodiorite occur along the periphery of the granodiorite stock.

At several places dikes and pods of light-colored, fine-grained, aplitic micro-quartz diorite, and dark, fine-grained diorite lamprophyre cut across both granodiorite and the contact metamorphic rocks along the margins of the stock. Simple granodiorite pegmatites are found occasionally along the periphery of the intrusive.

In the following sections general petrographic descriptions of phases of the intrusive are given. Thin section study of the intrusive rocks was supplemented by selective staining tests and heavy mineral separations.
Biotite Granodiorite

The interior mass and sometimes the marginal areas of the stock are composed of light-gray biotite granodiorite containing pink-tinted quartz, white feldspar, and black biotite.

In thin section, the granodiorite is a medium-grained, xenomorphic to hypidiomorphic, equigranular rock, occasionally containing autoclastic textures. Grain size ranges from 1.0 mm to 2.25 mm. Essential minerals are oligoclase (An 12), microcline, microperthite, quartz, and biotite-augite intergrowths. Accessory minerals include hornblende, garnet, magnetite, apatite, zircon, and sphene. Secondary sericite, epidote, chlorite, and calcite are present in minor amounts.

Oligoclase is the dominant feldspar, occurring as elongated subhedral grains, and frequently showing alteration to sericite or rarely to saussurite. Normal zoning (An 50-12) and Albite-Carlsbad twinning are usually exhibited in the plagioclase. Microcline is microperthized to varying degrees by the sodic oligoclase and usually formed into intergrowths with interstitial quartz or twinned orthoclase. Quartz is anhedral and often shows wavey extinction. In the
occasional autoclastic-textured granodiorite variety, quartz crystals appear to contain microshears and more pronounced rounding of crystal borders with prominent undulatory extinction. Quartz generally occurs as individual crystals or as poikilitic intergrowths with biotite and myrmekite. Green-brown biotite is found intergrown with pale green augite and both usually show alteration to chlorite.

**Quartz Diorite**

Typical quartz diorite occurs as a contaminated differentiate of the granodiorite intrusive and is commonly found near contact areas with metamorphic and basified rocks. The quartz diorite is a light-gray, granular rock containing white plagioclase, black biotite, and scattered pink quartz grains.

Thin section examination shows a medium-grained, hypidiomorphic-granular rock composed essentially of andesine (An 40), biotite, and quartz. Grain size ranges from 1.0 mm to 3.0 mm.

The most abundant constituent of the rock is subhedral andesine displaying weak to strong alteration to sericite, and polysynthetic Albite twinning combined with Pericline twinning. Zoned plagioclase (An 65-55) with corroded calcic cores are sometimes present.
Green-brown euhedral biotite intergrown with augite is the chief mafic mineral. It generally occurs as segregations with green hornblende. Poikilitic intergrowths of quartz in biotite are common. The mafic minerals usually exhibit some degree of alteration to chlorite. Anhedral quartz grains are commonly embayed and show undulatory extinction. Inclusions of indeterminate composition in quartz grains are abundant. Accessory minerals include anhedral, twinned orthoclase, microperthite, myrmekitic quartz-plagioclase intergrowths, apatite, sphene, garnet, zircon, magnetite, and microcline. Alteration minerals usually present in the quartz diorite include epidote, hematite, calcite, chlorite, and sericite.

**Biotite-Hornblende Diorite**

The rocks of dioritic composition are usually found as marginal facies of the granodiorite. They are somewhat darker in color than the granodiorite and quartz diorite but not distinctive enough for easy field recognition. The diorite is composed essentially of white to light-gray plagioclase, black biotite, and black hornblende.

Microscopic examination of thin sections of the diorite shows a glomeroporphyritic textured rock composed
of intergrown biotite-hornblende crystals in a matrix of sub-gneissoid texture consisting primarily of plagioclase (An 10-20). Grain size ranges from 0.5 mm to 3.5 mm.

Anhedral to subhedral plagioclase varies in composition from albite to oligoclase and shows marked normal and oscillatory zoning. Twinning according to the Albite and Carlsbad laws is frequently exhibited and occasional Pericline twinning is present. Preferential minor sericite alteration of the more calcic plagioclases is usually present. Brown-green biotite and green hornblende prisms occur as mafic clusters with magnetite and produce a porphyritic texture in the diorite not readily observable in hand samples. Accessory minerals include: interstitial quartz, orthoclase, diopside, hypersthene, and apatite. Secondary minerals, chlorite, sericite, and kaolinite are present in small amounts.

Micro-Quartz Diorite

Dike rocks of quartz diorite composition occur along the marginal areas of the intrusive rock and range in thickness from one foot to a few feet. They are irregular units and usually do not extend very far along their longer dimension, usually less than twenty feet.
There is a general trend of the dike attitudes toward the north. Association with pegmatitic rocks is usual.

Under magnification, thin sections of the microquartz diorite show equigranular anhedral quartz, orthoclase, microcline, antiperthite, and altered plagioclase. Grain size is less than 1.0 mm. Typical aplitic texture with interlocked mosaic grain boundaries is present.

**Granodiorite Pegmatite**

Simple granodiorite pegmatite consisting of quartz, orthoclase, plagioclase, and biotite with grain sizes in excess of 1.0 cm. is occasionally found as irregular pods cutting across both granodiorite and contact metamorphic rocks along the marginal areas of the stock.

**Diorite Lamprophyre**

Dark-gray, granular dike rock occurs along the contact areas of the granodiorite intrusive rock and the metamorphic rocks. It is usually associated with other lighter-colored dike rocks. The diorite lamprophyre dikes range in thickness from five to ten feet and usually trend to the northeast for less than ten to twenty feet.
In thin sections of the fine-grained dike rock, idiomorphic-granular textures with grain sizes ranging from 0.1 mm to 0.5 mm were observed. Pilotaxitic texture is present in some of the dike rocks. The dike rocks are composed essentially of andesine (An 40), mafic minerals, and accessory quartz.

Andesine microliths are polysynthetically twinned according to the Albite and Carlsbad laws, and usually arranged in sub-parallel positions with granular, green hornblende, brown-green augite, biotite, and strained quartz in the interstitial areas. Normal zoning in the plagioclase is usually present. Secondary minerals include calcite, sericite, chlorite, and epidote.

A variation in biotite content in the diorite lamprophyres is frequently present. Per cent biotite in diorite dike rocks varies from 2 to 40 per cent. Andesine shows a corresponding range from 20 to 75 per cent in individual diorite lamprophyre samples. The relationship of biotite to andesine in the rocks does not appear to be reciprocal, and further study would be necessary to verify the existence of any relationship.
TERTIARY VOLCANIC ROCKS

The relatively small stock of the Silver district is assumed to represent one injected (?) mass of granodiorite magma faulted into apparently discontinuous units. There is no observable evidence that separate injections of granodiorite occurred in the district. There is a very close chemical identity of the granodiorite with the volcanic rocks of the area. Volcanic rocks of the district consist predominantly of rhyodacitic and dacitic compositions. Rhyolitic and andesitic volcanic rocks are found, but in lesser quantities. Estimated thickness of the Tertiary volcanic sequence is probably one thousand feet in the northern part of the Silver district.

Several lithologic varieties of rhyodacite, dacite, rhyolite, and andesite are present in the district. They include fine-grained pyroclastic beds, volcanic flows, volcanic breccias, volcanic intrusives, and volcanic flow conglomerates. They range from white tuffaceous materials to dark-gray volcanic flow rock. Red, purple, green, and light-gray colors are also frequently present. Deuteric alteration, weathering, and localized silicification has affected nearly all of the Tertiary volcanic rocks so original textures are
poorly preserved. Some linearity of topographic forms in the volcanic rock series probably is a reflection of past deformation by faulting, but erosion has removed most of the physiographic evidence of faulting along with great amounts of volcanic material. Volcanic necks and dissected domes mark some areas of the district as vents of the volcanic materials. The volcanic necks still contain relict planar flow structures. The volcanic necks seem to lack basal contacts with the other underlying Tertiary volcanic rocks, indicating that they probably are shallow intrusive bodies.

Bedded, white to pinkish-white, tuff, tuff breccia, and lapilli tuff constitute distinctive units in the central part of the district. They are well-exposed, locally silicified, mappable units that occur usually as lenticular, discontinuous beds that can be traced less than fifty to one hundred feet along their strike. The lithology of the tuffs is suggestive of deposition in a standing body of water. Sorting and graded bedding of tuffs is usually well displayed in exposures. The tuffs consist primarily of glassy or cryptocrystalline material.

Volcanic flows vary in thickness, color, and mineral composition within very short vertical and
horizontal distances and no attempt was made to differentiate individual flows. Cross-cutting relationships of other intrusive volcanic rocks with the flows have removed the continuity of flows so they cannot be easily followed along their strike.

Volcanic breccias consisting of flow, lapilli tuff, tuff, and rubble breccias are usually interbedded with volcanic flows. Texturally defined changes and color changes do not appear to occur within individual layers. The breccias are extrusive rocks and apparently rest conformably on the underlying units. No cross-cutting relationships of the breccias with other volcanic rocks was observed in the field. Fragments in the breccias are angular to rounded volcanic particles, usually identical in mineral composition with the matrix, although color differences occasionally exist. Volcanic flow conglomerate with metamorphic rock clasts occurs in several small exposures throughout the district.

Volcanic intrusive units include dikes, sills, volcanic plugs and necks, and small pod-like intrusive masses. Included with the intrusives are porphyritic volcanic rocks thought to be shallow intrusive rocks on the basis of their cross-cutting relationships to other
rocks, although some are probably domes or possibly very thick volcanic flows.

An attempt was made early in the field mapping to differentiate between separate flows, breccias, and intrusive volcanic rocks on the basis of mineral content, color, or distinctive lithology, but the stratigraphy proved to be far too complex to map on the scale used. All the Tertiary volcanic rocks, with the exception of the bedded pyroclastic rocks, were mapped as one unit. Individual petrographic descriptions of some of the more common volcanic rocks follow in a separate section. Petrographic study was supplemented with index of refraction determinations of fused glass beads to estimate the silica content of the fine-grained volcanic rocks.

Silica Content of Volcanic Suites

Microscopic study indicated a need for supplemental study on the finer-grained and glassy varieties in order to determine the silica content and the ultimate classification. Rittman (1962) recognized that identifiable phenocrysts in a fine-grained or hyaline groundmass are not necessarily representative of the composition of the rock and that a hyaline groundmass may contain hidden alkali feldspars and silica. It is
evident that microscopic study of hyaline or fine-grained volcanic rocks would be of limited classification value. Microscopic study of the fine-grained volcanic rocks was used primarily for textural, alteration, and phenocryst mineralogy study.

A moderately close correlation is known to exist between the index of refraction and the silica content of an artificial glass prepared from a rock (George, 1924). Curves of the index of refraction versus the per cent silica content were prepared for several rocks of one volcanic suite by George (1924) and Kittleman (1963).

Artificially fused glass beads of finely crystalline rocks were obtained using the technique of Matthews (1951) modified by Callaghan and Sun (1956) and Wargo (1960) in which a small powder of the sample is fused with a carbon-arc torch.

Although each volcanic province has its own characteristic silica-index of refraction curve (Matthews, 1951), the data obtained from all volcanic rocks of western North America have a small degree of scatter (Kittleman, 1963). Huber and Rinehart (1966) believe that the data obtained from individual volcanic suites indicates that the silica-refractive index
relationship is non-linear and that a separate silica-refractive index curve should be determined for each volcanic rock suite in order to estimate the silica content more accurately, but they also note the usefulness of an "average" curve such as the one used in this study (Fig. 4) for the rapid determination of the silica content of fine-grained volcanic rocks.

The technique of preparation of glass beads will not be described as the interested reader can refer to the excellent description of Kittleman (1963). The index of refraction of the prepared glass beads was determined using sodium light illumination and immersion oils. A refractometer was used to calibrate the immersion oils at the time of use. The index of refraction determined for each sample was plotted on the curve determined by Huber and Rinehart (1966). From the estimated silica content, a comparison with the silica content of chemically analyzed volcanic rocks (Johannsen, 1932) (Clark, 1924) was made to tentatively classify the rocks of the district.

**Vitric-Crystal Rhyodacite Tuff and Lapilli Tuff**

Vitric-crystal rhyodacite tuffs and lapilli tuffs are quite abundant in the central part of the Silver district and are usually observed to contain graded
SILICA-REFRACTIVE INDEX CURVE USED TO DETERMINE THE SILICA CONTENT OF VOLCANIC ROCK SUITE FROM THE SILVER DISTRICT YUMA COUNTY, ARIZONA
bedding. Colors range from light-pink to white.

Thin sections of the tuffs consist primarily of faintly polarizing devitrified "spherulitic" glass particles composed of cristobalite-plagioclase fibers, quartz, biotite, plagioclase, augite, magnetite, hematite, and sanidine. Particle sizes of glass "spherulites" range in size from 0.25 mm to 1.0 mm. Crystal sizes range from 0.25 mm to 0.50 mm. The lapilli tuff particles were observed to be greater than 4.0 mm in size.

The devitrified glass particles constitute 60 to 85 per cent of the tuffs and the crystal particles, 15 to 40 per cent. Quartz is the most abundant mineral present in the tuffs, occurring either as subhedral grains or as rounded detrital fragments. The detrital quartz particles and graded beds in the tuffs strongly suggests deposition in a standing body of water.

Silicification is frequently present and achieved by the introduction or redistribution of silica and is found in the thin sections occurring as opal, chalcedony, or cryptocrystalline quartz. Alteration to clay minerals is not usually present, but alteration to cristobalite is.
Vitric-Crystal Rhyolite Tuff Breccia

Associated with the rhyodacite tuffs, but limited to local areas, are red to green vitric-crystal rhyolite breccias. Clast sizes range from 8.0 mm to several centimeters.

Thin section study of clasts and matrices of the breccias indicate a general similarity of mineralogy with the exception that the clasts usually have a tendency to contain less iron oxide minerals than the matrix. The tuff clastic particles have a composition of "spherulitic," devitrified glass particles, plagioclase, quartz, and hornblende, in a vitrophyric-textured groundmass. Albite (An 8-10) is the most common feldspar found in the matrix of the clastic particles and usually shows alteration to clay minerals. The size of euhedral albite ranges from 0.5 mm to 1.0 mm in length. Albite polysynthetic twinning is generally exhibited in the plagioclase. Euhedral lamprobolite is commonly present with some normally zoned plagioclase (An 40-20). Cristobalite-plagioclase (?) fibers are present as the probable product of devitrified glass particles.

The matrix of the breccia has a vitrophyric texture containing spherulitic, devitrified glass particles,
microcrystalline feldspar, quartz, and hematite. Plagioclase composition is generally slightly more calcic in composition than the composition of the clast plagioclase. Composition of the matrix plagioclase ranges from andesine (An 40) to oligoclase (An 20). Plagioclase twinning according to the Albite and Carlsbad laws is usually present. Cristobalite-plagioclase fibers are frequently present as an alteration product of the devitrified glass particles. Minor amounts of kaolinite and chlorite are found in the groundmass.

**Rhyolite Vitrophyre**

Dark-gray rhyolite vitrophyre occurs occasionally as relatively thin layers between thicker crystalline flows.

Thin section examination of rhyolite vitrophyre displays perlitic and lithophysae structures averaging 0.25 mm in diameter. A faint eutaxitic texture is sometimes exhibited and accentuated by the alternation of glassy and finely crystalline layers.

Biotite flakes, 1.0 mm in size, are included with normally zoned plagioclase (An 40-10), orthoclase, quartz, magnetite, and hornblende, that range in size from 0.50 mm to 2.0 mm. No indication of the
devitrification of glassy material is exhibited.

**Andesite Vitrophyre and Porphyritic Andesite Vitrophyre**

Andesite vitrophyre is a dark-gray, glassy rock, occasionally porphyritic with hornblende, biotite, and plagioclase.

Thin sections examined of the andesite vitrophyre show a hypocrystalline matrix of glass, minor quartz, and feldspar microliths. The commonly exhibited texture is hyalopilitic. Size of matrix crystals are usually smaller than 0.03 mm.

Phenocrysts, when present, can be either euhedral green-brown biotite, green hornblende, or andesine (An 42). Occasionally all three minerals are present in the same rock. Sizes of the phenocrysts range from 0.25 mm to 1.50 mm. Hornblende is more frequently present as pseudohexagonal basal sections containing varying amounts of crystal corrosion and resorption. Andesine usually is Albite and Carlsbad twinned. Normally zoned plagioclase (An 60-40) phenocrysts are rarely present; but when present, are associated with glomeroporphyritic masses of andesine containing a nucleus of granular hypersthene. Inclusions of zircon are sometimes present in the andesine. Accessory minerals occasionally found in the andesite vitrophyres are magnetite and apatite.
Secondary minerals usually present include sericite, chlorite, and iron oxides.

**Hornblende Andesite and Porphyritic Hornblende Andesite**

Red to purple-colored hornblende andesite, occasionally vesicular or amygdular, usually displays weakly developed flow structure by the alignment of phenocrysts.

Thin sections of the hornblende andesite show a porphyritic texture in some varieties with andesine (An 40) and hornblende phenocrysts ranging in size from 0.50 mm to 1.0 mm. The groundmass is usually hypocrystalline containing feldspar microliths and devitrified glass particles in a pilotaxitic texture.

Kaolinitized euhedral andesine occurs only as a phenocryst. The matrix plagioclase apparently is more sodic than the phenocryst plagioclase. Andesine phenocrysts are twinned according to the Albite law and frequently exhibit broken or irregular crystal borders. Some normally zoned plagioclase (An 70-40) is present in minor amounts as a phenocryst. Biotite phenocrysts are almost completely resorbed by magnetite and hematite. The hexagonal outline of former biotite, now containing magnetite-hematite, is the only indication left of some completely resorbed biotite. Euhedral hornblende phenocrysts commonly have dark rims of magnetite and
augite around their crystal borders. Inclusions of magnetite in the hornblende are regularly oriented to produce a schiller texture. Accessory minerals include hypersthene, apatite, and quartz. Secondary minerals frequently present are limonite, hematite, chlorite, and kaolinite. Cavity fillings in the vesicular andesites include quartz and calcite, or cristobalite.

**Dacite Porphyry and Dacite Microporphyry**

Green-black dacite porphyry and microporphyry occurs as flow rock associated with other andesite and rhyodacite flows.

Thin section study of dense dacite microporphyry and dacite porphyry shows a marked similarity of the phenocryst composition in a microgranular matrix. The texture of both porphyries is typically seriate porphyritic with phenocrysts of green-brown biotite, hornblende, and zoned plagioclase. Phenocrysts range in size from 0.5 mm to 1.5 mm. The matrices appear to be composed primarily of holocrystalline plagioclase, biotite, quartz, and epidote in a sub-pilologentic texture.

Zoned euhedral plagioclase phenocrysts show a composition range from labradorite (An 60) to andesine (An 40), with epidotization of the more calcic core.
The matrix plagioclase is microlithic andesine (An 40 ?). Albite and Carlsbad twinning is common in the feldspars. Inclusions of ferromagnesian minerals are usually abundant in the plagioclase. Biotite and hornblende phenocrysts usually display embayed anhedral crystals with magnetite rims. Quartz is nearly always present in the matrix as interstitial rounded grains, but rarely occurs as a phenocryst. Some cristobalite is usually present in all thin sections of the andesites. Secondary minerals include sericite, chlorite, iron oxides, and calcite. Cavity fillings of calcite and chalcedony are frequently present.

Rhyodacite Porphyry

Purple rhyodacite porphyry is a common volcanic rock present in the complex of flows, sills, and dikes of the northern part of the district. Vesicular rhyodacites are occasionally found. Thin section examination of rhyodacite porphyries show a porphyritic texture with a hypocrystalline groundmass. Phenocrysts of andesine (An 36-40), quartz, and hornblende are usually present. Size of phenocrysts range from 0.5 mm to 1.0 mm.

Andesine phenocrysts are usually euhedral and twinned according to the Albite and Carlsbad laws.
Occasionally, normally zoned plagioclase is present. Clay mineral alteration of plagioclase is usually present. Green hornblende phenocrysts show dark magnetite-hematite borders, and commonly crystal schillerization. Replacement of hornblende by augite is generally present.

Matrix composition includes quartz, sanidine, plagioclase microliths, cristobalite, glass, and iron oxides. Secondary minerals frequently present are chlorite, epidote, sericite, kaolinite, and hematite. Vesicles are usually filled with secondary silica minerals.

**Rhyolite, Porphyritic Rhyolite, and Rhyolite Porphyry**

Red to white-colored rhyolite with its porphyritic varieties occurs as small isolated flows or intrusive bodies.

Thin sections of the rhyolites exhibit seriate porphyritic to typically porphyritic textures with microgranular matrices. Porphyritic textures present are either megaporphyritic or microporphyritic, depending on the size of the phenocrysts. Size of phenocrysts range from 0.5 mm to 3.0 mm. Matrix crystal sizes are usually less than 0.5 mm. Phenocrysts commonly present are quartz, andesine (An 46), and augite.
Matrix composition includes alkali feldspar, quartz, and devitrified glass.

Euhedral quartz bipyramidal phenocrysts are usually present in the rhyolites and occur associated with andesine. Plagioclase composition varies within a short range from one rhyolite to another, but andesine is statistically the most abundant feldspar. Albite and Carlsbad twinning is usually present in the plagioclases. Augite frequently is associated with biotite and magnetite and occasionally occurs as a phenocryst. Accessory minerals generally present include polysynthetically twinned sanidine, micrographic intergrowths of plagioclase and quartz, and biotite. Secondary minerals present in the rhyolites are hematite, kaolinite, chlorite, and fracture fillings of chalcedony.
The Quaternary volcanic rocks consist of a relatively small area of basaltic flows and rhyolitic ash or pumice tuffs in the northeast part of the district.

Most of the basalt flows are massive, vesicular varieties containing minor flow breccias. The maximum exposed thickness is probably less than 200 feet. The lower contact was not observed in the field since the flows slope to the southwest and are intermixed with flank extrusions of the central volcanic domes. Individual basalt flows are not separable.

Associated with the basalt flow rock are white, structureless rhyolitic pumice tuffs and unconsolidated ash falls. The weathered tuffs usually are brown-colored due to an excess of oxidized iron particles. The pyroclastic materials underlie the basalt flows in the northeast part of the district and overlie some of the Tertiary volcanic rocks in the north central part of the district. The following section contains a brief petrographic description of the basalt.

**Basalt**

Black, vesicular basalt, usually porphyritic, overlies the Tertiary volcanic sequence. Hand samples
of the basalt from different locations are very similar, with little variation in texture or mineralogy. Thin sections show a pilotaxitic matrix with crystal sizes averaging less than 0.5 mm. Typical matrix includes plagioclase, pigeonite, quartz, and devitrified glass particles.

Euhedral plagioclase phenocrysts, generally tabular, range from labradorite (An 70) to andesine (An 40). Albite and Carlsbad twin lamellae in plagioclase are broad and sharp. Normal and irregular zoning in plagioclase is frequently present. Some diopside phenocrysts are usually present in the basalt. Phenocrysts range in size from 0.5 mm to 1.0 mm.

Matrix pigeonite is colorless and usually anhedral, and occurs with microliths of plagioclase laths (Andesine ?). The pigeonite is occasionally polysynthetically twinned with (100) as the twin plane. Accessory minerals usually included in the basalt are magnetite, apatite, and biotite. Vesicle fillings of secondary calcite and chalcedony are common. Alteration products are absent or very weakly developed.
QUATERNARY ALLUVIUM

Pleistocene and Recent alluvium derived from erosion of the present mountains and deposited by ephemeral streams are divisible into three separate types based on the degree of consolidation and attitude. Alluvial units distinguished in the field consist of older stream terrace deposits, valley fill, talus, and slope wash deposits; and stream deposits.

**Terrace Deposits**

Older alluvium of the district consists of consolidated, subangular to rounded, flat-lying gravel-sand-silt deposits that can be correlated with the present drainage patterns. The terraces are dissected by the existing ephemeral streams of the area and usually stand ten to fifteen feet above the present stream bed elevations. The composition of the terraces is similar to the existing stream deposits with the exception that calcareous cement is present in the terrace deposits, forming a more consolidated deposit. Bedding in the terrace deposits is usually distinctively displayed and individual beds are traceable for several hundred feet in some areas.
Valley Fill, Talus, and Slope Wash Deposits

Most of the valley fill of the district is the result of stream transportation and sorting of material on the adjacent land surfaces. When torrential rains occur, they carry heavy loads of detrital material down the mountain slopes and deposit their loads either as slope wash or valley fill, depending on such variable factors as amount of precipitation and local base-level fluctuations. Most of the talus deposits intergrade with slope wash deposits. The only distinction between talus and slope wash made in this study is that the slope wash represents water-deposited material and the talus does not. Small alluvial fan deposits are sometimes present at the base of mountain slopes. The alluvial fill material, talus and slope wash materials consist of a heterogeneous mixture of gravel, sand, silt, and frequently boulder-sized material. Little sorting of material is evident.

Stream Deposits

Recent stream deposits consist of subangular to rounded gravels, sand, and silt in well-defined channels near the mountain slopes. The channels divide into several channels and spread out into broad sheets further downstream. Some reworked terrace material is
apparently included in the present stream deposits. The stream deposits are well sorted with coarser gravels found near source areas and finer sands and silts further downstream.
ROCK AGES AND CORRELATION

The metamorphic rocks found in the Silver district have tentatively been assigned to the Mesozoic Era by Wilson (1962) on the basis of correlation with the Triassic-Jurassic Barranca formation of Sonora, Mexico. McKee (1947) recognized nearly 2,000 feet of Cambrian, Devonian, Mississippian, Pennsylvanian (?), and Permian clasts in a Cretaceous (?) sedimentary sequence in the New Water Mountains, forty miles northeast of the Trigo Mountains. He based the rock ages found in the Cretaceous (?) sequence on fossil evidence and suggested that central western Arizona was covered with marine waters during parts of the Paleozoic Era. Many feet of claystones, siltstones, sandstones, and limestones are described by McKee (1947) from a carefully measured stratigraphic section. The sediments are possibly similar to the pre-metamorphosed schists, argillites, and phyllites of the Silver district. King (1939) thought that geosynclinal sedimentation during the Triassic and Jurassic Periods in Sonora, Mexico, was linked with sedimentation in Nevada, California, and parts of southwestern Arizona. This conclusion agrees with the conclusions reached by Tenney (1930) and Eardley (1949).
However, Wilson and Moore (1959) extended the length of deposition in the Sonoran Geosyncline to the Lower Cretaceous Period for southwestern Arizona. On the evidence presented, it seems probable that sedimentation during the Mesozoic Era in Sonora, Mexico, extended as far north as Yuma County, Arizona, and included parts of the Trigo Mountains. If the Trigo Mountains metamorphosed sediments can be correlated with the Cretaceous (?) sequence of the New Water Mountains, then a tentative Cretaceous age can be assigned to the metamorphic rocks of the Silver district. The fact that the metamorphic rocks of the Silver district are highly schistose probably has no relationship to their age, but rather is related to their nearness to the granodiorite intrusive. There is no logical reason for attempting to correlate the Silver district schists with schists of Precambrian age of northwestern Arizona on the basis of similar appearance. As further proof that the New Water Mountains sedimentary sequence might represent a correlative unit with the Trigo Mountains metamorphic rocks, Wilson (1962) reported that the New Water Mountains sequence locally grades into schistose rock where it has undergone metamorphism near a granitic intrusion. It is suggested that the schists of the
Silver district were formed as a result of a granodiorite intrusion.

Gneissoid granite found as isolated, small exposures in the metamorphic complex of the district, is thought to represent Precambrian basement rock similar to the granite dated, using rubidium–strontium methods, from the Hualpai Mountains of Mohave County, Arizona, (Wasserburg and Lamphere, 1965). Similar rubidium–strontium ages for granite gneiss from Chloride, Mohave County, Arizona, were obtained by Giletti and Damon (1961). The gneissoid granite of the district produces no thermal effects or cross-cutting relationships to the schistose rocks. It is thought that the Cretaceous (?) sediments were deposited on the Precambrian granite basement rocks; however, good exposures of the basement rocks are lacking. Until the basement rocks can be dated using radiometric methods, a tentative pre-Mesozoic age should be assigned to them; but in all probability, they will prove to be the same age as the granites from Mohave County.

Intrusive granodiorite of the district can be dated as Upper Cretaceous, if related to some of the other plutonic rocks of Yuma County. No dating of the district granodiorite has ever been made, but a tentative age can be assigned on the basis of radiometric
dates obtained from related (?) intrusive rocks of the county. Quartz monzonite from near Yuma gave a rubidium-strontium age of 73 million years (Wasserburg and Lanphere, 1965) corresponding to the Upper Cretaceous Period, according to Kulp (1961). The Laramide hypabyssal plutonism of the district is closely associated with volcanism, similar to other northwest trending plutons of Arizona (Damon, 1965). Composition of the igneous rocks and the dates determined for Laramide plutons usually are closely associated. In the Roskruge Mountains of Pima County, Arizona, Bikerman (1964) found rhyodacite ash flows to be temporally and spacially related to Laramide granodiorite plutons. Whether the tuffs of the Silver district are temporally or spacially related to the granodiorite is not directly known; however, crystal-vitric tuffs of Yuma County have been dated using potassium-argon methods and ages of 26.3 million years were obtained (Damon, 1965). This might indicate a period of approximately 47 million years between the initial intrusion and the probable later stages of plutonism marked by pyroclastic volcanism, but direct evidence is lacking. The thick sequence of volcanic flows, dikes, and sills of the district would probably have to be included during the period of granodiorite intrusion and pyroclastic
volcanism, placing it somewhere in the Upper Cretaceous Period or Lower Tertiary Period.

Ages for basalts of the Colorado River area, using potassium-argon methods, range from 1.2 million years to 10.6 million years (Damon, 1965). If these basalts were formed during the same time as the basalt of the Silver district, then a probable Pliocene-Pleistocene age can be assigned. However, the basalts of the district have not been radiometrically dated and only a tentative age can be given for them at this time.
STRUCTURE

The general structural features of the Silver district seem to be closely associated with igneous activity or crustal disturbances. The most easily recognized structural features in the district are the predominant northwest-trending normal faults that are locally mineralized. Northwest faults strike at relatively small angles to the regional structural trend of the metamorphic rocks. Dips of the faults are generally steep to the northeast or southwest, with northeasterly dips being more common. Northwest-trending faults are observed to be displaced short distances by later transverse faulting. Vertical displacements are not usually resolvable, but normal faulting in the vicinity of the Padre Kino mine has lowered the hanging wall, relative to the foot wall, nearly 400 feet as indicated by offset bedded tuffs. The faulting of the district has produced horst-graben type structural relationships, in the central part of the district primarily, where volcanic rocks are downfaulted in relation to the intrusive rocks. The prominent fault extending north and south of the Red Cloud mine, called the Red Cloud fault (Thompson, 1925), is paralleled on the east by the
McNeal fault (Thompson, 1925) with the intervening graben containing andesite breccia and bedded tuffaceous rocks. The graben has been downfaulted, in relation to the granodiorite footwalls, for an estimated distance of 200 feet.

Transverse faults striking N. 60-75° E., offsetting the primary northwest faults, have in some areas occurred simultaneously or later than the northwest faults; but prior to mineralization because the intersecting faults have formed areas of ore deposition. Occasional offsetting of mineralized veins occurs along the transverse faults indicating renewed movement after ore deposition along the transverse directions. Minor brecciation of vein material is present as additional proof of post-mineralization movement along the fault zones. Branching faults from the primary northwest faults strike N. 25° E. and dip northwest or southeast at steep angles. They contain some mineralization, but not as great as the north and northeast-trending faults. Wilson (1951) noted northeast and northwest fissures along which little movement had occurred. These fissures are numerous in the district and some do indicate major movement has occurred, contrary to what Wilson (1951) reported.
Iron-stained, slickensided fault surfaces, occasionally containing gouge or silicified, iron-manganese-stained, brecciated wall rock are prominently exhibited along fault zones. Striations, when observed on fault surfaces, indicate a down-dip direction of movement. Polished, rolling, fault plane surfaces are well displayed in the fourth level of the Clip mine of the northeast part of the district along the Revelation fault.

The normal faulting of the district is thought to be the result of relaxation of strong northeast-southwest compressive forces that are responsible for pre-metamorphism folding. Probably shear movements along northeast-southwest axes, determined by slip parallel to the surfaces of high resolved stress, occurred also as a result of compression. The shear movements would occur during compression and the normal faulting during relaxation of compressive forces, probably accompanied with intrusion of granodiorite. No field evidence is found to indicate the amount of strike-slip movement along shear planes, but lateral displacements of schists of several hundred feet along northeast directions do occur in the district. Folding in the metamorphic complex generally parallels the northeast
shear trends. Normal faulting probably continued intermittently from the beginning of compressive force relaxation in the Late Cretaceous–Early Tertiary until Quaternary time.

Gneissic and schistose structure is frequently displayed in the metamorphic rocks of the district. Folds with northeast trends are discordant to the granodiorite contact and the structural trend of the intrusive and normal faulting to the northwest. The strike of fold axes, generally parallel to the strike of the schistosity, is about N. 20° E. with dips to the southeast and northwest at 50° to 70°. Local variations in attitude are common, but the major structure persists in the metamorphic complex throughout the district. The folding in the schists is apparently not related to the emplacement of the granodiorite because of the discordant structural trend to the igneous contacts and represents an early stage of deformation prior to the emplacement of the granodiorite. Lineation in the metamorphic rocks is exhibited by the alternating shape of light and dark-colored minerals and commonly trends parallel to the regional northeast fold axes.

Jointing in the area has reached far greater development in the granodiorite intrusive than in any of
the other rock types of the district, but is not easily noted due to the highly eroded condition of exposures. In some parts of the granodiorite, jointing is entirely lacking or not visible. No single jointing system appears to prevail over any great area; however, two stronger systems appear to be more consistent than any others. One joint set strikes N. 60°-70° E., with dips of 40 to 65 degrees to the southeast (transverse to the general trend of the stock), and the other strikes N. 80° W., with dips averaging 35 degrees to the southwest. Another jointing system that is inconspicuously displayed in the field, but relatively well on aerial photographs, trends parallel to the granodiorite ridge-tops with a strike of about N. 30° W. and dips steeply to the east or west.

In the metamorphic rocks of the district fold axes strike to the northeast, but in the volcanic rock sequence minor fold axes strike northwest. Most of the folds in the Tertiary volcanic rocks are too indistinct, containing gently plunging axes, or the rocks lack primary layering to determine their attitudes. Folding is also hard to determine in the field because of cross-cutting volcanic rocks within the folded flow rocks. One fold axis in the volcanic rock sequence, near the
Red Cloud mine, strikes N. 70° W. with a gentle plunge to the southeast. The volcanic rocks strike predominantly to the northwest and dip northeast at 10 to 30 degrees.

Most of the centers of Tertiary volcanic eruption are concealed by later flows or have been removed by erosion. A few plug domes are still present in the district, but seem to be relatively too small to account for all of the volcanism present. Probably much of the volcanic rock was extruded from concealed fissures. Andesite breccia constitutes the lowest exposed volcanic rock in the sequence and is locally found in the cores of eroded anticlinal structures. Later flows tend to be more rhyolitic in composition and occur along eroded anticline flanks.

Small, nearly vertical aplitic or pegmatitic dikes occur along the northern margin of the granodiorite–metamorphic rock contact zone and strike generally to the northwest or north. The dikes probably formed through the injection of granodioritic magma into primary joints developed along the margins of the consolidating granodiorite stock.

Tertiary lake beds existed in the downfaulted grabens of the district, with deposition of pyroclastic
rocks during the later stages of volcanism being common. West-flowing streams were probably blocked by volcanic rock dams sometime during the Tertiary Period because evidence of these dams still remains in some of the larger drainages of the district.

Natural rock tanks are found along some of the stream channels where bedrock is exposed below the sediments. The rock tanks are depressions in the bedrock and include potholes, scour hollows, and plunge pools probably caused by stream gradient changes.

Peculiar erosional features are usually present in the Tertiary volcanic rock sequence such as natural niches or small caves. The niches are probably due to the removal of certain joint (?) blocks by disintegration or possibly by a process of cavity formation in which a boulder is dislodged in a particularly porous area of volcanic rock. Niches are enlarged inward by crumbling of the backwall and scaling of the roof due to rainwater seepage through the roof.
ORE DEPOSITS

Hypogene mineralization, or deposition from ascending thermal solutions, probably formed the primary vein deposits of the Silver district along pre-existing fault zones. The deposits are mesothermal since they share many common characteristics with other silver-lead-zinc veins of the southwestern United States classified as mesothermal. Lindgren (1933) reports that mesothermal deposits are usually formed under a temperature range of 175 to 300 degrees Centigrade and a pressure range of 140 to 400 atmospheres. Granodiorite intrusion into the Cretaceous (?) meta-sedimentary rocks and possibly pre-intrusive andesites during the Upper Cretaceous-Lower Tertiary period, released differentiation products during later stages of crystallization and deposited metal-bearing solutions along weakened crustal zones. Andesite apparently was formed at an early stage of volcanism prior to the intrusion of granodiorite because brecciated, mineralized andesite is present along the Red Cloud fault zone. Fault zones containing brecciated volcanic rock and granodiorite produced open spaces favorable for deposition of minerals due to the rapid change in pressure and temperature of the metal-bearing solutions. Most of the ore deposits have been
affected by oxidation and later supergene action.

The paragenesis of the ore deposits is difficult to determine because of the highly oxidized state of the minerals and the formation of secondary carbonates and sulfates. It appears that the hypogene mineralization was pyrite followed by sphalerite, and argentiferous galena. Quartz and calcite seem to have been deposited simultaneously with the metallic sulfides; however, relationships are not always clear. There is some indication from ore samples examined that quartz and calcite of a much later period of deposition, not related to the metallic sulfides, occurred in the same veins. Cross-cutting quartz and calcite deposition is frequently present in the veins of the district. The paragenesis of the metallic sulfides was determined through polished section study of the sparse unoxidized vein material.

The deposits are well-defined fissure veins occurring in the steeply dipping northwest-trending fault zones. Vein materials generally have straight, well-defined foot and hanging walls of granodiorite, metamorphic rocks, or volcanic rocks. Some pinching and swelling along the fissure veins is observed, but apparently does not form important open space zones for ore deposition. The fault zones, whether mineralized or
barren, can usually be traced on the surface for distances of several hundred feet because of the development of resistant prominent silicified or carbonatized fault breccia ridges. Metallization is not always associated with the silicified-carbonatized fault zones; but rather occurs in irregular ore shoots (in the fault zones) containing an assemblage of metallic sulfides, carbonates, oxides, and sulfates with calcite, quartz, and barite, controlled by the intersection of northwest faults with transverse faults. Trace amounts of lead, silver, copper, zinc, and other metal ions can usually be detected in the silicate and carbonate rocks of mineralized fault zones. Table I contains a list of the metallic ions present in the carbonates and silicates associated with silver-lead-zinc veins of the district. Trace analysis of fault zone carbonates and silicates is thought to be a promising method of locating ore shoots along fault zones in the Silver district (See Table I).

Scheelite in aplitic dikes near the granodiorite contact with metamorphic rocks in Arrastra Wash is related to the granodiorite intrusion as are the silver-lead-zinc veins of the district, but absence of faulting in the area has apparently limited mineralization to scheelite-bearing dikes. However, tungsten is
TABLE I

ELEMENTS PRESENT IN TRACE AMOUNTS IN CARBONATE AND SILICATE ROCKS ASSOCIATED WITH MINERALIZATION DETERMINED BY X-RAY FLUORESCENCE

<table>
<thead>
<tr>
<th>Mine or Prospect</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrastra Wash prospect</td>
<td>Pb, Ag, Cu, Ba, Sr, Fe, W</td>
</tr>
<tr>
<td>Amelia mine</td>
<td>Pb, Ag, Cu, Ba, Sr, Fe</td>
</tr>
<tr>
<td>Chloride claim</td>
<td>Pb, Ag, Cu, Zn, Fe, Cs, Mo, W</td>
</tr>
<tr>
<td>Clip mine</td>
<td>Pb, Ag, Cu, Zn, Fe, Ba, Sr, Cd</td>
</tr>
<tr>
<td>Cash Entry claim</td>
<td>Pb, Va, Sr, Se, Sb, Cs</td>
</tr>
<tr>
<td>Black Rock mine</td>
<td>Pb, Ag, Cu, Zn, Au, Sr</td>
</tr>
<tr>
<td>Black Rock claim</td>
<td>Pb, Ag, Cu, Zn, Au, Mn, Fe, Sr</td>
</tr>
<tr>
<td>Mandan claim</td>
<td>Pb, Ag, Zn, As, Sr, Mn, Fe</td>
</tr>
<tr>
<td>Mendevil claim</td>
<td>Pb, Ag, Zn, Cu, As, Ba, Sr</td>
</tr>
<tr>
<td>Padre Kino mine</td>
<td>Pb, Ag, Zn, Cu, Mn, Fe, Sr, Ba, W</td>
</tr>
<tr>
<td>Padre Kino claim</td>
<td>Pb, Ag, Zn, Cu, Fe, Ba, Sr, Cd</td>
</tr>
<tr>
<td>Papago mine</td>
<td>Pb, Ag, Zn, Mn, Fe, Mo</td>
</tr>
<tr>
<td>Papago claim</td>
<td>Pb, Zn, Cu, Sr, Mn, Fe</td>
</tr>
<tr>
<td>Princess mine</td>
<td>Pb, Ag, Zn, Cu, Ba, Sr, Fe</td>
</tr>
<tr>
<td>Silver Glance mine</td>
<td>Pb, Ag, Zn, Cu, Se, Sr, Ba</td>
</tr>
<tr>
<td>Silver King mine</td>
<td>Pb, Mo, Cu, Zn, Ba, Sr, Fe, Mn</td>
</tr>
<tr>
<td>South Geronimo claim</td>
<td>Pb, Ag, Zn, Cu, Mo, Au, Ba, Fe, Sr</td>
</tr>
<tr>
<td>South Rioho claim</td>
<td>Pb, Ag, Zn, Cu, Rb, Sr, Fe</td>
</tr>
<tr>
<td>North Rioho claim</td>
<td>Pb, Ag, Zn, Cu, Ba, Se, Fe</td>
</tr>
<tr>
<td>North Geronimo claim</td>
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</tr>
<tr>
<td>Red Cloud mine</td>
<td>Pb, Ag, Zn, Cu, Mo, As, Sr, Se, Mn, Fe, W</td>
</tr>
<tr>
<td>Revelation claim</td>
<td>Pb, Zn, Cu, Ba, Sr, Mn, Cd, Fe</td>
</tr>
<tr>
<td>West Black Rock claim</td>
<td>Pb, Zn, Ag, Cu, Au, As, Se, Sr, Mn, Fe, Ba</td>
</tr>
</tbody>
</table>
present in most oxidized veins of the district and not limited to aplitic dikes only. Most of the tungsten occurs with wulfenite, possibly in the scheelite-powellite series associated with silver-lead-zinc mineralization. Some tungsten occurs in trace amounts in silicates associated with mineralized zones.

Cross, Shaw, and Scheifele (1960) noted that the occurrence of fluorite-barite veins trends across Arizona in a defined zone including southern Yuma County. Much fluorite and barite is found in the district associated with mineralized fault zones.

**Hypogene Alteration**

With the exception of frequent brecciation, the granodiorite and metamorphic rocks of the district appear to be relatively unaltered near fault zones. Little or no chloritization or sericitization of wall rock in the fault zones is readily apparent without the aid of thin section study to show the frequent and typical alteration of biotite and feldspar to chlorite and sericite, and the addition of coarse, secondary quartz. Generally, the hypogene alteration can be classified as belonging to the argillic alteration facies of Burnham (1962). In most of the fault zones carbonatization and silicification is quite pronounced
within the brecciated rock zone. No detailed petrographic study was made of wall rock alteration other than examination of hand samples of the volcanic wall rocks. Of the samples examined, chloritization and sericitization seemed to be absent, but petrographic study would probably show alteration similar to that found in the coarser-grained igneous wall rock.

**Supergene Mineralization**

Oxidation has been an important event in the formation of the present vuggy, cellular, limonitic ore bodies of the district. Oxidation of primary pyrite was undoubtedly responsible for the production of ferric sulfates and sulfuric acid in the deposits with the resultant formation of metallic sulfates. The pyritiferous areas of the deposits are now indicated by the presence of cellular, limonitic masses, partially filled with quartz.

Zinc sulfide in the presence of sulfuric acid is fairly soluble, moderately mobile, and usually rapidly dispersed as zinc sulfate (Lindgren, 1933). No zinc sulfide is now present in the oxidized ore deposits of the district. Zinc occurs in the vein material as zinc carbonate. Lead is only slightly mobile (Hawkes and Webb, 1962) and once sulfates or carbonates are formed,
it becomes quite stable (Lindgren, 1933). Lead is found in the vein material of the district (occasionally) as lead sulfide and frequently as lead oxide, lead carbonate, or lead sulfate. Silver sulfides have been oxidized to silver chlorides of low solubility through reaction with ferric sulfate and halogen solutions of undetermined origin. The silver chlorides, bromides, and iodides occur only in the most strongly oxidized zone. Lindgren (1933) reports that silver supergene deposition is rarely observed in silver deposits of the southwestern United States. Molybdenum, in the form of wulfenite, is usually present in the oxidized zone of the silver-lead-zinc veins. It is doubtful that molybdenum forms zones of supergene enrichment in the fissure veins of the Silver district. Hess (1924) found that wulfenite deposition extends only as deep as the zone of oxidation and Mitchell (1945) reported that there is no usual change in the total molybdenum content from the oxidized zone to the sulfide zone. Lead is apparently an effective precipitant of minor molybdenum in the oxidation zones of deposits although molybdenum in wulfenite is closely associated with "limonite." Actually molybdenum is fixed with "limonite" through adsorption of molybdenum ions on the iron oxide (Jones, 1957).
The oxidation zone in the Silver district extends to at least 500 feet in the Red Cloud mine, and possibly 700 feet. The water table is usually found at a depth of 500 feet in the Red Cloud mine. Oxidation below the present water table can probably be explained by a change in water table level or by possible tectonic movement of oxidized parts of mineralized areas to a position below the water table.

Age of Mineralization

The silver-lead-zinc deposits of the district seem to have a common origin and apparently are younger than the granodiorite intrusive. The period of mineralization is tentatively considered Early Tertiary, although no age determinations using radiometric dating methods have been made. Basis for an Early Tertiary age determination for mineral deposits is an assumed relationship with ore deposits of the Castle Dome district found approximately twenty-five miles east of the Silver district. In the Castle Dome district similar silver-lead mineralization occurs and lead isotope ratios for galena from the Sonora mine give "modern" ages related to the accumulation of Tertiary volcanic rocks (Mauger, Damon, and Giletti, 1965). In the Silver district there are no known major intrusive bodies other than the
granodiorite stock that could have been sources of the metalliferous hydrothermal solutions forming the ore deposits. It is suggested that mineralization could have occurred at some time during the late crystallization stages of the granodiorite intrusive, probably contemporaneously with Tertiary mineralization in the Castle Dome district, although mineralization at some later date not associated with granodiorite intrusion cannot be ruled out until a further investigation is made.
MINERALS OF THE SILVER DISTRICT

Minerals genetically related to the formation of the ore deposits of the Silver district, as well as some of the other minerals of interest, will be briefly described in the following sections. Common rock-forming minerals have been omitted if they have no apparent economic importance or bearing on the origin of the ore deposits. Most of the minerals described have no economic importance, but because they are genetically related to the ore minerals, will be described. When possible, identification of minerals was made in the field. Oxidized minerals, carbonates, and sulfates were identified in the laboratory using either chemical analysis or X-ray fluorescence techniques.

X-Ray Fluorescence

X-ray fluorescence was used as a technique to determine trace elements in carbonate and silicate rocks and also as a means of mineral identification of oxides, carbonates, and sulfates from mineralized areas of the district.

For all X-ray analyses, a General Electric XRD-5 spectrometer with a molybdenum target Machlett AEG-50T tube, operated at 40 KVP and 23 ma, was used. A
continuous recording graph was made of each sample analyzed to obtain a permanent record for further comparative purposes. From the graphs a future rough semi-quantitative analysis could also be made.

**Primary Minerals**

**Gold, Au.** Traces of gold occur associated with the silver-lead-zinc ores of the district or in small non-related quartz veins. Flattened scales of very fine gold can be found associated with magnetite sands in some of the dry washes of the Trigo Mountains.

**Galena, PbS.** The sulfide of lead is the chief primary ore mineral found in most of the veins of the district, occasionally displaying strong oxidation effects or alteration to anglesite. Galena is one of the few sulfide minerals of the district of which polished section study could be made. It frequently occurs as cubes, or cubo-octahedrons in clusters, as massive fissure fillings, vug linings, or cellular linings. Galena is generally found associated with quartz, calcite, and fluorite.

Polished section study of galena usually exhibits triangular cleavage pits, frequently in rows parallel to each other, as a result of cubic or octahedral cleavage. The sides of cleavage pits are usually parallel to the
cleavage cracks and are easily observed after hydro-chloric acid etching. Acid etching occasionally reveals the presence of lamellar and deformation twinning. Microscopic inclusions of rounded, single grains of chalcopyrite in galena are usually present, but in small amounts. They could be accidentally included during the crystallization of galena, but probably represent exsolution products of a galena-chalcopyrite solid solution formed as the temperature of crystallization decreased (Cameron, 1961). Edwards (1954) found that inclusions or emulsion intergrowths are usually rounded blebs, with sharp, smooth boundaries, and nearly always occur as single crystals, similar to those observed in the Silver district galena sections. Finely disseminated argentite grains are present in the galena, but are not apparent in polished sections until treatment with dilute nitric acid. The argentite occurs as minute blebs oriented along the (111) planes of the galena.

Alteration of galena to anglesite is frequently present and usually occurs along the cleavage cracks. Covellite rim replacement is nearly always present and shows extensions into the galena crystal. Copper substitution for lead is facilitated by copper sulfate solutions diffusing into the galena lattice, exchanging
ions, and diffusing out as lead sulfate, precipitating the lead sulfate on the exterior of the crystal. The condition of replacement that must be made is an intermittent supply of oxidizing solution (Edwards, 1954).

Trace elements found in galena using X-ray fluorescence include copper, selenium, arsenic, antimony, zinc, silver, cadmium, and manganese. Arsenic, manganese, and cadmium are thought to be trace elements left by sphalerite upon alteration to smithsonite. Wurtzite, the less common, high temperature, hexagonal polymorph of sphalerite is reported to carry trace amounts of manganese and cadmium in its lattice, while arsenic can be a common impurity of sphalerite (Deer, Howie, and Zussman, 1962). The other identified trace elements are probably present as inclusions in galena and do not represent ions incorporated in the crystal lattice. Earley (1950) reported the existence of a solid solution series of selenium and sulfur in galena, but such a series probably does not exist in the galena of the district.

**Argentite, Ag₂S.** The sulfide of silver occurs only as microscopic inclusions along galena (111) planes. Acanthite, the lower temperature, orthorhombic form of silver sulfide is thought to be present rather than the
higher temperature, isometric form. Acanthite (?) is nearly always found associated with quartz, calcite, and fluorite.

**Fluorite, CaF₂.** Dense, massive forms of green or purple fluorite occur frequently in the silver-lead-zinc veins of the district. Occasionally, cubic or octahedral crystals occur. Both forms are found associated with quartz, calcite, and sometimes with barite and manganese oxides. Green fluorite attains a more pinkish color in veins exposed to greater oxidation or light by mining.

**Calcite, CaCO₃.** White, massive calcite or black, manganiferous calcite is usually present in ore deposits of the district. Rhombohedral or scalenohedral crystals occur with masses of barite, quartz, and fluorite. Black calcite analyzed with X-ray fluorescence indicated that trace amounts of lead, zinc, copper, iron, manganese, strontium, and rubidium were present in specimens associated with silver-lead-zinc veins. Carbonate rocks of the Coer d'Alene district of Idaho, particularly black calcite, was found to be associated similarly with silver, lead, and zinc sulfides (Deer, Howie, and Zussman, 1962). Clear or white calcite seems to be from a later period of carbonate deposition, free from most trace elements found in the black calcite.
Barite, $\text{BaSO}_4$. Barite is one of the more common gangue minerals and occurs either associated with silver-lead-zinc minerals or as an independent vein deposit with no associated minerals. It usually occurs as white or brown columnar or platey masses. Barite samples analyzed with X-ray fluorescence indicated the presence of varying amounts of strontium. Celestite probably occurs in a continuous solid solution with barite and it is not possible to form a separation of the two minerals without specific gravity methods.

Celestite, $\text{SrSO}_4$. Celestite occurs only in solid solution with barite being found as a gangue mineral in silver-lead-zinc veins or as an independent solid solution mineral in veins free of other minerals.

Quartz, $\text{SiO}_2$. Quartz is probably the most abundant gangue mineral of the district and is nearly always found associated with calcite, barite, and fluorite in silver-lead-zinc veins. It also occurs as cavity linings in volcanic rocks, or as cryptocrystalline pseudomorphs after wood.

Prisms of quartz crystals ranging in length from 0.25 inch to 0.50 inch found in vug linings of veins of the district are common. Massive varieties and fine
veinlets of quartz are also quite abundant in veins. Occasional amethyst vug linings are present in some of the fissure veins.

 Translucent, white to gray cryptocrystalline quartz, filling cavaties in volcanic rocks are frequently present. Pearly to resinous common opal and quartz pseudomorphs after wood are relatively abundant along the western border of the silver district.

 Schecelite, CaWO₄. The tungstate of calcium is comparatively rare to the Silver district and limited to granodiorite-schist contact areas in the southern part of the district where aplitic dike rocks and quartz veins carry traces of scheelite. It usually is associated with calcite and quartz and occurs as scattered, brown, fine crystals.

 Tourmaline, H₉Al₃·(B,OH)₂Si₆O₁₈. The complex silicate of boron and aluminum occurs usually as a slender, black, prismatic crystal in pegmatite veins along the periphery of the granodiorite intrusive. It is usually associated with quartz.

 Actinolite, Ca₂(Mg,Fe)₅Si₈O₂₂. Bright-green to dark-green, fibrous or bladed masses of actinolite are
found in many of the rocks of the contact metamorphic zone.

**Secondary Minerals (Oxides)**

*Massicot, PbO.* Yellow, earthy, lead oxide of secondary origin from galena is found associated with cerussite and smithsonite and occurs in minor amounts in the oxidized zone of deposits.

*Plattnerite, PbO₂.* The massive black lead dioxide, probably formed from galena, is a relatively rare oxidation product of lead sulfide in the district. It is usually concealed by manganese oxide minerals making its identification difficult.

*Minium, Pb₃O₄.* Red, pulverulent, earthy minium is found in small amounts with massicot in the strongly oxidized parts of silver-lead-zinc fissure veins.

*Hematite, Fe₂O₃.* Hematite is found occasionally in the silver-lead-zinc veins as red, ocherous vug linings, cavity fillings, or small fissure fillings. Some hematite apparently forms as a result of a metasomatic replacement in volcanic rock exposures located near fault zones. Polished section study of hematite samples display concretionary zoning or colloform texture with
occasional frambooidal textures. Edwards (1954) found colloidal and frambooidal textures to be indicative of colloidal deposition, but suggested that they be used as a criteria of colloidal deposition only when other sedimentary features are detected in the same rock. From the field evidence observed in the Silver district, it is thought that the hematite is not a colloidal ore, but rather a replacement mineral in volcanic rocks associated with hydrothermal alteration near known fault zones.

*Magnetite, FeO*(Fe₂O₃).* Magnetite is a common mineral in many of the metamorphic rocks of the district, usually occurring as small or microscopic octahedrons. Magnetite sands can be found in most of the dry washes of the Trigo Mountains. Magnetite present in the metamorphic rocks of the area is probably due to the alteration of ferric oxide cement or limonitic staining of sediments during thermal metamorphism. Deer, Howie, and Zussman (1962) report that an intermediate stage of hematite is probably present during metamorphism of limonitic stained sediments before magnetite is formed.
Limonite, approximately $2\text{Fe}_2\text{O}_3\cdot(3\text{H}_2\text{O})$. Limonite commonly occurs as an oxidation product of pyrite (?) in the silver-lead-zinc veins of the district. It always occurs as yellow or yellow-brown, earthy masses lining vugs, or as cavity fillings with quartz. Wulfenite is frequently associated with limonite.

Pyrolusite, $\text{MnO}_2$. Gray to black, partially crystalline pyrolusite occurs in most of the oxidized zones of silver-lead-zinc veins. It is usually found associated with iron oxides and other manganese oxide minerals. Pyrolusite occurs in manganese veins independent of silver-lead-zinc mineralization in the northern part of the district. Jones (1919) regarded pyrolusite deposits of Imperial County, California, to be formed as the result of decomposition of primary manganite deposits. It can not be determined if alteration of manganite was responsible for the formation of the Silver district manganese deposits; however, pyrolusite is certainly more abundant than manganite.

Psilomelane, hydrous $\text{MnO}_2$. Gray to black, massive, and occasional botryoidal psilomelane occurs associated with pyrolusite and manganite. It usually is present in fault fissures and fault breccia as a
replacement mineral in volcanic rocks. Psilomelane occurs associated with silver-lead-zinc minerals or in independent manganese veins associated with other manganese oxide minerals.

**Manganite, MnO·(OH).** Black, wedged-shaped or fibrous crystals of manganite are occasionally present with other manganese oxide minerals in cavities or fissures. Manganite is rarely present in massive psilomelane cavities. Manganese oxides found in the northern part of the district as fissure fillings in fault zones are apparently related to the time of silver-lead-zinc mineralization in other parts of the district. The possibility exists that the time of manganese mineralization may be later than the silver-lead-zinc mineralization because younger volcanic rocks are present as the wall rock of the fissure veins of manganese minerals than those present in the silver-lead-zinc veins. No known occurrence of silver, lead, or zinc minerals has been reported from the northern manganese veins. The manganese minerals are nearly always associated with calcite and quartz. It is possible that supergene enrichment of hypogene manganiferous calcite may be responsible for the formation of the veins of manganese, in which case they would be related to the
manganese deposits of Imperial County, California, reported by Hadley (1942).

**Chromite, FeO\cdot(Cr_2O_3).** Black, disseminated grains of chromite are occasionally found in some of the schistose metamorphic rocks of the Trigo Mountains as detrital particles in dry washes or as mineral segregations in muscovite schist. The origin of chromite in some metamorphic rocks is probably due to an incorporation of detrital chromite particles in sediments prior to metamorphism.

**Gahnite, ZnAl_2O_4.** Green zinc spinel is sometimes found in schistose metamorphic rocks of the Silver district as finely disseminated, microscopic particles. Deer, Howie, and Zussman (1962) report that considerable substitution of iron and magnesium for zinc occurs and that there are many gradations between magnesian gahnite and pure zincian spinel.

**Wulfenite, PbMoO_4.** Wulfenite occurs frequently in several of the silver-lead-zinc fissure veins as red, square or tabular crystals. Occasional white crystals are found. Yellow wulfenite has been reported from the Castle Dome district (Foshag, 1919), but none was found in the Silver district veins. Red, dipyramidal crystals
of wulfenite are abundant in a few of the ore shoots, but statistically they constitute a rare occurrence in the district. Wulfenite is found only in the oxidized zone of mineral deposits in cavities as linings or as fracture fillings associated with limonite and occasionally with vanadinite.

**Vanadinite, \((\text{PbCl}) \cdot \text{Pb}_4 \cdot (\text{VO}_4)_3\).** Small, red to red-brown, prismatic crystals of vanadinite occur in several of the silver-lead-zinc veins of the area. It is generally found as cavity fillings or vug linings associated with wulfenite.

**Secondary Minerals (Carbonates)**

**Cerussite, \(\text{PbCO}_3\).** The white carbonate of lead is a common alteration product of galena and usually occurs as crustose deposits along fractures or as scattered crystal aggregates associated with anglesite and lead oxides in cellular masses or vug linings in the oxidized zone of ore deposits.

**Smithsonite, \(\text{ZnCO}_3\).** The white to greenish-white carbonate of zinc is one of the most abundant zinc minerals of the Silver district formed from the alteration of primary sphalerite. Smithsonite usually occurs as earthy masses lining vugs or as cavity fillings in
the oxidized zone of silver-lead-zinc deposits. It is usually associated with cerussite, pyrolusite, and limonite.

**Siderite, FeCO₃.** Rhombohedral brown carbonates occasionally are present in veins of the district; however, they are not pure siderite, but rather impure iron calcites containing traces of manganese. Deer, Howie, and Zussman (1962) report that a complete solid solution series exists between siderite and rhodochrosite, and siderite and magnesite. It is thought that the siderite of the Silver district is most likely an impure iron calcite and that solid solution series with other minerals do not exist.

**Rhodochrosite, MnCO₃.** Pink rhodochrosite is rarely found in the silver-lead-zinc deposits of the district. When it is found, it occurs in very small quantities as a granular crystal associated with manganese oxide minerals. Thin section study of rhodochrosite indicated an alteration or replacement of pyrolusite to rhodochrosite was strongly developed. The rhodochrosite found in the district is probably a manganese-bearing calcite rather than pure rhodochrosite because little manganese was present in analyzed
samples; however, for practical reasons the mineral was reported as being rhodochrosite.

**Malachite, CuCO$_3$·(CuOH)$_2$.** Minor green carbonate of copper is occasionally present as encrustations or disseminated particles in silver-lead-zinc deposits. In the southern part of the district malachite occurs as a coating or as veinlets in massive quartz veins where it is associated with azurite and limonite.

**Azurite, 2CuCO$_3$·(CuOH)$_2$.** The blue carbonate of copper is usually found in lesser amounts with malachite and limonite in quartz veins of the southern part of the district.

**Secondary Minerals (Sulfates)**

**Anglesite, PbSO$_4$.** The white sulfate of lead is found in small amounts as coatings in fissure veins or as cavity fillings in oxidized zones of silver-lead-zinc veins. It is commonly associated with oxidized galena and cerussite.

**Gypsum, CaSO$_4$·2(H$_2$O).** Minor amounts of gypsum and anhydrite occur in the silver-lead-zinc veins of the district. The gypsum has probably formed from the
hydration of primary anhydrite, but its occurrence is so limited that detailed study was not possible.

**Secondary Minerals (Chlorides)**

**Cerargyrite, AgCl.** Massive to crustiform, purple-brown, cerargyrite occurs in the oxidized part of silver-lead-zinc veins of the district in an isomorphous series of silver chloride-bromide-iodide minerals. "Cerargyrite" was used to identify the series of mineral rather than to attempt a separation and name individual species. Cerargyrite is found in disseminated masses associated with oxidized galena, manganese oxide, and iron oxide minerals. The silver halide minerals probably formed from the alteration of primary silver sulfide.

**Trace minerals.** Table I, page 89, contains a list of trace elements present in carbonate and silicate rocks associated with silver-lead-zinc mineralization in the Silver district. In all samples analyzed, lead was always present. Silver was generally present in most carbonate rocks with zinc or copper. Because a molybdenum target was used in the X-ray analyses, it was difficult to determine the presence of molybdenum in
samples, although in some cases a very large peak was obtained for molybdenum and its presence was noted.
The history of mining in Yuma County, Arizona, is directly related to the early Spanish explorations of the southwestern United States. In 1530, the President of the Governing Board of New Spain, Nuño de Guzman, became interested in the Southwest because of rumors of gold and the Seven Cities of Cibola. He probably was responsible for the organization of the Arizona explorations by Coronado in 1540. During that same year, Hernando de Alarcon entered the mouth of the Colorado River and ascended the river for many miles (Bryan, 1925). By 1604, Juan de Onate began explorations along the Colorado River. He descended the Colorado River from the area of the Bill Williams fork to the Gulf of Lower California. On his journey he reported silver veins along the river (Cross, Shaw, and Scheifele, 1960), but no attempt was made to develop the veins at that time. In 1691, Padre Kino began one of his many exploratory journeys across southwestern Arizona and noted in his memoirs of having seen much gold and silver mineralization near the present Mexican border (Cross, Shaw, and Scheifele, 1960). Probably the first Spaniards to travel north through Yuma County would be
Padre Sedelmair and Fray Garces. Sedelmair traveled cross-country in 1743 from the Gila River to the area near Ehrenberg, Arizona. Garces also traveled overland in 1776 from the Gila River to near Needles, California. Both men probably passed through or near the Silver district on their journeys.

Beaver trappers, Sylvester and James Pattie, were probably the first Americans to explore along the Colorado River from 1825 to 1828 (Bryan, 1925). After 1848, mining activity began with the opening of the Arizona Territory. By 1857, placer gold had been discovered in Mohave County, and in 1858, gold was found twenty miles east of Gila City, Yuma County (Tuck, 1963). Pauline Weaver discovered the rich La Paz gold placers along the Colorado River in 1862, near Ehrenberg, Arizona (Tuck, 1963). By 1863, the Castle Dome district of Yuma County became known, and two years later the Silver district became known (Thompson, 1925).

Probably the first person to give any geological descriptions of southern Arizona was Dr. Thomas Antisell (1857). Later Pacific Railroad exploration reports by Ives (1861) added to the geological information on Arizona. Ives ascended the Colorado River in a steamboat as far as the present Nevada state line in 1858,
and described his travels and observations in the 1861 Pacific Railroad report.

The Silver mining district was an area of much exploratory mining activity during the period from 1865 to the late 1880's, after being organized into a district in 1862 (Raymond, 1872). Actual mining did not begin until about 1879. The town of Silent was established near the Red Cloud mine in 1879, followed by the town of Clip, in 1883, near the Clip mine mill site on the Colorado River (Wilson, 1951).

Few records of early mineral production from the Silver district are available, but Thompson (1925) reported that during 1878, 1879, and the early 1880's, mining activity was at its height with three million dollars production reported from the Red Cloud mine and one million dollars from the Clip mine. He estimates the total production of the district closely approached five million dollars. The total mineral production figures given by Wilson (1951) are reproduced in Table II.

Ore from the district was hauled from the mines to the Colorado River and loaded on boats for transport to the Selby smelter in San Francisco (Wilson, 1951). Some ore smelting was attempted on the Colorado River,
<table>
<thead>
<tr>
<th>Years</th>
<th>Tons Ore</th>
<th>Silver Ounces</th>
<th>Silver Value</th>
<th>Lead Pounds</th>
<th>Lead Value</th>
<th>Zinc Pounds</th>
<th>Zinc Value</th>
<th>Total Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1880</td>
<td>?</td>
<td>30,000</td>
<td>34,500</td>
<td>300,000</td>
<td>$ 15,000</td>
<td>-</td>
<td>-</td>
<td>49,500</td>
</tr>
<tr>
<td>1881-85</td>
<td>?</td>
<td>270,000</td>
<td>302,400</td>
<td>800,000</td>
<td>36,000</td>
<td>-</td>
<td>-</td>
<td>338,400</td>
</tr>
<tr>
<td>1883</td>
<td>?</td>
<td>146,000</td>
<td>160,600</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>160,600</td>
</tr>
<tr>
<td>1884-87</td>
<td>?</td>
<td>914,000</td>
<td>950,000</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>950,000</td>
</tr>
<tr>
<td>1887</td>
<td>?</td>
<td>124,200</td>
<td>121,716</td>
<td>400,000</td>
<td>18,000</td>
<td>-</td>
<td>-</td>
<td>139,716</td>
</tr>
<tr>
<td>1888</td>
<td>?</td>
<td>13,248</td>
<td>12,453</td>
<td>104,345</td>
<td>4,591</td>
<td>-</td>
<td>-</td>
<td>17,044</td>
</tr>
<tr>
<td>1889</td>
<td>?</td>
<td>22,500</td>
<td>21,150</td>
<td>300,000</td>
<td>11,700</td>
<td>-</td>
<td>-</td>
<td>32,850</td>
</tr>
<tr>
<td>1890-1928</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1929</td>
<td>700</td>
<td>7,000</td>
<td>3,731</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3,731</td>
</tr>
<tr>
<td>1930-33</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1934-37</td>
<td>286</td>
<td>580</td>
<td>422</td>
<td>21,414</td>
<td>1,145</td>
<td>-</td>
<td>-</td>
<td>1,567</td>
</tr>
<tr>
<td>1938-40</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1941</td>
<td>3,300</td>
<td>27,786</td>
<td>19,759</td>
<td>315,000</td>
<td>17,955</td>
<td>-</td>
<td>-</td>
<td>37,714</td>
</tr>
<tr>
<td>1942-46</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1947-49</td>
<td>?</td>
<td>3,887</td>
<td>3,518</td>
<td>88,300</td>
<td>14,773</td>
<td>14,200</td>
<td>1,761</td>
<td>20,052</td>
</tr>
<tr>
<td>1879-1949</td>
<td>?</td>
<td>1,559,201</td>
<td>$1,630,249</td>
<td>2,329,059</td>
<td>$119,164</td>
<td>14,200</td>
<td>$1,761</td>
<td>$1,751,174</td>
</tr>
</tbody>
</table>
but proved to be unsuccessful as did later attempts with ore concentration (Wilson, 1951).

Intermittent mining activity of small scale operations has existed in the Silver district since the early days of large production, mainly at the Red Cloud and Clip mines. Current activity is limited to occasional exploration by interested individuals or mining companies. The mining system employed in the district consists of sinking inclined shafts every few hundred feet, or less, along the veins. Where high silver values were found usually in ore shoots in the fault zones, large stopes were made to extract the ore, usually timbered with stulls cut from willows growing along the Colorado River.
DESCRIPTION OF MINES AND PROSPECTS

Although there are actually few large mines and relatively few mineral prospects in the Silver district, all accessible mines were examined in some detail and all the prospects were carefully sampled and studied. Most of the older workings are in fair condition, but inclined and vertical shafts usually do not have ladders so access is impossible in some of the mines. The Red Cloud, Black Rock, and Clip mines are partly accessible, but it was not possible to obtain much information in regard to the ore bodies or present ore reserves. Copies of mine maps of the larger mines of the district are included with this study because they were found to be complete and usually accurate for the parts of the mines still accessible. Some corrections and additions were made to the maps to bring them up to date when necessary. During Wilson's visit to the district in 1930, most of the workings were still accessible and much information concerning the ore reserves, mining claims, and mineralogy was available through people residing in the area so much of his data remains as the most reliable source of published information on the mines of the district. No conscious attempt was made
by this writer to duplicate the data published by Wilson (1933), but certainly some duplication was unavoidable. Surface geological maps made during the field work of this study in areas thought to be of particular interest are included as photographic reductions for convenient reference. In the following sections general descriptions of most of the mines and mineral prospects of the district are given. Figure 5 shows a map of the district mining claims.

**Red Cloud Mine**

The Red Cloud mine is located in sections 11 and 12, T. 4 S., R. 23 W., nearly due west of bench mark 673 on the Red Cloud-Yuma Wash road.

The Red Cloud claim is one of the earlier claims of the district dating back to the early 1880's. It was surveyed for patent in 1885 for Mr. C. J. Knapp and Mr. M. Horton after purchasing the property from the Red Cloud Mining Company of New York. By 1917, the Red Cloud Consolidated Mines Company began ownership of the mine and held it until 1925 when the E. R. Beericke (Primos) Company took over control. Penn Metals, Inc. acquired the property in 1941 and finally the Red Cloud Mining and Milling Company acquired the mine in 1947.
Workings on the Red Cloud claim consist of several inclined shafts along the length of the exposed Red Cloud fault. The main workings of the mine have been along the incline of the fault to a depth of 500 feet below the surface. Considerable stoping along favorable ore shoots is present above the 270 foot level, as indicated in Figure 6. A 200 foot vertical shaft intercepts the fault foot wall at the 270 foot level. The workings are accessible to the 270 foot level and lower, but not considered safe below the 270 foot level.

Most of the production from the Red Cloud mine was during the period 1880 to 1889 and later activity was limited to sampling, exploratory drifting and drilling, supplemented by installation of test flotation plants and dry concentrators for treatment of the dump materials.

The general geology of the Red Cloud claim area was mapped and is included as Figure 7 of the thesis and consists of andesite breccia, dacite porphyry, and rhyolitic to dacitic tuffs and lapilli tuffs striking to the southeast and dipping 20 to 24 degrees north. They are separated by normal faulting from granodiorite and quartz diorite on the west. Maximum vertical displacement is apparently less than 200 feet. The fault
FIGURE 6

CROSS SECTION THROUGH THE RED CLOUD MINE, LOOKING NORTH

Adapted from E.D. Wilson, 1951. Arizona Bureau of Mines Bull.158.
FIGURE 7
GEOLOGIC MAP OF THE RED CLOUD MINE AREA,
SILVER DISTRICT, YUMA COUNTY, ARIZONA
strikes N. 10-15° W. and dips from 30 to 60 degrees to the east. The foot wall is granodiorite and the hanging wall is an andesite breccia, separated by 5 to 10 feet of oxidized vein material. Another fault, parallel to the strike of the Red Cloud fault, seems to be present, but no evidence to support its existence was found other than strong topographic expression. An aplitic dike striking northwest from the conjectured fault has several test pits along its length. Figure 8 is a geologic cross section of the mine area.

The vein occurs within the brecciated fault zone between silicified, sericitized, and carbonatized wall rock and consists of vuggy quartz, limonite, crystalline fluorite, black and white calcite, and vug or fissure fillings of silver-lead-zinc minerals. Argentiferous lead oxides, sulfides, carbonates, and sulfate of lead is found associated with wulfenite, vanadinite, silver chlorides and bromides, malachite, and zinc carbonate. Figure 9 shows a section transverse to the fault zone in the area of the mine.

Best mineral values are found in the ore shoots at intersections of the Red Cloud fault with transverse faults striking N. 60-70° W. Two ore shoots were stoped to depths of 300 and 400 feet. The average width of
FIGURE 8

CROSS SECTION OF THE RED CLOUD MINE AREA, LOOKING NORTH
SILVER DISTRICT, YUMA COUNTY, ARIZONA

EXPLANATION

- Alluvium
- Andesite and dacite porphyry
- Quartz diorite

Note: See figure 7 for location of section. Vertical scale exaggerated 1½ X.

Horizontal scale

1000 Feet
FIGURE 9

LONGITUDINAL SECTION ON THE RED CLOUD VEIN LOOKING WEST
RED CLOUD MINE, SILVER DISTRICT, YUMA COUNTY, ARIZONA

EXPLANATION

VOLCANIC ROCKS
GRANITIC ROCKS


0 50 100 Feet
ore shoots was approximately 3 feet with an average length of 60 feet.

Oxidation in the mine extends below the 500 foot level as determined by diamond drill coring made in 1948 by Holmes and Riley (Wilson, 1951). Below the 360 foot depth in the mine the fault steepens in dip, assumes a "granitic" hanging wall, and is less mineralized (Wilson, 1951). This information could not be verified.

Assays generally average 5 to 6 per cent lead and 10 ounces of silver per ton, according to Wilson (1951).

**Geronimo Claims**

The Geronimo claims consist of two groups of claims, the North Geronimo and South Geronimo claims, located in section 35, T. 3 S., R. 23 W., about 1½ miles northwest of the Red Cloud mine and apparently also on the Red Cloud fault.

The early history of the claims is not known and probably not of any significant value since working on the claims consists only of a few shallow trenches and a few vertical or inclined shafts. Apparently no production from the claims was ever recorded.

The geology of the South Geronimo claims area was mapped and included in this thesis as Figure 10 and Figure 11 is a geologic cross section of the area. The
FIGURE 10

GEOLOGIC MAP OF THE SOUTH GERONIMO CLAIMS AREA,
SILVER DISTRICT, YUMA COUNTY, ARIZONA
FIGURE 11

CROSS SECTION OF THE SOUTH GERONIMO CLAIMS AREA, LOOKING NORTHWEST SILVER DISTRICT, YUMA COUNTY, ARIZONA.

EXPLANATION

Alluvium

Andesite breccia
Rhyodacite tuff
Undifferentiated metamorphic rocks

Vertical scale exaggerated 1 1/2 X.

Horizontal scale 600 Feet

Note: See figure 10 for location of section.
major rock units found in the area are bedded rhyodacitic tuffs, lapilli tuffs, and andesite breccia. They are separated from contact metamorphic rocks (migmatites) by normal faulting. Later dip and strike separation has offset the normal fault a short distance to the west. The normal fault is probably a northern continuation of the Red Cloud fault and found to strike N. 30° W. and with dip 40 to 55 degrees to the northeast. It has a migmatite foot wall and a andesite breccia or silicified rhyodacite tuff hanging wall. Brecciation, silicification, sericitization, and carbonatization is common along the fault zone. The transverse fault strikes N. 75° W. and dips steeply to the southwest. No apparent mineralization occurs in the transverse fault zone.

Lineation in the migmatites trends in a westerly direction. The tuffs are well bedded, usually exhibiting graded bedding. They strike northwest and dip 12 to 30 degrees to the northeast.

Mineralization is similar to that reported for the Red Cloud mine, and limited to a 3 foot thick oxidized zone between the migmatite foot wall and volcanic rock hanging wall. Vug linings and cavity fillings of argentiferous lead sulfide, lead oxides,
lead carbonates, zinc carbonates, wulfenite, and vanadinite are found associated with limonite, quartz, calcite, and fluorite. Some manganese oxides are also quite common.

The North Geronimo claims have similar geology and mineralization as the southern claims with the exception that the fault has a volcanic rock foot wall. The fault strikes generally due north and dips 30 to 40 degrees to the east.

Wilson (1933) reports assays of 6 per cent lead and 8 ounces of silver per ton.

**Papago Mine**

The Papago mine is located in section 11, T. 4 S., R. 23 W., about 2500 feet south of the Red Cloud mine, along the same mineralized Red Cloud fault zone.

The geology and mineral deposits are similar to those of the Red Cloud mine and Geronimo claims. The vein is reported to have been discovered in the early 1880's by placer miners working auriferous (?) gravels along the bed rock in Black Rock Wash (Wilson, 1933).

The vein is reported to have been worked through several inclined shafts, drifts, and small stopes
(Wilson, 1951), but all workings except one shaft have been filled with stream gravels.

Assays of ore from the Papago mine vein, averaging 4 feet wide, range from 0.1 to 7.33 per cent lead and 1.10 to 17.60 ounces of silver per ton (Wilson, 1951).

Riho Claims

The two Riho claims, formerly the Pacheco claims, are located in section 14, T. 4 S., R. 23 W., approximately 1½ miles south of the Papago mine.

Earliest records indicate that the claims were held by the Red Cloud Mining and Milling Company in 1951 and before that by Yuma Metals, Inc. Presently, the claims have been relocated by Arthur Davis and Herbert Gifford.

Workings on the claims consist of numerous pits, small shafts, and 2 to 4 feet wide open stopes. Most of the workings are caved and inaccessible.

The geology consists of deformed hornfels, quartz-mica schists, and argillite with an apparent trend of lineation and foliation N. 20° E. and dipping 25 degrees to the east. Normal faulting of unknown displacement trends N. 40-60° W. and dips steeply to the northeast at 70 to 85 degrees. Brecciation, and
chloritization is common along the fault zone. Aplitic dikes have apparently formed along portions of the fault zone.

Fissure fillings of crystalline calcite, quartz, barite, and limonite contain vugs and cavities of cellular masses of argentiferous galena, cerussite, lead oxides, and occasionally some malachite.

**Black Rock Mine and Silver Glance Mine**

The Black Rock and Silver Glance mines are included together because they are located along the same vein and have similar geology. They are located in sections 11 and 12, T. 4 S., R. 23 W., about 5000 feet southeast of the Red Cloud mine. Both mines are patented mining claims.

The Black Rock claim was one of the earlier mining claims of the district and patented during 1880, followed a year later by the Silver Glance patent. Production for both mines was limited to the period between 1883 to 1887. In 1948, a gravity mill was constructed on the Colorado River to treat material from the Black Rock mine dump, but apparently proved unsuccessful since operations ceased after one year.

Workings on the Black Rock claim consists of one 420 foot inclined shaft down the dip of the mineralized
fault zone. The inclined shaft has five short levels. Additional short adits and pits are found on the claim. The Silver Glance mine has one 250 foot adit connecting to a shaft on the Black Rock vein.

The geology of the area consists of mica schists, quartz-mica schists, and other altered schists and hornfelsic rocks that have been intruded by granodiorite producing a zone of migmatite. Dacitic lava flows and pyroclastic rocks cap the metamorphic and migmatitic rocks. Figure 12 shows a general geologic map of the area and Figure 13, a geologic section.

Mineralization occurs along a fault zone varying in strike from N. 60° W. to N. 15° E. and dipping 40 to 60 degrees northeast or southeast. Faulting is normal with an unknown displacement. The hanging wall consists of silicified, brecciated, and altered metamorphic rock and the foot wall is apparently migmatite or granitized metamorphic rock. Much carbonatization and chloritization of the wall rocks is present. The fault zone can be traced on the surface northward to the Silver Glance claim. Figure 14 is a map of the principal workings of the Black Rock mine.

Vein material is limited to an average thickness of 10 feet of oxidized material containing black and
FIGURE 12

GEOLOGIC MAP OF THE BLACK ROCK MINE AREA
SILVER DISTRICT, YUMA COUNTY, ARIZONA
FIGURE 13

CROSS SECTION OF THE BLACK ROCK MINE AREA, LOOKING NORTH
SILVER DISTRICT, YUMA COUNTY, ARIZONA

EXPLANATION

Rhyodacite
Granodiorite
Undifferentiated metamorphic rocks

Horizontal scale  \[ \text{1000 Feet} \]

Note: See figure 12 for location of section. Vertical scale exaggerated 1½ X.
FIGURE 14

COMPOSITE MAP OF LEVELS IN THE BLACK ROCK MINE
SILVER DISTRICT, YUMA COUNTY, ARIZONA

white calcite in silicified and brecciated wall rock, fluorite, iron and manganese oxides, vuggy quartz, with irregular cellular masses of lead oxides, lead carbonates, and sulfates, zinc carbonates, and occasionally lead sulfide.

According to Wilson (1951), assays from the Black Rock mine averaged 4.87 per cent lead, 9.8 per cent zinc, and 6.7 ounces silver per ton.

**Chloride, Mandarin, and Cash Entry Claims**

The Chloride, Mandarin, and Cash Entry claims are all located in section 9, T. 4 S., R. 22 W., about two miles east of the Red Cloud mine area, and two miles south of the Clip mine.

None of the claims have had any production recorded and very little development work has been done. Early records of claim holders are not important and will not be mentioned.

The geology of the area around the claims consists of dacitic to andesitic lava flows, breccias, and pyroclastic rocks faulted by north to northwest-trending normal faults, dipping at various attitudes to the west.

Mineralization is limited to a 2 foot wide oxidized zone along the foot wall of the faults, and consists of quartz, fluorite, iron oxides, barite,
calcite, and minor lead sulfide and oxides in vugs. Occasional wulfenite, vanadinite, and cerussite are also found as cavity linings.

**Princess Mine, Hamburg Mine, and Silver King Mine**

The Princess mine, Hamburg mine, and Silver King mine are on adjoining claims in section 1, T. 4 S., R. 23 W., about one mile northeast of the Red Cloud mine. Figure 15 shows a geologic map of the area and Figure 16, a geologic cross section.

The Princess claim was patented in 1880 and has one inclined shaft of 100 feet along the dip of a mineralized fault zone. Wilson (1933) reported several open stopes on the claim, but apparently have caved since he reported seeing them. The Hamburg claim adjoins the Princess claim on the south and contains one inclined shaft down the dip of the fault. No other development work is present. The Silver King claim joins the Princess and Hamburg claims on the east and has one short adit with a 30 foot open stope along the vein, and a 50 foot shaft.

Geology of the area consists of undifferentiated contact metamorphic rocks, intruded by granodiorite, and capped by dacitic flows and pyroclastic rocks. Lineation of the metamorphic rocks has an apparent trend to the
FIGURE 15
GEOLOGIC MAP OF THE PRINCESS MINE AREA, SILVER DISTRICT, YUMA COUNTY, ARIZONA
EXPLANATION

- Dacite and dacite porphyry
- Dacite tuff
- Diorite
- Undifferentiated contact metamorphic rocks

Horizontal scale
0____________________________000 Feet

FIGURE 16
CROSS SECTION OF THE PRINCESS AND HAMBURG MINES AREA,
LOOKING NORTHWEST, SILVER DISTRICT,
YUMA COUNTY, ARIZONA
northeast and a plunge of approximately 40 degrees in the same direction. Normal faulting, of unknown displacement, has created areas favorable for silver-lead-zinc mineralization. Two parallel faults trend north to northwest and dip at about 40 degrees to the northeast, separating the metamorphic rocks on the east from the granodiorite on the west. Wall rocks are usually well brecciated, silicified, and carbonatized.

Mineralization along the fault zones is limited to an average width of 2 feet and contains black crystalline calcite, iron and manganese oxides, quartz, fluorite, barite-celestite, and irregular fissure fillings or cavity filling of galena, lead oxides, cerussite, anglesite, smithsonite, wulfenite, and vanadinite. Wilson (1933) reported that argentite and cerargyrite was present in the vein material of the Princess mine.

**Padre Kino Claim**

The Padre Kino claims, formerly known as the Dives or Saxon claims, are sixteen unpatented mining claims located in section 36, T. 3 S., R. 23 W., about 6000 feet northeast of the Red Cloud mine and 8000 feet southwest of the Clip mine.
The claims, or part of them, were held by the Neal Mining Company during the 1930's, later by Yuma Metals, Inc., and currently by Carl Self of Yuma, Arizona.

No production is recorded except that two carloads of high-grade silver ore were shipped sometime before 1930 (Wilson, 1933). Several shallow trenches along the mineralized fault zone and two vertical shafts are the only workings on the claim. One shaft is 86 feet deep with a 45 foot crosscut to the vein, and the other is 50 feet deep.

A normal fault of 400 foot maximum displacement separates dacitic and andesitic lava flow rocks, rhyolitic tuffs and lapilli tuffs from undifferentiated contact metamorphic rocks. The fault strikes N. 20-30° W. and dips approximately 70 degrees to the west. Branching faults with south and northwest trends and northeast trending faults have offset the metamorphic-volcanic rock contact to some extent. Figure 17 is a generalized geologic map of the Padre Kino claims area. A geologic cross section of the area is shown in Figure 18.

Mineralization along the main fault consists of a zone 7 to 10 feet wide of iron and manganese oxides, vuggy quartz, black crystalline calcite, and crystalline
FIGURE 17

GEOLOGIC MAP OF THE PADRE KINO MINE AREA, SILVER DISTRICT, YUMA COUNTY, ARIZONA
FIGURE 18
CROSS SECTION OF THE PADRE KINO MINE AREA LOOKING NORTH SILVER DISTRICT, YUMA COUNTY, ARIZONA
calcite, and crystalline barite-celestite. Lead and zinc carbonates, lead oxides, and some copper carbonate occur as irregular fissure fillings or as massive cellular cavity fillings. The length of the fault zone is traceable for nearly 1500 feet along the surface with brecciation and alteration of wall rocks common. The vein is usually observed to contain metamorphic rock both in the foot wall and hanging wall. Assays average are about normal for silver-lead-zinc veins of the district.

Clip Mine

The Clip mine, originally the Silver Clip claim, is located in section 25, T. 3 S., R. 23 W., approximately 2½ miles northeast of the Red Cloud mine. The mine was patented in 1897 as the J. G. Blaine claim, later to be renamed.

The claim was developed early in the history of the Silver district during the period 1883 to 1887, when one million dollars in silver was produced (Wilson, 1933). The claim remained idle from 1897 to 1925, until the Silver Mines Consolidated Company put in a 100 ton cyanide mill to treat the ore. Recovery was poor and the mill was redesigned and rebuilt in 1928, but unsuccessfully. United Silver Mines of Yuma, Arizona, held
ownership of the mine during the 1930's but did little development work. Present owner of the mine is William Hindle of San Pedro, California.

Workings on the claim are still accessible and consist of five levels drifted along a mineralized fault zone at 40 to 50 foot depth intervals. Figure 19 shows a plan of the principal workings of the mine. The two higher levels form part of the open stopes and extend from the fourth level to the surface. The stopes are about 40 to 150 feet long by 15 feet wide and apparently were placed along favorable ore shoots in the fault zone. The mine was developed to a depth of about 120 feet, at which depth ore shoots appear to terminate or pinch out.

The mine is located on a branch normal fault of the main Revelation fault that passes through the Amelia, Revelation, and Mendevil claims. In the area of the Clip mine, the fault is entirely in andesitic to dacitic volcanic rocks. The fault zone trend strikes N. 15° E. to N. 15° W. and dips 60 to 80 degrees to the west. Transverse faults are common and trend to the northeast. They probably formed areas of increased permeability forming ore shoots of high silver values, similar to those of the Red Cloud mine.
FIG. 19. MAP OF THE THIRD AND FOURTH LEVELS, CLIP MINE, SILVER DISTRICT, YUMA COUNTY, ARIZONA.

EXPLANATION

- Raise
- Winze
- Ore chute
- Manway
- Portal
- Exposed fault, showing dip
- Mineralization
- Andesite and dacite flows

The vein averages 5 feet in width and consists of black calcite, barite, celestite, iron and manganese oxides, vuggy quartz, fluorite, and irregular zones of lead oxides, lead carbonate, silver chlorides and bromides, and vanadinite. Brecciation, silicification, and chloritization of the wall rocks is common. According to Wilson (1933), ore assays ranged from 20 to 140 ounces of silver per ton.

Amelia Mine

The Amelia mine is located on the Amelia claim, formerly the Gallo claim, in section 25, T. 3 S., R. 23 W., approximately 1500 feet southwest of the Clip mine.

The original claim was recorded by the Sterling Silver Mines Consolidated and later transferred to the United Silver Mines Company of Yuma, Arizona, and lastly to Carl Self of Yuma, Arizona.

Workings on the claim consist of a 200 foot adit with raises, winzes, and open stopes to the surface. Wilson (1933) reports that the mine produced considerable silver during the 1880's, but nothing of its early history was recorded.

Figure 20 of this thesis contains a map of the general geology of the area. The major rock types are
GEOLOGIC MAP OF THE AMELIA AND REVELATION CLAIMS, SILVER DISTRICT, YUMA COUNTY, ARIZONA
andesitic to dacitic lava flows, breccias, and agglomerates separated by the normal Revelation fault from similar volcanic rocks to the west. Brecciation, silicification, and carbonatization is common along the fault zone. The fault strikes to the northwest and dips 60 to 80 degrees to the west or east. Another normal fault striking N. 30° W. and dipping approximately 80 to 85 degrees east or west is 200 feet west of the main Revelation fault.

Mineralization is found along both fault zones and widths of 4 to 10 feet of oxidized material is present. Fissure fillings of quartz, black calcite, iron oxides, barite-celestite, with cavity fillings of zinc and lead carbonate, and lead oxides are usually present. Assay results are average for silver, lead, and zinc values found in fault fissures of the Silver district.

The open stope of the Amelia mine shows stoping of an ore shoot that apparently had a height of 100 feet from the surface downward to where it terminated.

**Revelation Claims**

The Revelation claims consist of two unpatented claims located on the Revelation fault, in sections 25 and 36, T 3 S., R. 23 W., approximately 2000 feet southwest of the Clip mine. The Revelation claim number 2
adjoins the Amelia claim on the south.

The original Revelation claims are old claims of the district, but little development work has been done. Carl Self of Yuma, Arizona, is the present holder of the claims.

Workings on the claims consist of several shallow trenches along the fault zone and one 40 foot vertical shaft. Figure 21 is a geologic cross section of the Revelation claims and Amelia mine area.

The geology of the area is similar to that of the Amelia mine except that contact metamorphic rocks are exposed along the west side of the fault, and constitute the foot wall along the fault in the area of the Revelation claims. The fault strikes N. 20° W. and dips both to the east and west at steep to nearly vertical angles. Transverse faults are commonly found but do not appear to offset the main Revelation fault. Considerable alteration of wall rock is found along the fault zone and consists of brecciation, chloritization, silicification, and carbonatization.

The volcanic flow rocks generally strike northeast and dip 20 to 30 degrees south. Gneissic layers in the metamorphic rocks show a parallelism of dark minerals with apparent lineation to the southeast and
Figure 21

CROSS SECTION OF AMELIA AND REVELATION CLAIMS,
LOOKING NORTH, SILVER DISTRICT
YUMA COUNTY, ARIZONA
plunge of 35 degrees in the same direction.

Mineralization occurs along the length of the Revelation fault with an average vein width of 12 feet. Pinching and swelling of the vein occurs with the larger ore shoots. In several places the vein forms stringers. The vein material consists of iron and manganese oxides, quartz, black massive calcite, crystalline barite-celestite, silicified brecciated wall rock, and vug linings of nodular zinc and lead carbonates.

**Mendevil Claim**

The Mendevil claim is located in section 36, T. 3 S., R. 23 W., approximately 2000 feet south of the Revelation claims, and 2000 feet east of the Padre Kino claims.

The claim is along the Revelation fault, found to strike northwest and dip 70 to 80 degrees to the northeast. Although the claim was surveyed for patent in 1887, little development work has been done. Workings consist of shallow trenches and pits along the fault zone. The normal fault separates contact metamorphic rocks on the west from volcanic flow rocks on the east. The foot wall is composed of metamorphic rocks and the hanging wall consists of volcanic rock.
Mineralization along the fault zone consists of barite-celestite, calcite, and vuggy quartz. Wilson (1933) reported that certain portions of the vein contains vugs of calcite containing 5 per cent lead and 15 ounces of silver per ton.

**Gold Reef Claim**

The Gold Reef claim is an unpatented tungsten claim in Arrastra Wash located in section 30, T. 4 S., R. 22 W., approximately 2½ miles from the Colorado River.

Nothing is known about the history of the claim and little development work has been done. Wilson (1941) reported the occurrence of scheelite in a narrow vein within a fault fissure striking N. 55° W. and dipping 80 degrees south. The vein contains quartz, iron oxides, calcite, and a little scheelite.

The geology of the area consists of a contact area between schistose metamorphic rocks and granodiorite. Aplitic dikes and rhyolitic dikes are common in the area.

**Unnamed (?) Copper Claims**

Several copper claims are located near Arrastra Wash in the southern part of the district in section 36,
T. 4 S., R. 23 W., approximately 1500 feet from the Colorado River. The claims are about one-quarter mile south of the thesis mapped area.

The claims are quite old, probably dating back before the organization of the Silver district. Many "antiquas" or old Spanish shafts and prospect pits are present. Currently, Mr. Walt Seegar is doing development work on the claims.

A fault striking N. 50-60° E. intersected by fissures striking N. 50-70° W. has formed areas of mineralization in silicified, laminated, quartz-schist country rock. The schists dip at various angles, but have a general strike to the north.

Mineralization consists of limonite, quartz, and copper carbonates in ore shoots along fault intersections. Thickness of the veins averages 2 feet, but occasional swells to 15 feet occur.

Cibola Claims, H. H. and L. Claims, Kirk and Lee Claims, and Peggy B. Claims

The Cibola claims, Hess, Hess, and Lilly claims, Kirk and Lee claims, and Peggy B. claim are all manganese claims located in sections 34 and 35, T. 2 S., R. 23 W., and sections 3 and 4, T. 3 S., R. 23 W., approximately 4 miles northwest of the Clip mine. The
claims are north of the thesis mapped area and occur in the volcanic sequence of rhyolitic to andesitic flows, breccias, and agglomerates. All the claims are included together since their geology and mineralogy are similar.

The manganese deposits of the northern part of the Silver district have been known for many years, but were not developed until 1953, when a market for low-grade manganese ore was created. The claims are idle at the present time. Total production for all claims is probably less than 5000 tons of 20 to 30 per cent manganese ore.

Andesitic and dacitic flow rocks are the most common rock type found in the area of the manganese claims. Mineralization almost always occurs in brecciated, north to northwest-trending normal fault zones. Dips are generally to the west at 30 to 45 degrees, but some vertical dips are also found. The manganese mineralization apparently is limited to ore shoots or lenticular bodies within the fault zones, ranging in length from 25 to 150 feet, and in width from 5 to 10 feet. Depth of ore shoots is probably limited to 50 feet.

Manganese minerals commonly present are pyrolusite, manganite, and psilomelane. They are usually associated
with quartz, minor iron oxides, calcite, and other finely divided carbonates. The manganese oxides occur as fillings in the open spaces of the fault fissures or as impregnations in the fault zone brecciated rock.

Workings on the claims consist of several shafts, with levels and small stopes, and a few short adits along the fault zones.
FUTURE OF MINING IN THE DISTRICT

If there should be an expectation of high prices for silver, lead, and zinc, additional exploration might be justified in some of the more favorable areas along fault zones.

The Revelation and Padre Kino claims, and a few other claims in the Silver district could be potential silver and lead producers as long as favorable prices exist. Probably no large deposit will ever be found, judging by the past history of other mines in the district, but it is conceivable that more ore shoots similar to those found in the Red Cloud and Clip mines exist elsewhere in the district and could be as productive in silver and lead as those of the Red Cloud mine and Clip mine.

The outlook is encouraging that lower grade milling ore may be developed in sufficient tonnages to insure continued production under favorable economic conditions.

Metallurgical tests performed on the silver ore of the district by the Arizona Bureau of Mines (George Rosevere, personal communication), indicate that most of the silver occurs not only as a sulfide or halide
mineral, but also as a silver manganate or silver-manganese silicate that is not readily amenable to flotation or cyanidation processes. Concentration of oxidized ores by gravity, flotation, and cyanidation methods yield only 55 per cent of the silver (Wilson, 1951). This value agrees closely with tests made by the Ore Testing Division of the Denver Equipment Company (A. L. Poarch, personal communication). Recovery of 80 per cent lead and 4 per cent zinc is possible using flotation methods of concentration. Tables III, IV, and V, contain some of the test flotation data of the Denver Equipment Company. Leaching and electrolytic processes of recovery of zinc might be effectively used on the oxidized ore or selective flotation tailings after silver and lead had been removed.

Table VI gives a rough calculation of the approximate gross value of the Silver district ore from 460 assays made by Yuma Metals, Inc. The calculations are for illustrative purposes only and are not intended to indicate the actual value of the district ore. Zinc was included in the calculations only as an illustration to indicate the gross value of the ore if the zinc could be effectively recovered.
<table>
<thead>
<tr>
<th>Product</th>
<th>Per cent Weight</th>
<th>Ag, Oz./ton</th>
<th>Assays</th>
<th>Per cent Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Assay</td>
<td>-</td>
<td>8.2</td>
<td>5.2</td>
<td>4.65</td>
</tr>
<tr>
<td>Calculated Assay</td>
<td>100.0</td>
<td>7.8</td>
<td>5.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Rgr. Flot. Conc't. (a)</td>
<td>7.4</td>
<td>57.3</td>
<td>56.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Rgr. Flot. Conc't. (b)</td>
<td>2.2</td>
<td>37.1</td>
<td>17.5</td>
<td>5.8</td>
</tr>
<tr>
<td>Scav. Conc't. (c)</td>
<td>1.34</td>
<td>17.3</td>
<td>10.3</td>
<td>5.5</td>
</tr>
<tr>
<td>Flotation Tailing (d)</td>
<td>89.06</td>
<td>2.8</td>
<td>0.5</td>
<td>4.2</td>
</tr>
</tbody>
</table>

TABLE III

RECOVERY DATA FOR SILVER DISTRICT ORES
TABLE IV

FLOTATION TEST DATA FOR SILVER DISTRICT ORES

<table>
<thead>
<tr>
<th>Operation</th>
<th>Grinding Time (Min.)</th>
<th>%Solids</th>
<th>pH</th>
<th>Reagents: Pounds per ton heads*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NaS</td>
</tr>
<tr>
<td>Grinding</td>
<td>25</td>
<td>67</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Rgr. Flot. Conc't. (a)</td>
<td>12</td>
<td>25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rgr. Flot. Conc't. (b)</td>
<td>12</td>
<td>25</td>
<td>9.7</td>
<td>-</td>
</tr>
<tr>
<td>Scav. Conc't. (c)</td>
<td>5</td>
<td>22.5</td>
<td>9.3</td>
<td>-</td>
</tr>
</tbody>
</table>

*Reagent Symbols
NaS--Sodium Sulfide
NHS--Sodium Acid Sulfate
A31--Aerofloat #31
z8--Butyl Xanthate
### TABLE V

**SUMMARY OF FLOTATION TEST DATA FOR SILVER DISTRICT ORES**

<table>
<thead>
<tr>
<th>Product</th>
<th>Per cent Weight</th>
<th>Ag, OZ./ton</th>
<th>Assays Pb, %</th>
<th>Zn, %</th>
<th>Per cent Recovery Ag</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated Head Assay</td>
<td>-</td>
<td>7.78</td>
<td>5.17</td>
<td>4.10</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24 min. Rgr. Conc't. (a) and (b) combined</td>
<td>9.6</td>
<td>52.7</td>
<td>47.4</td>
<td>3.0</td>
<td>63.0</td>
<td>87.8</td>
<td>7.1</td>
</tr>
<tr>
<td>24 min. Rgr. Tailing (c) and (d) combined</td>
<td>90.4</td>
<td>3.0</td>
<td>0.69</td>
<td>4.2</td>
<td>35.0</td>
<td>12.2</td>
<td>92.9</td>
</tr>
<tr>
<td>Total Flot. Conc't. (a), (b), and (c) combined</td>
<td>10.94</td>
<td>48.4</td>
<td>42.8</td>
<td>3.3</td>
<td>68.0</td>
<td>90.5</td>
<td>8.9</td>
</tr>
<tr>
<td>Final Flot. Tailing</td>
<td>89.06</td>
<td>2.8</td>
<td>0.55</td>
<td>4.19</td>
<td>32.0</td>
<td>9.5</td>
<td>91.1</td>
</tr>
</tbody>
</table>

**NOTE:** The above table shows the products reported in Tables III and IV.
### TABLE VI

**NET SMELTER RETURN ESTIMATES FOR CONCENTRATES**

<table>
<thead>
<tr>
<th></th>
<th>Average Assays for Silver District Ores:</th>
<th>Gross Value of Ore:</th>
<th>Basic Recoveries of Ore using Selective Flotation:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>per cent/ton</td>
<td>6.07</td>
<td>Lead: 121.4 pounds/ton at 16 cents/pound</td>
</tr>
<tr>
<td>Lead:</td>
<td>6.07</td>
<td></td>
<td>$19,424</td>
</tr>
<tr>
<td>Silver:</td>
<td>ounces/ton</td>
<td>10.15</td>
<td>Silver: 10.15 ounces/ton at 1.293 dollars/ounce</td>
</tr>
<tr>
<td>Gold:</td>
<td>ounces/ton</td>
<td>0.02</td>
<td>$13,124</td>
</tr>
<tr>
<td>Zinc:</td>
<td>per cent/ton</td>
<td>4.03</td>
<td>Gold: 0.02 ounces/ton at 35.00 dollars/ounce</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$0.700</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Zinc: 80.6 pounds/ton at 14 1/2 cents/pound</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$8.887</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$42,135</td>
</tr>
</tbody>
</table>

- **Gross Value of Ore:**
  - Lead: 121.4 pounds/ton at 16 cents/pound
  - Silver: 10.15 ounces/ton at 1.293 dollars/ounce
  - Gold: 0.02 ounces/ton at 35.00 dollars/ounce
  - Zinc: 80.6 pounds/ton at 14 1/2 cents/pound

- **Basic Recoveries of Ore using Selective Flotation:**
  - Lead: 121.4 pounds/ton at 90% recovery will yield 109.26 pounds/ton. At a 8:1 concentration ratio there will be 874.08 pounds (43.7%) of lead/ton concentrates.
  - Silver: 10.15 ounces/ton at 68% recovery will yield 6.90 ounces/ton. At a 8:1 concentration there will be 55.2 ounces silver/ton concentrates.
  - Gold: 0.02 ounces/ton at 83% recovery will yield 0.0166 ounces/ton. At a 8:1 concentration there will be 0.1328 ounces gold/ton concentrates.
  - Zinc: not recoverable from ore using selective flotation methods.
TABLE VI (continued)

Proposed Smelter Payment Schedule:

**Lead:** Payment for 90% of total lead/ton concentrates at 16 cents/pound, less 2 cents/pound of payable lead. 786.672 pounds lead at 16 cents/pound: $125,867
Less 2 cents/pound of payable lead: 15,730
Total: $110,137

**Silver:** Payment for 95% of total silver at current market price (1.293 dollars) less 0.015 cents per ounce of payable silver. 52.44 ounces silver at 1.293 dollars/ounce: $67,647
Less 0.015 cents/ounce of payable silver: .787
Total: $66,860

**Gold:** For 0.03 ounces/ton or over, payment for 92.57% at the net realized price or equivalent payment for 100% at 32.3185 dollars/ounce: $4,292

Total Gross Value of one ton of Concentrates less the U.S. Tax on Bullion: $178,33
Less Charge of Freight Costs and Base Charge: 23.38
Final Net to Shipper for one ton of Concentrates: $164.95

Net Per Ton Of Ore: $26.52
Scarcity of water for milling purposes should not have a great influence on the future development of silver-lead-zinc mining in the district because it is available from the Colorado River which is five to ten miles west of the district. Additional water might be obtained from some of the deeper mines of the district such as the Red Cloud mine where the water table is found at about the 500 foot level. Shipping costs are high and a concentrated ore shipment would be more satisfactory. However, it should be determined first whether the milling expenses would be compensated for by the freight savings and bonus payments. The nearest rail shipping point is on the Southern Pacific Line at Dome, Arizona, approximately thirty-seven miles east of the Red Cloud mine. The shipping cost of ore concentrates from a mine on the district to a railhead in Yuma is estimated at $3.50 per ton, including about twenty miles of road maintenance expense. Table VI, page 163, includes a rough calculation of the net smelter returns and freight costs for one ton of ore concentrates, but deductions for mining, milling, and amortization costs have not been included in the net yield.

Martinez Lake, Arizona, is the closest settlement to the Silver district and is located twenty miles
south of the Red Cloud mine. Food, gasoline, and a telephone is available. Boats can be obtained for river travel to the district if necessary.

The apparent limiting factors to future development of the deposits of the district seem to be a consideration of the proven reserves of ore and a correct milling process to recover more silver from the ore.
CONCLUSIONS

The Silver mining district is concluded to consist of Mesozoic, possibly Cretaceous, sediments that have undergone metamorphism probably during the Upper Cretaceous or Lower Tertiary Period. Metamorphism is thought to be directly related to the intrusion of granodiorite. Metamorphic facies of rocks display an increase of possible metamorphic intensity from a low greenschist facies furthest from the exposed contact zone to a hornblende-hornfels facies nearest to the contact zone of granodiorite with the metamorphic rocks. Basification, metasomatism, and migmatization are processes of alteration of contact zone rocks frequently exhibited along the margin of the granodiorite.

Northeast to southwest compressive forces present contemporaneously with granodiorite intrusion, or prior to intrusion, are apparently responsible for the north, nearly parallel alignment of lineation, foliation, and fold axes of the metamorphic rocks. Possible northeast-southwest shear movement was present as a result of the compressive forces from the northeast and southwest, but the record left is not too clear. Later normal faulting along north to northwest trends occurred as a result of
relaxation of compressive forces. Probably granodiorite was intruded at this time rather than at an earlier period with compressive forces. The structure produced by normal faulting is a series of horst-graben blocks.

At the time of granodiorite intrusion, or shortly after intrusion, large volumes of Tertiary volcanic rocks were extruded or intruded as flows, sills, or dikes from fissures and domes. Pyroclastic material was deposited during later stages of volcanism in lakes formed in lava-dammed grabens. The Tertiary volcanic sequence displays a close chemical identity with the intrusive rock of the district. Composition of the larger percentage of volcanic rocks is predominantly rhyodacite or dacite. Lesser amounts of andesite and rhyolite are present.

Pliocene-Pleistocene basalt flows overlie the deformed Tertiary volcanic sequence and are locally associated with rhyolitic ash and pumice tuffs. Basalt flows are apparently flank eruptions from volcanic domes.

Ore deposits of the district are related in time and space to the intrusion of granodiorite. The deposits are oxidized, probably mesothermal, silver-lead-zinc veins that occur in brecciated north to
northwest-trending fault fissures. North to northwest fault intersections with transverse faults are found to be areas of increased mineralization where shallow ore shoots have formed. Depth of ore shoots is apparently limited to approximately 200 feet and lengths limited to approximately 100 feet. Average widths of fissure veins is less than 10 feet. Mineralization is thought to be contemporaneous with the extrusion of Tertiary volcanic rocks in the district. Mineralogy of the deposits consists of lead oxides, lead carbonate, lead sulfate, zinc carbonate, silver halides, argentiferous lead sulfide, and lead sulfide. Pyrite and sphalerite are thought to have been present in the fissure veins prior to oxidation and supergene action. Associated gangue minerals consist of quartz, barite, fluorite, and calcite. Limonite and manganese oxide minerals are usually present in most vein deposits. Oxidation exists to a known depth of 500 feet in the deepest workings of the district. No supergene enriched zones apparently exist.

Trace analyses of carbonate and silicate rocks associated with known mineralization indicate their satisfactory use to determine ore shoot locations, or to define areas of possible unknown mineralized zones.
The further development of mineral deposits of the district is dependent upon the use of a satisfactory ore recovery and concentration method and an analysis of the ore reserves.
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BIBLIOGRAPHY

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B. U.S. GOVERNMENT AND STATE PUBLICATIONS


C. PERIODICALS


Holt, E. B. "New production from the Castle Dome district, Yuma County, Arizona, Mining Jour. (Phoenix, Arizona), Vol. 27, pp. 4-5, 1942.


D. UNPUBLISHED MATERIALS


APPENDIX
APPENDIX

PHOTOS AND MAPS GIVING ADEQUATE COVERAGE
OF THE SILVER DISTRICT

Arizona County Geologic Map Series: Yuma County, map 3-11 (1:375,000 scale).

U.S. Army Map Service Topographic Map: Salton Sea sheet, map NI 11-9 (1:250,000 scale).
- Limiting parallel: 33-34
- Limiting meridian: 114-116

- Picacho 15' quadrangle (1943-1951), (1:62,500 scale).
- Picacho 7 1/2' quadrangle (1954), (1:24,000 scale).
- Picacho SW 7 1/2' quadrangle (1954), (1:24,000 scale).
- Hidden Valley 7 1/2' quadrangle (1965), (1:24,000 scale).

U.S. Geological Survey Aerial Photographs: Series GS-COL (1:20,000 scale).
- 1-87 to 1-94
- 3-107 to 3-113
- 1-123 to 1-129
Plate 1. View of the area near the Red Cloud mine, looking west toward a granodiorite ridge. The townsite of Silent, Arizona is located in foreground.

Plate 2. Looking northwest along the exposed granodiorite footwall of the Red Cloud mine.
Plate 3. View of the area around the Black Rock mine, looking east. Contact metamorphic rocks are in the foreground, volcanic flow rocks are in the right background.

Plate 4. Looking northwest along the migmatite hanging wall of the Black Rock mine.
Plate 5. View of the area near the Silver King mine, looking northwest toward the mine dump.

Plate 7. Bedded, silicified Tertiary rhyodacite tuffs in the vicinity of the South Geronimo claims. Dip is north.

Plate 8. Exposure of brecciated granodiorite near the Red Cloud fault zone, west of the Red Cloud mine.
Plate 9. Typical erosional niche common to the Tertiary volcanic rock sequence of the Silver district. Area of picture is north of Padre Kino mine.

Plate 10. Exposure of Tertiary rhyodacite tuff with secondary joints normal to the bedding. Pick is aligned with bedding.
Plate 11. Typical amphibolite inclusion in quartz diorite found near contact zone with schistose rocks.

Plate 12. Exposure of granodiorite showing the relative poorly exhibited jointing sets. View is looking southwest.
Plate 13. View of the area near the South Geronimo claims, looking west. Bedded tuffs are to the right of the fault trace and migmatites to the left.

Plate 14. View of alluvial types in the Silver district including slope wash, alluvial fan, terrace deposit, and stream deposit.
ABSTRACT
The Silver mining district consists of thirty square miles of the southern end of the Trigo Mountains, Yuma County, Arizona. From 1879 to 1900, 2,329,059 pounds of lead and 1,559,201 ounces of silver were recovered largely from argentiferous galena and silver halides from oxidized fault-fissure veins of the Red Cloud and Clip mines.

The rocks of the district include Pre-Tertiary schist, gneiss, phyllite, hornfels, and amphibolite intruded by a late Cretaceous or early Tertiary granodiorite stock, overlain by middle Tertiary volcanic flows, flow breccias, and pyroclastics of andesitic to rhyolitic composition. All of these rocks are unconformably overlain by basalt of Pliocene or Pleistocene age.

Schistose and gneissic rocks display a prevailing parallel trend of lineation, foliation, and fold axes to the northeast with steep dips to the southeast or northwest. Persistent north to northwest-trending normal faults are occasionally offset by later strike-slip faults with east-west trends.
Mineralization occurs in north to northwest-trending fault fissures associated with granodiorite intrusion. More favorable zones of ore deposition are at intersections of these faults with transverse faults, where ore shoots have formed. Typical ore deposits are limited to a depth of approximately 200 feet of limonitic, quartz-barite-calcite fissure-fillings with irregular zones containing argentiferous galena, lead oxides, argentite, silver halides, cerussite, smithsonite, and anglesite. Pyrite and sphalerite are thought to have been present in the primary ore, but oxidation and supergene action has removed all traces of these sulfides. Ore shoots usually are limited to lengths of less than 100 feet and widths of less than 10 feet. Average assay values are 6 per cent lead, 4 per cent zinc, and 10 ounces of silver, and 0.02 ounces of gold per ton of ore.

Future exploration in the district can be supplemented with trace analyses of carbonate and silicate rocks associated with normal faulting and hydrothermal activity to define promising ore targets. Improved ore recovery methods and an analysis of ore reserves in the district are desirable.
PLATE 15
GEOLoGIC MAP
OF THE
SILVER DISTRICT, YUMA COUNTY, ARIZONA

Scale: 1:24,000

EXPLANATION

- General and local of ore and mine workings
- Ore
- Oxidized ore
- Alluvial deposits
- Volcanic rocks
- intrusive bodies
- Dikes
- Faults
- Overthrusts
- Secular changes
- Masonry
- Native silver
- Native sulfur
- Native arsenic
- Native antimony
- Native lead
- Native copper

In shades of brown, gray, and green to indicate the extent of the various geological features.

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