ORE CONTROLS AT THE GOLDEN RULE MINE
COCHISE COUNTY, ARIZONA

by

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Abstract

Mineralized quartz veins in the Golden Rule mine area, Cochise County, Arizona show increased gold content in areas adjacent to or within the locally glauconitic and pyrite-rich calcareous rocks of the Cambrian Abrigo Formation. Fluid inclusion studies indicate that quartz veins containing base and precious metals formed from an early 275-315 °C, CO₂-rich fluid of low salinity (2-7 wt % NaCl) and a later 195-235 °C fluid of slightly higher salinity. Pressure estimates obtained from density measurements on primary inclusions imply a high pressure environment possibly exceeding 1500 bars. The results of the fluid inclusion studies and the implications based on mapping, geophysical information, and sulfur isotope data suggest that the ore bodies may have formed on the periphery of an intrusion.
CHAPTER I
INTRODUCTION

Purpose of Study

The purpose of this study was to characterize the occurrence of precious and base metals in the Golden Rule area with respect to host lithology, structure, and associated ore constituents in order to define possible controls on ore localization. The relatively high grade of the gold mineralization at the Golden Rule mine is anomalous compared with other ore deposits in southeastern Arizona. Homogenization temperatures and depth of burial estimates gained from fluid inclusion studies will serve to illuminate the environment within which the Golden Rule deposit formed.

Methods of Study

The geology of approximately one square mile incorporating the Golden Rule mine was mapped at a scale of 1:3000. Because mineralization occurs in several locations in the map area in addition to the Golden Rule mine, samples from various other prospects and workings were sampled for comparative purposes and the precious and base metals as well as As, Sb, Hg, Mo, Bi, Se, and Te content were determined.

In addition to sampling for metals, fluid inclusions
from vein quartz collected from a few of these mineralized sites as well as from the main mine workings were studied. The fluid inclusion studies were used to estimate the temperature and pressure of the system at the time the Golden Rule deposit formed.

Sulfur isotope data obtained from ore constituents at the mine were also determined to assess possible sources of sulfur in the sulfides. The isotope studies were undertaken to examine the possibility that the primary host lithology may have originally contained and contributed significant amounts of sulfur in the form of $H_2S$.

The Abrigo Formation (Cambrian), was studied in detail petrographically to determine what lithologic characteristics make it such an excellent host for mineralization at the Golden Rule mine as well as many other mining districts in southeastern Arizona. Literature research concerning alteration and mineralization in many of these other districts suggests a conspicuous relationship between ore localization and favorable horizons within the Abrigo Formation.

**Location**

The Golden Rule mine is located at the extreme northeastern tip of the Dragoon Mountains approximately 4.4 miles east of the town of Dragoon, Arizona (fig. 1). The
Figure 1. Location map of the Golden Rule mine, Cochise County, Arizona.
mine lies within the NE1/4 sec 23, T. 16 S., R. 23 E. of the Cochise Quadrangle. The mine area is easily accessible from Interstate 10 via the Dragoon road year round. An old stage stop along the Butterfield stage route was once located near the entrance to the Golden Rule property and the adobe remains, which are located on the south side of the Dragoon road, were still standing at the time of writing.

**Previous Work**

The first written evaluation on mineral potential at the Golden Rule mine is a reconnaissance survey conducted by Wuensh (1927) for the Missouri-Kansas Zinc Corporation. The survey involved a brief description of the mine workings, geology, and inventory of existing equipment with recommendations for further exploitation of potential ore reserves. Later visits to the property by Hight (1928) and Lundquist (1929) for appraisal purposes offer little more additional geologic information.

A more recent thesis by Hamph (1972) on the geology of the Golden Rule mine provides a detailed description of the main ore body, rock types, and workings at the mine with some speculations on the genesis of the deposit.

The most recent available information concerning the Golden Rule area is a survey of mineral resources in the
"Dragoon Roadless Area" by Drewes and Kreidler (1984). The Golden Rule area is listed as one of six areas of probable mineral resource potential based on an evaluation of favorable geologic relationships and results of large-scale geochemical sampling in the northern Dragoons. Maps outlining areas of Pb, Mo, and B anomalies in the Golden Rule area are included in the USGS Miscellaneous Field Studies Map MF-1521-E.

In addition, geophysical surveys conducted in the region show a large positive magnetic anomaly in the area southeast of the Golden Rule; the surveys were published in the USGS Miscellaneous Field Studies Map MF-1521-C.
CHAPTER II
REGIONAL GEOLOGY

The Golden Rule mine lies within a structurally complex zone at the extreme northeastern edge of the Dragoon Mountains, Cochise County, Arizona. Various portions of the Dragoons have been mapped by Drewes (1980-1:125,000,1987-1:24,000), by Cooper and Silver (1964-1:31,680), and by Gilluly, (1956-1:62,500).

The Dragoon Mountains are a northwest-trending belt of Precambrian granitic and metamorphic rocks overlain by Paleozoic and Late Mesozoic sedimentary rocks. The Precambrian and Phanerozoic section is intruded by stocks of Jurassic, Late Cretaceous, and Tertiary age. The stratigraphic section has been extensively disrupted by a northeast-vergent system of thrust faults that affect rocks as young as Upper Cretaceous (fig. 2).

A brief chronology of the stratigraphic and structural development of the Dragoon mountain region is given here to provide a framework for further discussions relating to the geology of the Golden Rule mine area.

The oldest rocks known in the Dragoon Mountains are Precambrian in age and consist of metasedimentary and metavolcanic rocks of the Pinal schist (1.68-1.70 Ga). These are intruded by 1.65-1.40 Ga granites. Parts of this
Figure 2. Simplified geologic map of the northeastern Dragoon Mountains. (Adapted from Drewes, 1980).
section are exposed southwest of the Golden Rule mine outside the mapped area. Unconformably overlying the Precambrian section are over 6,000 feet of Paleozoic sedimentary rocks comprising predominantly shallow water carbonates, siltstones, and sandstones. The basal unit of the Paleozoic is the middle Cambrian Bolsa Quartzite which in many areas is believed to be derived from Precambrian granitic rocks. The Abrigo Formation, also of middle to late Cambrian age, was deposited on the Bolsa surface and shows a transitional relationship with the quartzite beds below.

The Abrigo Formation comprises 700-800 feet of siltstones and thinly-bedded limestones grading upward into dolomitic sandstones. These tidal flat facies of the Abrigo Formation are thought to represent early encroachment of the shallow seas that influenced the style of sedimentation throughout much of Paleozoic time. The Abrigo Formation will be discussed in greater detail later as its importance as an exceptional host to mineralization in many districts in southeastern Arizona warrants closer examination.

Disconformably overlying the Abrigo Formation are 270 feet of interbedded dolomite, siltstone, shale, and limestone of the Upper Devonian Martin Formation. Both the Martin and the Abrigo Formations are slope-formers and are therefore easily recognized as a topographic low between
the resistant Bolsa Quartzite outcrops and the ledge-forming limestones and dolomites that lie above the Martin Formation. Although the Bolsa Quartzite is missing in the Golden Rule area, a considerable change in relief is apparent where the Martin/Abrigo lithologies are exposed.

The Mississippian Escabrosa Limestone lies conformably above the Martin Formation and is one of the most easily recognized and widespread carbonate units in southeastern Arizona. The Escabrosa Limestone is a thick-bedded, fossiliferous cherty limestone that exceeds 700 feet in thickness where a complete section is present.

Lying above the Escabrosa Limestone are over 4,000 feet of limestones and dolomite with minor sandstones, shales, and siltstones of the Permian/Pennsylvannian Naco Group. These are, in order of decreasing age, the Horquilla Limestone, Earp Formation, Colina Limestone, Epitaph Formation, Scherrer Formation, and the Concha Limestone.

A major erosional surface separates Mesozoic rocks from the underlying Paleozoic section. Throughout much of southeastern Arizona this surface is distinguished by the Glance Conglomerate of latest Jurassic to early Cretaceous age (Bilodeau, et al, 1987). The Glance Conglomerate crops out less than a mile east of the Golden Rule mine. The topography during deposition of the Glance Conglomerate has been interpreted as one of high relief signaling a
significant change in tectonic style during Mesozoic time (Titley, 1976). The Glance Conglomerate is the lowermost member of the Bisbee Group which comprises over 2,500 feet of sandstones, quartzites, shales, and minor limestone deposited in the Bisbee trough. The Bisbee Group was deposited between 115 and 100 m.y. ago and is the last major sedimentary sequence deposited in the area prior to the onset of Laramide deformation.

Laramide thrusting in southeastern Arizona began some 85 m.y. ago and continued throughout Cretaceous time. Compressional deformation of probable Laramide age is indicated in the Golden Rule area by folded and silicified limestones thrust over a 74.1 m.y. andesite dike.

The most recent events that may be considered relevant to this study are the intrusion of the 53 m.y. old Texas Canyon quartz monzonite and the intrusion of the Oligocene/Miocene Cochise Stronghold Granite. The intrusive rocks truncate all rock types and structures discussed previously and are considered to have been the source for the skarn-type mineralization at nearby Johnson Camp. The effects of contact metasomatism from the Texas Canyon quartz monzonite can be recognized in much of the Paleozoic section adjacent to the intrusion throughout the area northwest of the Golden Rule mine.
CHAPTER III

MINE AREA GEOLOGY

Surface and underground mapping by Hamph (1972) at a scale of 1:1200 covered an area immediately surrounding and including the Golden Rule mine. Mapping in the present study encompassed the mine as well as the area to the south where a number of prospects and small workings have been developed. The geology was mapped at a scale of 1:3000 and covered an area of approximately one square mile.

Stratigraphy

The Precambrian basement rocks and the overlying Bolsa Quartzite are unexposed in the Golden Rule mine area but may lie at a shallow depth beneath the Abrigo Formation north of the mine. Much of the carbonate section belonging to the Naco Group and the clastic rocks of the Bisbee Group lie exposed just outside the map area to the west.

The Abrigo Formation

The Abrigo Formation crops out extensively in the Dragoon Mountains as well as the nearby Whetstones, Little Dragoons, Tombstone Hills, and many other locations in the region and forms the low lying hills in the northern portion of the map area where the Golden Rule mine is
located (fig. 3). The total thickness of the Abrigo Formation averages over 800 feet but in the Golden Rule area, portions of the section have been tectonically thinned by low-angle faulting. The Abrigo strata at the mine have been folded and tilted to the northeast (Plate 1).

Sections of the Abrigo Formation have been measured and described in detail by Ransome (1904), Gilluly (1956), Cooper and Silver (1964), and McClure (1977). Additional work by Perry (1964), Weitz (1976), Rushing (1978), and others concerns alteration and ore localization within the Abrigo and will be discussed in a later section.

Thin sections from the various members of the Abrigo were prepared and examined with particular attention to those lithologic aspects that may have aided in ore localization or contribute to its conspicuous susceptibility for alteration that is characteristic of the Abrigo in other mining camps.

Based on gross lithologic variations, Cooper and Silver (1964) have divided the Abrigo Formation into three members: lower, middle, and upper. These distinctions have proved useful during mapping and are adopted here for descriptive purposes.

**Lower member**—The lower member is a weakly resistant slope-
Figure 3. Exposures of the Abrigo Formation (hatching) with some mining camps (numbered) where the Abrigo Formation is an important host rock. 1. Johnson Camp, 2. Golden Rule mine, 3. Abril mine, 4. Turquoise district, 5. Tombstone district, 6. Bisbee (Warren) district.
forming sequence of interbedded shale and siltstone with occasional lenses of coarse grained calcareous material (fig. 4). The lowermost 100 feet of the lower member is not well exposed in the Golden Rule area owing to the inferior resistance to weathering. In some areas, as in the northwest part of the map area, a rhyolite porphyry has intruded the lower member.

The rocks of the lower member are commonly pale yellowish brown to dark brownish-green, thinly-bedded to fissile shales. The shales are made up of quartz, feldspar, chlorite, biotite, muscovite, and clay minerals. The composition of the clay in the lower member, as determined by X-ray diffraction methods, is illite (McClure, 1977). Thin laminae of muscovite and chlorite along bedding are also easily recognized in hand specimen. Detrital muscovite locally comprises up to 25% of the shales.

A conspicuous aspect of the Abrigo Formation is the ubiquitous presence of authigenic pyrite. In the lower member pyrite occurs as clots and disseminations and more commonly as euhedral grains along fine laminae in the silt horizons (fig. 5). Glauconite is also common in the Abrigo Formation but less so in the lower member. Clots of hematitic mud make up much of the finer grained material in the lower member, occasionally in association with chlorite. Very weak veinlet controlled biotite alteration
Figure 4. Outcrop of siltstones and shales of the lower member of the Abrigo Formation.
Figure 5. Photomicrograph of calcareous siltstone with authigenic pyrite from the lower member of the Abrigo Formation (10X magnification).
of the shales is evident near some of the mineralized quartz veins.

The lower member is a structurally incompetent unit that is involved in low-angle bedding plane faulting in the Golden Rule area. A few narrow mineralized quartz veins occur along such structures in the lower member northwest of the mine. The incompetent behavior of the shales and siltstones in response to stress apparently does not make the lower member as conducive to the formation of rigid open conduits for mineralization as is the habit of the middle and upper members.

**Middle member**—The middle member of the Abrigo Formation is 225-255 feet thick in areas where a complete section is present (Cooper and Silver, 1964). At the Golden Rule the thickness of the middle member has been exaggerated by folding or thinned to as little as 60 feet as a result of bedding plane faulting. At the mine itself, the middle member lies in contact with the lower member along a mineralized bedding plane fault. The contact with the lower member, where a depositional one, is commonly marked by an edgewise conglomerate.

The middle member of the Abrigo Formation is a distinctive unit that is easily recognized in many areas by a characteristic "crenulated" appearance on weathered
The middle member is composed of irregularly laminated limestone and siltstone with subordinate shale becoming increasingly dolomitic higher in the section. The crenulated appearance of the middle member is not evident underground at the mine or on a freshly broken surface and is simply a response to weathering of the slightly more resistant silt horizons. In many mining districts as at Johnson Camp, the crenulated appearance is preserved even though the unit has been completely replaced with calc-silicate assemblages. At the Golden Rule, the crenulations are locally obliterated by silicification near faults.

The limestones of the middle member are pinkish gray on fresh surfaces and weather to buff or mottled orange gray. The silty horizons weather dark greenish-brown to black and become increasingly abundant higher in the section. The limestone contains abundant trilobite fragments cemented with sparry calcite. Much of the sparry calcite is unevenly distributed with finer grained micrite, indicating the rock has undergone post-depositional neomorphic effects. Disseminated authigenic pyrite and magnetite is distributed throughout much of the rock and is particularly abundant along the silty crenulations. The crenulations are composed of fine grained silt, hematitic mud (algal material?), detrital muscovite, and pyrite (fig. 7). McClure (1977).
Figure 6. "Crenulated" middle member of the Abrigo Formation.
Figure 7. Photomicrograph of silty crenulations composed of fine silt, fossil fragments, muscovite, algal material, and authigenic pyrite in middle member of the Abrigo Formation (20X magnification).
suggested that the crenulations formed from algal mats that trapped the fine grained silt.

The middle member becomes increasingly sandy, dolomitic, and glauconite-rich up section. The glauconite is locally oxidized to hematite or in some cases shows replacement by calcite (fig. 8). Weak silicification is also indicated in some of the thin sections as clusters of fine-grained quartz replacing sparry calcite.

**Upper member** - The upper member is the most complete of the three at the Golden Rule and consists of over 150 feet of locally glauconitic calcareous sandstones, dolomite, and silty dolomite. The upper member is slightly more resistant than the middle and lower members and caps the low lying hill at the Golden Rule mine and the lower hillside to the west. Cross bedding forming ridged surfaces upon weathering is a distinctive feature in outcrop of the upper member. The contact with the silty limestones of the middle member is a gradational one and is distinguished by the predominance of sand sized material over carbonate.

The lower portions of the upper member are composed chiefly of locally fossiliferous calcareous sandstones containing as much as 25% detrital muscovite. The fossiliferous horizons in the upper member are coarse grained calcarenites with abundant iron oxide staining. The
Figure 8. Photomicrograph of glauconite partially replaced by calcite in middle member of the Abrigo Formation (10X magnification).
calcareous sandstones are interbedded with angular conglomerates that weather a rusty brown. The sandstones are orange gray to greenish gray on fresh surfaces and weather orange black.

Higher in the section the sandstones become dolomitic and contain subangular to subrounded grains of quartz, feldspar, glauconite, and mica with rare apatite and zircon. Pyrite is again ubiquitous and occurs as disseminated euhedral grains and clots enclosing quartz grains. Chlorite cement is also common in the upper member and imparts an olive green cast to the outcrops. Although much of the feldspar is detrital, Cooper and Silver (1964) have determined that some feldspar in the Abrigo Formation may be authigenic.

The sandstones are interbedded with fossiliferous calcarenites and occasionally stromatolitic siltstone. Near the top of the upper member, a resistant quartzite horizon stands out in relief from the less resistant sandstones and dolomite. On the hilltop at the extreme southern part of the map area, a resistant ledge of quartzite caps the hill and helps to distinguish the upper member from similar carbonate rocks of the Martin Formation.

Comments The only hydrothermal alteration of the Abrigo Formation observed in thin section was the weak veinlet
biotite in the lower member and replacement of calcite by idocrase in the middle member immediately adjacent to the mineralized quartz veins (fig. 9). Some recrystallization has also occurred near the veins and is usually best developed within the middle member. Areas of strong calcite veining are exposed in the mine workings suggesting that some decalcification of sedimentary calcite may have occurred.

The abundance of authigenic pyrite, glauconite, magnetite, chlorite, and hematite in the Abrigo Formation indicates the presence of considerable iron in the rock. Much of the iron was originally present in the sediments in the Fe\(^{2+}\) state indicating deposition in a poorly oxygenated environment. Both authigenic pyrite and glauconite form under reducing conditions that may be produced by decaying organic matter. Reduced carbon compounds produced during decay deplete the O\(_2\) content of the sediment. Sulfate-reducing bacteria will then metabolize the organic matter (as a source of energy) in the anaerobic environment, producing H\(_2\)S, which may later combine with Fe\(^{2+}\) to form pyrite (Schreiber, 1987).

The importance of the Fe\(^{2+}\) in the Abrigo Formation sediments becomes apparent when one considers what lithologic aspects make it such a prolific host to mineralization. The presence of pyrite, glauconite, and
Figure 9. Photomicrograph of rare alteration of calcite to idocrase in the Abrigo Formation adjacent to mineralized quartz veins (10X magnification, anomalous interference colors produced by thick section).
chlorite in the sediments may sufficiently reduce the $O_2$ content of the fluids migrating through the section that precipitation of some metals may occur preferentially within favorable horizons in the Abrigo.

The Martin Formation

Sandstones, siltstones, and dolomite of the Devonian Martin Formation crop out extensively in the southern half of the map area. Stratigraphic thicknesses and relationships within members of the Martin Formation are poorly defined owing to thrusting, but certain horizons can be recognized as compatible with the units within the upper and, to a lesser extent, lower members described by Cooper and Silver (1964).

The Martin Formation is also a slope-forming unit and forms the valley south of Porphyry Hill. Bedding in the Martin Formation, where less deformed by thrusting, generally strikes northeast and dips 18 to 30 degrees to the southeast. Units 5, 6, and 7 of Cooper and Silvers' upper member are well represented south and west of Porphyry Hill.

The more resistant carbonates forming the saddle west of Porphyry Hill are made up of styolitic dolomite (unit 6). The dolomite is light gray, sandy, and coarse-grained. The dolomite is juxtaposed with silty fossiliferous
dolomite and limy dolomite, also of the Martin Formation, on the south along a NE-trending fault. The rocks south of the fault belong to unit 5 of the upper member as defined by Cooper and Silver. Unit 5 in the Golden Rule area is composed of thinly-bedded dark gray silty dolomitic limestones that weather buff to light brown with mottled gray patches (fig. 10). The unit is abundantly fossiliferous with weakly silicified bryozoans, corals, and the brachiopod *Atrypa*.

Unit 7 of the uppermost Martin Formation comprises light brown to pale reddish brown dolomitic shale with calcareous sandy interbeds. The shale is a weakly resistant unit exposed along the NW-trending thrust faults and in the low-lying valley south of Porphyry Hill. The only area in which the shales of unit 7 can be easily observed is in an adit below the dumps in the extreme southern portion of the map area. This horizon has clearly provided a favorable surface of detachment for thrust faulting since the resistant limestones of the lower Escabrosa directly above overlap rocks from the uppermost Martin Formation down section through most of the Abrigo Formation.

The lower member of the Martin Formation is less well exposed in the swale just west of Porphyry Hill. The rocks here comprise mostly buff to brown dolomite and silty dolomite. Faulting and intrusion of the rhyolite porphyry
Figure 10. Mottled dolomitic limestone of unit 5 of the Devonian Martin Formation.
has largely obscured the stratigraphic relationships within the Martin Formation in this area.

Good exposures of the upper Martin Formation are lacking up section to the southwest but a significant geochemical anomaly in this area may indicate that a fault separates the Martin Formation from the Escabrosa Limestone here.

Escabrosa and Horquilla Limestones

The resistant ledge-forming fossiliferous limestones of the Escabrosa and Horquilla Limestones form the steep slopes on the west side of the map area. Areas of strong silicification of the Escabrosa Limestone lie along faults and, in one area west of Porphyry Hill, silicification has produced a prominent knob at the intersection between the westernmost thrust and the NE-trending fault in the center of the map area (fig. 11).

The Escabrosa and Horquilla Limestones are cherty, crinoidal limestones in beds up to 8 feet thick. The Escabrosa Limestone is dolomitic lower in the section and contains very little shale. The Escabrosa Limestone is locally recrystallized to marble, particularly near the thrust faults. The Horquilla Limestone is similar in appearance but is not dolomitic and contains shaly interbeds. The Horquilla Limestone may also be
Figure 11. Resistant knob formed by silicified Mississippian Escabrosa Limestone along a thrust fault.
distinguished by the presence of locally abundant fusilinid foraminifera.

**INTRUSIVE ROCKS**

**Rhyolite Porphyry**

The rhyolite porphyry crops out in the center and northwest portions of the map area (Plate 1 in pocket). Contact relationships with the Paleozoic section clearly indicate that the porphyry has intruded the sedimentary package. Dikes and small lobes can be observed extending into the wallrocks parallel to bedding in the lower member of the Abrigo Formation (fig. 12). Small altered roof pendants of the lower member are also exposed on the northwest lobe of the intrusion and just west of Porphyry Hill. Very little contact alteration of the sedimentary section was observed. Some horizons in the siltstones are hornfelsic in appearance, but this feature is common in the lower member even in areas where no intrusive rocks are exposed.

In a few areas, the porphyry is in apparent fault contact with the lower Paleozoic rocks. Mineralized quartz veins occupy some of these fault zones notably on the northeastern and southern flanks of the Porphyry Hill intrusive body.

In the field the rhyolite forms blocky resistant
Figure 12. Intrusive contact between the Abrigo Formation and rhyolite porphyry intrusive rocks.
topographic highs standing in relief from the less resistant sedimentary rocks. Numerous mineralized and unmineralized anastomosing quartz veins cut the rhyolite porphyry along a predominant ENE-WNW trend.

In hand specimen, the rhyolite is a yellowish gray porphyritic rock with large (up to 5 mm) clear dipyramidal quartz phenocrysts. Abundant groundmass sericite can be discerned on fresh surfaces. Altered phenocrysts of plagioclase feldspar are also evident in hand specimen when a fresh surface is examined. The plagioclase has been largely replaced by sericite and white calcite. On weathered surfaces the calcite has been dissolved away leaving a conspicuous cavity.

The most outstanding petrographic feature is the pervasive phyllic alteration. The sericite alteration has apparently affected groundmass and phenocrysts to an equal degree. Plagioclase feldspar phenocrysts have been altered to calcite, sericite, and quartz (fig. 13). The calcite has been dissolved on weathered surfaces leaving conspicuous cavities containing a goethite-stained siliceous latticework. This is particularly evident in areas adjacent to the mineralized quartz veins.

Traces of original biotite are rare. The biotite has been extensively altered to coarse grained sericite, apatite, pyrite, and Ti-oxides (fig. 14). Potassium
Figure 13. Photomicrograph showing alteration of plagioclase feldspar in rhyolite porphyry to an assemblage of calcite, quartz, and sericite (10X magnification).
Figure 14. Photomicrograph showing alteration of biotite in rhyolite porphyry to sericite, apatite, pyrite, and Ti-oxides (10X magnification).
feldspar crystals are strongly altered to sericite and quartz and are difficult to distinguish from the sericitized groundmass.

Silicification of the rhyolite porphyry is variable from strong silica flooding obscuring original textures, to weak veinlet replacement of feldspar and groundmass. Thin, fine-grained haloes of quartz intergrown with sericite occur surrounding the quartz phenocrysts.

The rhyolite porphyry has also undergone moderate to strong argillization adjacent to the mineralized quartz veins. Particularly intense argillic alteration of the porphyry is evident in a road cut east of the mine. The alteration here may be a result of the proximity of a major fault zone on the northern flank of Porphyry Hill.

Andesite Dikes

A few dikes of andesitic composition are exposed at various locations in the map area. Owing to their inferior resistance to weathering, the dikes are not easily recognized in the field. In some areas, the presence of the dikes can only be inferred from float.

One andesite dike is exposed in the road on the low saddle just west of Porphyry Hill. The dike is about 10 feet wide trending parallel to the road for over 200 feet and can be seen in a prospect pit next to the road on the
north. The dike is offset on the west by a thrust fault. To the east, the dike can be traced to a NE-trending fault where it is apparently truncated. Some andesite float can be seen along the trace of the fault for a distance to the east toward the rhyolite porphyry.

Another dike of the same composition is exposed in the mine workings on the first level at the Jackson shaft and the second level further east. The dike trends NE parallel to the "breccia fault" mapped by Hamph (1972), but is only seen in the hanging wall. Traces of float and occasional outcrop of the andesite can be seen on the surface for a distance northeast of the Jackson shaft.

In thin section, the dike material is strongly altered. Potassium feldspar originally altered to kaolinite shows incipient phyllic alteration. Mafic phenocrysts, probably hornblende, are completely altered to chlorite, epidote, leucoxene, and pyrite. Plagioclase is altered to chlorite and epidote (fig. 15). A few traces of biotite are evident with rims of chlorite. Magnetite and pyrite are abundant and occur as disseminated euhedral grains throughout the rock.

The dike exposed in the mine is pervasively argillized particularly adjacent to the breccia fault and its intersection with the mineralized quartz veins. The dike material at the mine was sampled by Hamph and was found to
Figure 15. Photomicrograph showing strong propylitic alteration of 74.1 m.y. andesite dikes (10X magnification).
contain anomalous traces of Au, Ag, and Pb (.34 ppm, 1.72 ppm, and 500 ppm respectively). The dike west of Porphyry Hill was sampled for the present study but did not contain these elements in amounts above background (Appendix A). K/Ar dating of the andesite dikes has yielded an age of 74.1 m.y. (Reynolds and others, 1986).
CHAPTER IV
GEOCHRONOLOGY AND STRUCTURE

Following deposition of the Paleozoic sedimentary section, the Dragoon region experienced widespread folding, faulting and intrusive activity.

Emplacement of the 74.1 m.y. andesite dikes took place prior to intrusion of the rhyolite porphyry in the Golden Rule area. There is some disagreement as to the timing of the intrusion of these dikes with respect to the age of mineralization. Hamph (1972) suggests that the dikes cut the mineralized quartz veins at the mine while Wuensh (1927) indicates that the opposite is true. Observations of contact relationships during the present study are consistent with Wuensh's interpretation, that the mineralization at the Golden Rule occurred after intrusion of the andesite dikes indicating that the age of mineralization is younger than 74.1 m.y. In one area of difficult access underneath the trap door to the second level at the mine, the mineralized quartz veins can be clearly seen to cut the andesite dike. This is the only place where this relationship is evident and it is likely that the trap door was installed after Wuensh's visit to the mine.

Temporal relationships between the dikes and the veins
are critical to obtaining the age of mineralization at the Golden Rule since the 74.1 m.y. age for the dikes is the only reference point for establishing the sequence of events. A futile attempt was made to locate zircon for age dating purposes in thin sections of the rhyolite porphyry. The strong sericite alteration of the porphyry also prohibits use of K/Ar dating techniques on muscovite or feldspar. The weak mineralization and vigorous argillization of the andesite dike at the mine described earlier is considered by this author to represent alteration in response to emplacement of the quartz veins.

Tensional (?) faulting along WNW and ENE-trending structures occurred after intrusion of the andesite dikes and may be in part coeval with intrusion of the rhyolite porphyry. Faulting related to this event is expressed in the N75W-trending "Porphyry Hill" fault located in the center of the map area on the south side of Porphyry Hill. Here sandy dolomites of the Martin Formation in the hanging wall lie in contact with the rhyolite porphyry along an irregular fault/intrusive contact. Mineralized quartz veins occur within the fault zone on the east where the contact maintains a linear trace and shows evidence of brecciation. To the west, the nature of the contact is less clear but appears to be intrusive. Stratigraphic relationships here require at least 500 feet of vertical separation between
siltstones of the lower member of the Abrigo Formation and dolomite of the Martin Formation indicating that some faulting occurred prior to and perhaps during intrusion of the rhyolite porphyry.

A similar EW-trending fault mapped by Hamph (1972) as the "Contact Fault" most likely represents the same pre-intrusive structure on the north side of Porphyry Hill but is concealed beneath alluvium. Material found on a dump in this area contains angular clasts of lower Abrigo Formation siltstone and rhyolite porphyry in a hematitic breccia cemented with calcite (fig. 16). Repeated movement on the Porphyry Hill and contact faults is indicated by the fact that the mineralized quartz veins originally emplaced along these faults are themselves brecciated. In both areas, portions of this structure are mineralized and a number of prospect pits and shafts have been developed on veins intermittently exposed at or near the fault/intrusive contact.

Another normal fault of this age is exposed in a thrust sliver in the southernmost portion of the map area. Relatively minor offset is indicated here as quartzite and dolomitic sandstones of the uppermost Abrigo Formation lie along an irregular fault contact with dolomite of the lower Martin Formation. A few small prospects have been developed on veins lying along this structure. All of the
Figure 16. Brecciated Abrigo Formation shales and rhyolite porphyry intrusive material from the "Contact" fault.
E-W-trending faults of this generation clearly pre-date Laramide compressional deformation, having been truncated by the thrusts.

Forceful intrusion of the rhyolite porphyry along the Porphyry Hill/Contact Fault is indicated by tilting of the Paleozoic section away from the intrusive body. This relationship is apparent on all sides of the intrusion except to the east where the contact lies beneath alluvium. Some faulting and folding at the Golden Rule mine may have occurred at this time. Tight folding about a N70E axis in association with minor faulting is expressed on the west side of the hill above the mine and the lower adjacent hillside. These folds are particularly well expressed in the silty crenulated limestones of the middle Abrigo (fig. 17).

Laramide thrusting in the Dragoons is thought to have begun as early as 85 m.y. ago and, continuing until Paleocene time (Hayes, 1987). Numerous NW-trending thrust faults of Laramide age have been mapped in the northern Dragoons by Drewes (1987). In the Golden Rule mine area, one of these faults is well exposed along the western side of the map area. Mineralization occurs sporadically along the thrust as pods of crushed and extensively oxidized sulfides in a quartz gangue.

The thrusting in the Golden Rule mine area must have
Figure 17. Folding expressed in the middle member of the Abrigo Formation.
occurred after intrusion of the andesite dikes but before emplacement of the rhyolite porphyry. The main thrust fault in the map area is clearly truncated by the rhyolite porphyry to the northwest while the andesite dike in the center of the map area is itself truncated by the same thrust.

An important observation with regard to intrusion of the rhyolite porphyry is the fact that no andesite dikes were noted that cut the porphyry. The marked difference in response to weathering of these rock types should make the presence of the andesite dikes conspicuous in outcrop. The dikes were observed to cut virtually all of the other rocks in the Golden Rule area. This observation further reveals that emplacement of the andesite dikes pre-dates intrusion of the rhyolite porphyry as well as the mineralization at the Golden Rule.

Drewes (1987), notes that rhyolite dikes of similar composition southwest of the Golden Rule area are cut by Miocene basalt dikes. If the rhyolite dikes mentioned by Drewes are related to the porphyry at the Golden Rule, it is possible to establish an age range of between Late Cretaceous and Miocene for the rhyolite porphyry at the Golden Rule.

Numerous northeast and northwest-trending faults are exposed in the mine workings at the Golden Rule. Mapping by
this author and Hanph (1972) has shown that, with one exception, both sets of faults post-date mineralization with the northeast set as the younger. The one exception is a NW-trending fault that has been mineralized and can be seen underground at the mine on the first level near the end of some recent workings to the west. Some of the younger structures show evidence of late stage silica flooding and brecciation but are not mineralized. Many of these faults are not evident on the surface, as displacement on most is not significant. Two important N40W-trending faults of this group, west of the mine, offset all three members of the Abrigo Formation and the mineralized quartz veins.

Two important faults of post-Laramide age include a N50E-trending high-angle normal fault in the center of the map area and the breccia fault at the mine. Locally strong silicification has occurred along the trace of the fault in the center of the map area most notably at its intersection with the thrust fault. The silica is characteristically vuggy, coarsely crystalline, and often includes angular fragments of silicified limestone of the Escabrosa Limestone. The breccia fault also shows significant silicification. In both cases, andesite dikes are intimately associated with the NE-trending structures.

The geochronology of events in the Golden Rule mine can
be summarized as follows:

1. Following deposition of Paleozoic sediments, faulting occurred along E-W-trending high-angle (?) structures.
2. Intrusion of 74.1 m.y. andesite dikes.
3. Laramide compressional deformation manifested by thrust faulting, bedding plane faulting, and folding.
4. Intrusion of the rhyolite porphyry and subsequent mineralization along the thrusts, bedding plane faults, and E-W-trending structures.
5. NE and NW-trending high-angle normal faulting of late Tertiary (basin and range) age.
CHAPTER V
MINERALIZATION

The Golden Rule mine area is listed as one of six areas of probable mineral resource potential in a study of the northern Dragoon roadless area by Drewes and Kreidler, (1984). Much of the mineralization noted in the survey occurs as skarn-type deposits in mixed limestone and shale near granitic intrusions. Production from various small properties accounts for nearly $2 million worth of lead, zinc, silver, and with minor gold and tungsten. In comparison, the Golden Rule is clearly anomalous both with respect to its high gold content and absence of skarn-type alteration.

Samples collected along the mountain fronts and tributaries of the northern Dragoon range for the survey were analyzed for a variety of elements including Wo, Bi, Mo, B, Be, Pb, Sn, Ag, Cu, Zn, and As. The results of the survey showed anomalous concentrations of Mo (150-200 ppm), B (50-70 ppm), and Pb (5000-7000 ppm) in heavy mineral separates from sediments derived primarily from the drainages southeast of the Golden Rule mine. These drainages emanate from a source area cut by the prominent northwest-trending thrust faults discussed earlier. It is likely that mineralization associated with these thrusts is
the source of the anomalous material since reconnaissance by this author of the upper portions of this drainage system did not reveal any other significant exposed mineralization.

Additional evidence for the influence of the thrusts on ore localization are results from a soil geochemistry survey conducted by Exxon Minerals in 1983. Exxon ran two soil sample lines across the Golden Rule mine area analyzing for Hg, Pb, Zn, Au, and Ag. The location of anomalous zones with respect to these elements corresponds closely to the trace of the thrust faults. The sampling by Exxon also indicates that the rhyolite porphyry intrusion is not preferentially enriched in base or precious metals over background levels. While the rhyolite porphyry is pervasively altered and locally mineralized along high angle vein structures, no stockwork type mineralization was observed.

Additional sampling and mapping during the present study has indicated that mineralization occurs in three settings:

1. Along bedding plane faults in the Abrigo Formation (Golden Rule mine).
2. Along the E-W-trending structures in and adjacent to the rhyolite porphyry intrusion.
3. Within shear zones along or related to the thrust
faults.

The most significant setting in terms of exploitation is the Golden Rule mine itself where over 9,000 ounces of gold were produced from mineralized quartz veins. Similar ore-bearing veins in the intrusive rhyolite porphyry south of the Golden Rule have been worked on a much smaller scale. The third area includes numerous prospects and shafts of unknown extent located primarily along traces of the major NW-trending thrust faults.

**Bedding Plane Faults (the Golden Rule mine)**

The workings, history of mining, and mine geology have been described in detail by Hamph (1972) so that only a brief summary will be given here.

The Golden Rule deposit or "Old Terrible" was located during the late 1870's and the first production of over 6,000 ounces of gold was reported in 1883. Various owners have since produced an additional 3,492 ounces of gold as well as over 340,000 pounds of lead. The present (1988) owners of the property have extracted 700 tons of ore from new workings on the extreme western side of the 70 ft. level in 1982. A 15 pound sample of this material assayed in 1987 averaged 2.95 oz/ton Ag, 0.68 oz/ton Au, and 7.47 % Pb.

Mineralization at the Golden Rule is characterized by
thin tabular quartz veins containing pyrite, argentiferous galena, minor sphalerite and chalcopyrite, gold, and small amounts of supergene cerussite and covellite. The main ore body (main vein) rarely exceeds 2 feet in thickness and is exposed on the surface for over 700 feet. The vein occupies a bedding plane fault surface that crosscuts bedding in the lower and middle members of the Abrigo Formation at a low angle. Mining has removed much of the known ore body down-dip from the surface to a vertical depth of 109 feet. The mineralized bedding plane fault is truncated by a normal fault on the west while to the east the extent of the veins is unknown. The original "Old Terrible" mine lies to the east of the Golden Rule but very little is known of the extent of the workings there. A cloudburst occurred prior to Wuensch's visit to the property in 1927 filling the workings to the east with sediments and blocking further access. Wuensch indicated that, according to some "old timers", exceedingly rich ore was encountered to the east where the vein approaches the contact with the rhyolite porphyry.

The veins at the Golden Rule are composed predominantly of milky quartz containing between 15 and 25 % sulfides. The quartz is primarily coarse grained, vuggy, and locally stained with hematite and manganese oxides. At least three generations of quartz deposition are evident, two of which
are coeval with sulfide mineralization. The last stage involves low temperature (?) silica flooding along structures like the breccia vein described by Hamph (1972) that crosscut and locally offset the mineralized veins.

The predominant sulfide minerals in the veins are pyrite and galena with pyrite occurring early in the paragenesis. The pyrite is euhedral and occurs both in the veins with the other sulfides and quartz and in the carbonate wallrock in well defined horizons along bedding. The observation that pyrite occurs along bedding in relatively unaltered limestone may suggest some reconstitution of original authigenic pyrite or addition of hydrothermal sulfur forming pyrite from glauconite-rich sediments.

According to Hamph (1972), over 90% of the gold in the veins occurs with iron oxides, presumably oxidized pyrite, suggesting that much of the gold may have been deposited early with the pyrite. In addition, petrographic examination of polished sections by this author suggests that some gold is present in veinlets cutting the main vein as free gold in quartz. The gold occurs as shreds, micro- veinlets, and rarely as coarse visible grains along fractures (fig. 18).

Deposition of sphalerite occurred after early pyrite followed by galena. Sphalerite has been largely replaced by
Figure 18. Visible gold in quartz (magnified 7X).
galena but, where visible, the sphalerite contains exsolution blebs of chalcopyrite indicating replacement of, or epitaxial growth with the sphalerite. Galena occurs late in the paragenetic sequence as open space fillings and has largely replaced all earlier sulfides except pyrite.

Minor supergene enrichment is indicated by covellite replacing sphalerite and chalcopyrite and as rims on pyrite and galena (fig. 19). The degree of oxidation of the sulfides is variable with some cerussite and hematite replacing galena and pyrite respectively.

The paragenetic sequence for mineralization at the Golden Rule consists of early pyrite, gold, and quartz followed by additional quartz with sphalerite and chalcopyrite (fig 20). Late galena replaces all other sulfide minerals and is in turn replaced to a very minor extent by covellite. Some additional gold mineralization occurred after galena.

Veins Hosted by the Rhyolite Porphyry

Mineralized quartz veins also occur sporadically within and adjacent to the rhyolite porphyry intrusion. The veins are narrow, steeply-inclined fissures most of which trend parallel or subparallel to the E-W-trending Contact and Porphyry Hill faults. Most of the veins are laterally discontinuous, rarely exceeding 100 feet in strike length,
Figure 19. Photomicrograph showing supergene replacement of intergrown chalcopyrite and sphalerite by covellite (20X magnification).
Figure 20. Paragenetic sequence of Golden Rule sulfides.
and often branch out into the wallrock (fig. 21). Many are barren, containing only milky quartz, while others are strongly mineralized. The mineralized vein material consists of very coarse-grained vuggy quartz, with largely oxidized pyrite, galena, and sphalerite with traces of chalcopyrite. Open space filling is indicated by euhedral quartz crystals enclosing masses of the oxidized material. Numerous prospect pits and shafts have been developed on those veins where significant surface indications of mineralization are present.

With the exception of one NW-trending vein system on the east end of Porphyry Hill, the veins along the contact between the rhyolite porphyry intrusion and the sedimentary rocks represent the principal mineralization in this area and have hence been developed to a larger extent than veins that lie entirely within the intrusive mass. The most important of these is the Contact Fault vein system in the northeast portion of the map area (RP-1, see plate I). A 70 foot shaft has been sunk along a vertical to steeply north-dipping vein at the contact between the lower member of the Abrigo Formation and the rhyolite porphyry intrusion. Minor drifting to the northeast was undertaken in an effort to reach the vein but the results are unknown. Crushing and brecciation of the rhyolite porphyry and some of the ore adjacent to the structure indicates that pre- and post-ore
Figure 21. Mineralized quartz vein cutting rhyolite porphyry.
faulting has occurred.

Samples taken from dump material by Hamph (1972) indicate significant gold mineralization at 0.40 oz/ton, a value significantly higher than the grades from veins encountered elsewhere within the intrusive rocks. Another shaft about 1100 feet WSW of the contact shaft has been sunk along a vein that lies within the rhyolite near the inferred porphyry/Abrigo Formation contact. Dump material assayed by Hamph indicates gold mineralization at 0.10 oz/ton (RP-2).

Other mineralized quartz veins occur on the south side of Porphyry Hill along the Porphyry Hill Fault. A number of prospect pits and shafts have been developed along veins associated with this structure. The brecciation along the fault contact here, as along the Contact Fault, suggests post-ore movement. A sample of dump material from one of these workings contained negligible amounts of precious and base metals (RP-5).

Another system of veins that lies entirely within the rhyolite porphyry intrusive rocks is located on the extreme eastern end of the exposed intrusion (RP-3,4). Three shafts have been sunk along veins oriented N70W dipping steeply to the northeast. Samples taken from dump material containing some fresh sulfides were remarkably low in gold (0.047, 0.69, 0.34, 0.34 ppm), with comparatively weak Ag values as
well (24.4, 10.0, 6.8, 10.0 ppm). One of four samples from these veins contained significant Pb (2.0 %) but very low Ag values (< 1.7 ppm). In comparison, over 60 samples of ore containing 2 percent Pb at the Golden Rule mine also contained more than 31 ppm Ag.

A number of smaller workings are developed elsewhere on veins that cut the rhyolite porphyry but these are of minor importance. Most do not extend for more than a few tens of feet and are less than one foot wide.

Alteration associated with the veins in the rhyolite porphyry is confined to the larger vein structures. Locally strong argillic alteration is present along a few of the veins with gouging and strong hematite staining.

Silicification has occurred along many of the smaller veins systems as numerous anastomosing veinlets of milky quartz in the wallrock.

Clearly, the most important event in terms of alteration of the porphyry is the pervasive phyllic alteration affecting the entire intrusive mass while the silica flooding may represent early and late stage quartz deposition along structural conduits cutting the intrusive and sedimentary rocks alike. The argillic alteration adjacent to the veins appears to post-date the widespread phyllic event.

Unoxidized material from the veins in the rhyolite
porphyry is scarce but a few polished sections were made from moderately fresh ore samples. At least three generations of quartz are evident. As was the case at the Golden Rule, deposition of pyrite occurred early with some of the more coarse-grained quartz and pre-dates all earlier sulfides. Weak sphalerite mineralization accompanies additional pyrite and appears to replace some quartz along grain boundaries. Late galena mineralization fills open spaces and replaces some pyrite while sphalerite and chalcopyrite are almost completely replaced with galena.

Late supergene processes are also evident in the rhyolite porphyry veins with replacement of galena by covellite and cerrusite.

Veins Along the Thrust Faults

Numerous shafts and prospects have been developed south and west of the Golden Rule mine and rhyolite porphyry along the main thrust fault and several smaller structures associated with this thrust in the southern part of the map area. Mineralization associated with these structures consists of poorly defined vein systems within dolomite of the lowermost Escabrosa Limestone and siltstones of the upper Martin Formation. The vein material is characteristically crushed and extensively oxidized so that the original sulfide mineralogy is difficult to ascertain.
The quartz gangue is pervasively fractured and stained with hematite (fig. 22).

Typically the veins are of very limited lateral extent, irregular in shape, and contain fragments of incorporated wall rock. Repeated post-ore movement along the thrusts has brecciated and modified the veins, disrupting any lateral continuity.

Vein material sampled for assay from dumps and outcrops along the thrust trace reveals variable Pb (.01-4.7%), Zn (.01-1.6%), Ag (.15-9.25 oz./ton), and occasional weak Cu mineralization. None of the samples contained gold in amounts exceeding 0.02 oz./ton.

A series of short adits, shafts, and prospect pits have been developed along the thrust fault trace just to the south of the saddle between Porphyry Hill and the steep slopes of Escabrosa Limestone on the west (TF-1,2). Here, vein material lies along an irregular zone of crushed and mineralized Escabrosa dolomites and recrystallized limestones. Brittlely deformed quartz gangue containing pockets of hematite-stained boxworks obtained from a dump at a small glory hole in this area contained over 9 oz/ton Ag with more than 5 % combined Pb and Zn.

Other workings along the thrust at the end of a jeep road in the southeastern part of the map area appear to be the most extensive judging from the size of the dump (TF-
Figure 22. Crushed and oxidized vein material along a major thrust fault.
4). No published information is available on these workings however a local resident, having descended an inclined shaft by ropes, indicated that substantial stoping was undertaken on ore lying along the thrust fault surface to the east. Material from the dump contained significant zinc mineralization (1.7 %).

About 500 feet northeast of these workings a few small prospects expose some veins at the intersection of an E-W-trending fault and a N-S-trending fault in a thrust wedge made up of upper Abrigo and lower Martin dolomites and sandstones (TF-6,7). Strong Ag and Pb mineralization (>4.5 oz/ton, 2.8 % respectively) occurs along narrow discontinuous milky quartz veins.

In hand specimen, most of the mineralized rock found in the thrust fault veins is extensively oxidized with intricate boxwork textures. Limonite associated with the oxidized material is orange-yellow to deep maroon indicating significant Pb and Zn oxidation in the presence of pyrite. Locally cores of sphalerite and galena can be seen in fresher material. Small amounts of copper are also present as coatings of chrysocolla and malachite.

Comments  Localization of ore in the Golden Rule area is clearly controlled by structure. The most economically significant occurrence is the main vein system at the
Golden Rule mine itself while the extent of production from the rhyolite porphyry and thrust fault systems is unknown. There is little doubt that the structures acted as conduits for the mineralizing solutions, and that some movement along the structures, most notably the thrusts, occurred after the mineralization. The occurrence and ratios of precious and base metals however, appears to vary greatly in each of the three settings described.

Veins in all three settings contain strong lead mineralization which occurred late in the evolution of the system, and replaced early sphalerite and chalcopyrite. The veins in the thrust faults appear to contain more zinc in association with high silver than do the veins in the rhyolite porphyry and Golden Rule mine. Areas of strong silver mineralization (0.83–9.25 oz./ton) along the thrusts also show correspondingly anomalous Te (>10 ppm), while silver-bearing ore at the mine contains less than 0.10 ppm Te.

The most significant relationship with respect to the distribution of metals is the occurrence of ore grade gold mineralization in association with the Abrigo Formation. Only those veins that occur in close proximity to the Abrigo Formation appear to contain gold in significant quantities. For example, the veins at the contact shaft and a prospect in the extreme northwest part of the map (RP-6)
contain mineralization at 0.40 and 0.078 oz/ton Au where lower Abrigo siltstones have been juxtaposed with the rhyolite porphyry. Other veins that lie entirely within the intrusive rocks are essentially barren with respect to precious metal mineralization even though they appear to be similarly mineralized with base metal sulfides.

Mineralized quartz veins along the thrust faults locally contain impressive Pb, Zn, and Ag values but very little gold. Of the eight samples collected from mineralized outcrops and dumps along the thrust faults, none contained gold in excess of 0.02 oz/ton.

Initially it was thought that perhaps the veins at the Golden Rule mine represent a separate mineralizing event temporally distinct from the mineralizing event that affected the other structures. The evidence from the paragenetic sequence of ore constituents for all three settings just described and the results of fluid inclusion studies (next chapter) however, indicate that the precious and base metal mineralization in all three settings most likely originated from the same fluid.
CHAPTER VI
FLUID INCLUSION STUDIES

Twelve doubly-polished thin sections were prepared from gangue quartz at the Golden Rule for fluid inclusion studies. These studies involved heating and freezing of the inclusions in order to establish the temperature and pressure of the system at the time the inclusions formed. Six samples were taken along the strike of the main vein system at the Golden Rule mine while the remaining samples consisted of material from veins in the nearby rhyolite porphyry and prospect pits located along the main thrust fault southwest of the mine. Additional material from these same locations was also assayed for base and precious metals.

In all, over 350 individual measurements were made on 179 separate inclusions. These measurements included homogenization temperatures for primary and secondary inclusions, homogenization temperatures for CO$_2$ phases in the primary inclusions, temperature of last melting for clathrate hydrate and ice phases, and triple-point temperatures for the CO$_2$ component. The eutectic temperature of the aqueous component in the primary inclusions could not be measured.

Measurements were made using a USGS/SGE Inc. gas-flow
heating and freezing stage. The stage was calibrated using artificial CO$_2$-H$_2$O inclusions prepared by Synflinc, Inc. (Sterner and Bodnar, 1984).

**Fluid Inclusion Petrography**

**Golden Rule veins** The six samples at the mine were taken from surface exposures spanning approximately 500 feet of continuous strike length along the main vein system. The samples contained an abundance of fluid inclusions ranging in size from a few microns to as much as 30 microns. Individual inclusions were classified as primary or secondary according to criteria established by Roedder (1984). Inclusions considered to be of a primary origin were located in areas free of fractures, were randomly distributed in three dimensions, and many were isolated from other inclusions by a few times the diameter of the inclusion under consideration.

Two types of inclusions (A and B) were identified and utilized for this study.

**Type A inclusions:** At room temperature type A inclusions contained a CO$_2$-rich vapor phase, separated from a low salinity liquid H$_2$O phase by a darker, less dense CO$_2$ liquid rim (fig. 23). Inclusions of this type were carefully examined for evidence of a primary habit. The
Figure 23. Photomicrograph of type A primary CO₂-rich fluid inclusion (40X magnification). Inclusion is 15 microns in length.
phase ratios in primary type A inclusions appear to be reasonably constant. Type A inclusions commonly occur in groups and many are well-formed negative crystals. Many of the inclusions are aligned along growth planes and show a preferred orientation of the long axis.

The most useful and abundant Type A inclusions are between 5 and 15 microns in length. The combined CO₂ liquid and gas phases occupy from 50 to 70 volume percent of the inclusion cavity. The volume of liquid vs. gas for the CO₂ component averages about 70% CO₂ liquid.

**Type B inclusions:** Inclusions of this type are considered to be secondary in origin and are much more abundant than type A. These inclusions range in size from less than one micron to over 25 microns. They consist of separate liquid and gas phases, with the gas bubble occupying less than 30% of the inclusion volume (fig. 24). These inclusions commonly occur in planar groups indicating formation along fractures. Type B inclusions consistently homogenized at temperatures much lower than type A.

**Veins in the rhyolite porphyry** The three samples examined from quartz veins in the nearby intrusive rocks contain both type A and B inclusions, although far fewer type A inclusions were noted than in the Golden Rule
Figure 24. Photomicrograph of type B secondary inclusion (40X magnification). Inclusion is 25 microns in length.
quartz. Type B inclusions in this material show a great deal of variation in size and shape with some inclusions exceeding 30 microns in diameter. The phase ratios of the primary type A inclusions in the rhyolite porphyry veins are similar to those of the inclusions from the mine but the total inclusion volumes appear to be somewhat smaller.

Veins in thrust faults The last three samples were obtained from ore-bearing quartz taken along a major thrust fault and a small prospect in the southernmost portion of the map area. Field evidence indicates tectonic deformation of vein material with fragments of wallrock incorporated into a shattered breccia with some late quartz. In thin section, the vein quartz is seen to be recrystallized along a preferred orientation and exhibits undulose extinction. Deformation obviously influenced the orientation and type of fluid inclusions observed in thin section. Although two of the samples contained both types of inclusions, evidence of a primary origin for type A was less certain because of the pervasive fracturing. In the sample from the southernmost prospect (TF-6), no type A inclusions were observed and the inclusions were almost exclusively entrained along fractures with a preferred orientation. In addition, the average size of the inclusions was notably smaller, most less than 5 microns in diameter making
inclusion behavior during freezing and heating runs difficult to observe.

**Salinity Measurements**

A total of 91 freezing point depression measurements were obtained from both types of inclusions. In type A inclusions salinities were determined from last melting temperatures of the clathrate hydrate \((\text{CO}_2 \cdot 5.75 \text{H}_2\text{O})\) (Collins, 1979). In the type B inclusions salinity measurements were obtained from last melting of ice (Potter, et al, 1977).

**Type A**

Fluid composition can be estimated from the behavior of \(\text{CO}_2\)-rich type A inclusions at temperatures below the critical point of \(\text{CO}_2\) (31.1 °C). In a pure \(\text{CO}_2\)-\(\text{H}_2\text{O}\) system, the triple point temperature of \(\text{CO}_2\) is -56.6 °C and melting of the clathrate hydrate should occur at 10 °C (Collins, 1979). The presence of dissolved salts such as NaCl or KCl in the fluids however, is known to lower the melting temperature of the clathrate. Collins has demonstrated that useful salinity measurements can be obtained from the temperatures of decomposition of the hydrate phase.

Dissolved gases may also affect phase equilibria. The presence of \(\text{CH}_4\) for example, is known to shift the triple point for \(\text{CO}_2\) to lower temperatures (Burruss, 1981).
A total of 55 triple point measurements were made on type A inclusions from the mine and the rhyolite porphyry veins. The measurements defined a range of between -56.2 and -58.3 with an mean of -57.0 for the CO\textsubscript{2} triple point. This represents a corrected range of values with respect to the analyzed precision for the synthetic CO\textsubscript{2} inclusions (1.4 °C). These data suggest that minor amounts of CH\textsubscript{4} or other gases may be present in type A inclusions.

Temperatures of clathrate decomposition indicate the presence of dissolved salts, probably NaCl, in the samples analyzed since clathrate melting occurred in all type A inclusions at temperatures below 10 °C. The presence of other salts such as KCl was not established because salt-water eutectic temperatures could not be measured. Of the 49 clathrate melting temperatures obtained for all eleven samples containing CO\textsubscript{2}-rich type A inclusions, over 90% lie between 6.3 and 8.9 °C. Most of those that lie outside this range were from the tectonically strained quartz from the prospect pits discussed earlier. This temperature range corresponds to a salinity of between 2.0 and 6.0 equivalent wt.% NaCl (Collins, 1979) (fig. 25).

Type B

Temperatures recorded for last melting of ice in the type B inclusions ranged from -3 to -6.5 °C indicating a salinity range of between 5 to 9.5 equivalent wt.% NaCl
with an average of about 6.5 % (fig. 25). The larger type B inclusions in the rhyolite porphyry veins were particularly useful for salinity measurements. These values for the type B inclusions indicate slightly higher salinities on average than those calculated for type A.

**Homogenization Temperatures**

A total of 44 homogenization measurements were recorded for type A inclusions. Difficulties arising from decrepitation due to increased internal pressure as the inclusions were heated limited the number of useful homogenization data for type A inclusions. Homogenization temperatures for type B inclusions were recorded in order to monitor changes in fluid temperature with time.

The temperatures of final homogenization for both types of inclusions are clearly grouped in two distinct ranges for veins at the mine and rhyolite porphyry (fig. 26). These data indicate a high temperature grouping for type A inclusions ranging from 275 to 315 °C and a lower temperature group for type B inclusions between 195 and 235 °C. The overall uniformity for type B homogenization temperatures is significant. It is likely that type B inclusions represent a later, temporally distinct circulation of lower temperature fluids.

Temperatures obtained from vein material from prospect
Figure 25. Fluid salinities for primary type A and secondary type B inclusions.
Figure 26. Homogenization temperatures for primary type A and secondary type B inclusions from the Golden Rule and rhyolite porphyry veins.
pits along the thrust faults are erratic and span the entire range of temperatures for the other veins (fig. 27). This observation is consistent with petrographic and field evidence for continued deformation of the mineralized quartz veins along the thrust faults. There does appear to be a small grouping at approximately 195 °C similar to the larger groupings in the rhyolite porphyry and Golden Rule veins.
Figure 27. Homogenization temperatures for primary type A and secondary type B inclusions from veins along thrust faults.
Geobarometry

Type A  In addition to salinity, estimates of the bulk molar volume of the fluid may be obtained based on the low temperature behavior of the CO₂ phases. Volumetric measurements of the CO₂ component in type A fluid inclusions are critical for obtaining estimates for a minimum pressure of trapping. The trapping pressure can be estimated (ideally) by comparison of the composition and homogenization temperatures for type A inclusions with experimentally derived solvi in the CO₂-H₂O-NaCl system. The composition of CO₂-rich inclusions can be determined by establishing: (1) the density of the CO₂ phases, (2) the internal pressure of the inclusion at 40 °C, and (3) the volume % H₂O of the inclusion (from petrographic observations at 40 °C). Once the composition, salinity, and temperature of homogenization of the fluid is known, an estimate for the pressure of trapping of type A inclusions can be made.

The temperature at which homogenization of CO₂ phases occurs is a function of fluid density (Roedder, 1984). For type A inclusions, the bulk density of the CO₂ phases is greater than the critical density of CO₂ (0.4 g/cm³) because the CO₂ phases homogenize to the liquid phase.

A total of 54 homogenization temperatures for CO₂ phases in type A inclusions were recorded primarily from
the Golden Rule veins (fig. 28). A mean temperature of homogenization of 27.4 °C was established with a standard deviation of 1.69. This indicates a fluid density for the type A inclusions of 0.76 g/cm³ (Roedder, 1984). A density of 0.76g/cm³ corresponds to an internal pressure of 130 bars (Burruss, 1981).

Figure 29 illustrates how the bulk density of the fluid can be obtained if the volume % H₂O and the internal pressure is known. A mean volume of 43.4 % H₂O of the total inclusion cavity was established after a survey of phase volumes for a number of primary type A inclusions was conducted. The mean volume lay within a range of between 30 and 50 % with a standard deviation of 13.4. Visual estimates of volume % H₂O will naturally introduce some error since the inclusions are not equidimensional.

Volume ratios of the CO₂ and H₂O phases were measured at 40 °C. At this temperature, it is assumed that the CO₂ and H₂O phases are essentially pure. For type A inclusions, an internal pressure of 130 bars with a 43 volume % H₂O component corresponds to a bulk fluid density of 32 moles/liter. This density projected to the isotherm representing homogenization of the CO₂ phases at 27.4 °C in figure 30 yields a value of 78 mole % H₂O for type A inclusions in a range of between 63 and 80 mole %.

An estimate of the minimum pressure of trapping of
Figure 28. Temperatures of homogenization of CO₂ phases for type A inclusions.
Figure 29. Density-pressure diagram for coexisting CO$_2$-H$_2$O fluids at 40 °C. Dashed lines indicate 42.4 volume % H$_2$O and 130 bar pressure for type A inclusions. From Burruss, 1981.
Figure 30. A polythermal density-composition diagram for \( \text{CO}_2 \)-rich fluid and \( \text{H}_2\text{O} \)-rich liquid. \( Th \) = homogenization to \( v \) (vapor), \( cr \) (critical), \( l \) (liquid). Dashed line indicates type A bulk fluid density. From Burruss, 1981.
type A inclusions can be obtained by comparing the T-X for A inclusions with T-X solvi for the system CO$_2$-H$_2$O-NaCl at various pressures and salinities once the mole % H$_2$O in the inclusions has been determined. The presence of dissolved salts in the CO$_2$-H$_2$O system is known to cause a dramatic displacement of the solvi to higher temperatures, such that significant errors in pressure estimates could arise if the salinity of the fluid were not considered (Roedder, 1984). Bowers and Helgeson (1983) have presented a series of XC$_{CO_2}$-T diagrams at various pressures based on data from Takenouchi & Kennedy (1965), Souirajan & Kennedy (1962), and Gehrig (1980), using salinities of 6, 12, and 20 wt. % NaCl.

Figures 31, 32, and 33 show phase diagrams for a solution containing 6 wt. % NaCl at 500, 1000 and 2000 bars presented by Bowers and Helgeson with the solvus for a pure CO$_2$-H$_2$O system at these pressures superimposed for comparative purposes. The XC$_{CO_2}$ and temperature ranges for type A inclusions plot below the solvus at 500 bars for a pure CO$_2$-H$_2$O system and well below that for a 6 wt. % NaCl solution at the same pressure. At 1000 bars type A inclusions again lie below the 6 wt. % solvus but slightly above the solvus for a pure CO$_2$-H$_2$O system. Although the solvus curve for a 6 wt. % solution is further depressed at higher pressures, the data from the type A inclusions still
Figure 31. Phase diagram for the CO₂-H₂O-NaCl system at 500 bars for a solution containing 0 and 6 wt. % NaCl. Shaded area represents T-X values for type A inclusions. From Bowers and Helgeson, 1983.
Figure 32. Phase diagram for the CO₂-H₂O-NaCl system at 1000 bars for a solution containing 0 and 6 wt. % NaCl. Shaded area represents T-X values for type A inclusions. From Bowers and Helgeson, 1983.
Figure 33. Phase diagram for the CO$_2$-H$_2$O-NaCl system at 2000 bars for a solution containing 0 and 6 wt. % NaCl. Shaded area represents T-X values for type A inclusions From Bowers and Helgeson, 1983.
lie below the solvus even at pressures exceeding 2000 bars. This suggests that either: 1. the clathrate melting temperatures for the type A inclusions were made in error resulting in erroneous salinity estimates or, 2. that the solvus curves for solutions containing less than 6 wt. % NaCl are significantly depressed to lower temperatures or, 3. that other salts or gases were not detected in the type A inclusions or, 4. that the pressure of trapping of type A inclusions exceeded 2000 bars.

Some error in measuring the clathrate decomposition temperatures in the type A inclusions may have resulted from failure to distinguish the first and last melting of the hydrate. The size of the type A inclusions made separate determinations of first and last melting temperatures impossible.

With regard to the second possibility, no P-T-X data is available for a solution containing less than 6 wt. % NaCl for the CO₂-H₂O-NaCl system and it is clear from the above discussion that even a slight variation in salinity has a substantial effect on phase equilibria. Simply depressing the solvus curve for fluids of lower salinity assumes that the relationship is linear and may not be justifiable.

The internal pressure calculated for the type A inclusions discussed earlier indicates that trapping occurred at a pressure exceeding 130 bars. In addition, it
is evident from figure 31 that the minimum pressure of trapping exceeded 500 bars since the T-X data for type A inclusions plot below the solvus for both fluids containing zero and 6 wt. % NaCl.

**Type B** A minimum pressure of trapping for type B inclusions can be obtained using the data of Haas (1971), assuming that the fluids did not boil. The absence of vapor-rich inclusions in the samples analyzed suggests that boiling did not occur. A minimum of 15.1 bars was the calculated trapping pressure for type B inclusions which corresponds to a depth of approximately 153 m providing only hydrostatic load is considered. A density of 0.904 g/cm$^3$ was used for the pressure calculation to represent a fluid containing 5 wt. % NaCl at 200 °C.

Since the equilibrium vapor pressure of the fluid was less than the pressure at the time of entrapment of the type B inclusions, a temperature correction must be applied to the homogenization temperatures recorded during the heating runs (Potter, 1977). Isobaric correction curves are presented by Potter for solutions of various salinities. The temperature correction for the type B homogenization temperatures at a salinity of 5 wt. % NaCl and a minimum pressure of 15.1 bars is negligible. It should be pointed out however, that the trapping pressure of 15.1 bars is a minimum and evidence from the type A inclusions suggests
that the trapping pressure exceeded 500 bars. If the 500 bars pressure is applicable to the type B inclusions, then the temperature correction may increase by several tens of degrees.

Fluid Inclusion Discussion

The fluid inclusion studies indicate that the hydrothermal system that formed the Golden Rule deposit consisted of a 275-315 °C, CO₂-rich fluid containing an average of approximately 5 equivalent wt.% NaCl. The minimum pressure in the ore zone was high, exceeding 500 bars. Evidence from secondary inclusions indicates a later, temporally discrete circulation of lower temperature fluids of slightly higher salinity.

A minimum pressure of 500 bars would require a depth of burial of 1.9 km (lithostatic), or 2.5 km (hydrostatic). The lithostatic load assumes a density of 2.71 for limestone and the hydrostatic pressure was calculated using additive densities of 0.904 g/cm³ (200 °C, 5 wt. % NaCl solution) and 1.0 g/cm³ (cooler, denser solution higher in the fluid column). The thickness of a column of rock that may have existed above the Golden Rule veins in the Laramide ranges from approximately 2.8 to a maximum of 3.73 km assuming that no repetition of the strata has occurred. Hydrostatic pressures at these depths would range from
approximately 400 bars to a maximum of 550 bars.

As suggested earlier however, the evidence from mapping in the area indicates that many of the mineralized quartz veins lie along thrust faults. If portions of the section were repeated by thrusting, the additional overburden would have increased the pressure on the system at the time of entrapment.

The pressure estimates discussed above are consistent with the minimum pressure estimates derived from the type A inclusions suggesting that the trapping pressure during formation of the Golden Rule ore body exceeded 500 bars.

Since the average geothermal gradient for the Basin and Range of 30 °C/km would yield temperatures of only 84 to 112 °C at these depths, some other heat source would be required to generate temperatures in the range calculated for the Golden Rule deposit. It is possible that the veins in the Golden Rule area were formed peripheral to an intrusive center since the minimum temperatures and pressures calculated from the fluid inclusions suggest deposition at the upper limits for an epithermal system and may be more compatible with a mesotherm al environment.
CHAPTER IX
SULFUR ISOTOPES

Sulfur isotope studies were undertaken to test a hypothesis that the Abrigo Formation may have been a potential source for sulfur and perhaps other ore constituents at the Golden Rule mine. The Abrigo Formation has been termed a "fetid" limestone and studies of thin sections indicate the presence of substantial authigenic pyrite which is known to form from \( \text{H}_2\text{S} \) produced by anaerobic bacteria. The Abrigo Formation was deposited in a tidal flat setting during middle to late Cambrian time, an environment conducive to the production of algae and \( \text{H}_2\text{S} \) (McClure, 1977). The abundance of glauconite and authigenic pyrite, and the presence of fossilized algal material within the Abrigo Formation indicate deposition in the presence of decaying organic matter.

If the sulfur present as sulfide in pyrite and galena from the mineralized quartz veins at the Golden Rule could be shown to be enriched in the light isotope \( ^{32}\text{S} \), it would suggest a biogenic origin for the sulfur, i.e. from the enclosing sediments. Sulfate reducing bacteria in modern euxinic environments are known to contain \( \text{H}_2\text{S} \) which is enriched in \( ^{32}\text{S} \) by as much as 50 per mil compared to the coexisting sulfate (Faure, 1977).
Four samples of pyrite and galena were obtained from ore collected from the Golden Rule mine for isotopic analysis. The samples were crushed, and then reacted with cuprous oxide at 900 °C. A system of ethanol and pentane baths was used to extract H₂O, CO₂, and finally SO₂ gas. The SO₂ was then placed in a modified VG602C mass spectrometer to obtain δ³⁴S values. The corrected δ³⁴S values are shown in table I.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Corrected δ³⁴S</th>
</tr>
</thead>
<tbody>
<tr>
<td>S979py</td>
<td>-1.8</td>
</tr>
<tr>
<td>S980gn</td>
<td>-1.6</td>
</tr>
<tr>
<td>S981py</td>
<td>-2.6</td>
</tr>
<tr>
<td>S982gn</td>
<td>-1.7</td>
</tr>
</tbody>
</table>

Table I. Corrected δ³⁴S values for pyrite and galena from the Golden Rule mine. Sample numbers S979py and S980gn are from one ore sample, numbers S981py and S982gn from another.

Differences in the δ³⁴S values of cogenetic sulfides in mineral deposits have been demonstrated to have a linear relationship to the temperature of formation, provided there was isotopic equilibrium (Faure, 1977). In an equilibrium assemblage, the δ³⁴S values are highest for pyrite followed in order by sphalerite, chalcopyrite, and galena. If the sulfides were deposited from the same fluid
at the same time, then the equilibration temperature should approximate the trapping temperature obtained from the fluid inclusion studies. It is evident from the data above that there is very little difference in the $^{\delta^{34}}$S values between pyrite and galena.

An equation for calculating the temperature of isotopic equilibrium between pyrite and galena pairs was presented by Ohmoto and Rye (1979) and was used in this study in an attempt to corroborate the homogenization temperatures generated from fluid inclusion studies (eqn. 1).

$$T^0 K = (1.01 + 0.04)10^3 \frac{\Delta^{34}S}{\Delta^{34}S}$$

A clear discrepancy exists between the fluid inclusion temperatures and those calculated using the above equation. Temperatures in excess of 800 °C were calculated from the $^{\delta^{34}}$S values from Golden Rule pyrite and galena suggesting that either the isotopic data or the results of fluid inclusion studies are in error. There is little doubt that the minimum temperatures of homogenization obtained from the fluid inclusion studies are more reliable since it has been demonstrated from petrographic evidence that deposition of galena post-dates all earlier sulfides and
hence was not likely to be in isotopic equilibrium with pyrite (see Chapt. V). In addition, a temperature of over 800°C is extremely high and is not compatible with a pyrite-galena-sphalerite assemblage.

The δ³⁴S range for the Golden Rule sulfides is limited; -2.615 to -0.68 per mil. This may suggest a magmatic origin for the sulfur since o³⁴S values associated with biogenic sulfide tend to be in the low negative range of values.

An attempt was made to generate H₂S gas from the Abrigo carbonate rocks to compare the δ³⁴S values with those from the pyrite and galena at the Golden Rule. The limestones were crushed in a weak NaOH solution to trap any acid gases, and then leached; no H₂S was recovered. In another experiment, an attempt to recover authigenic pyrite from insoluble residues was made by crushing and panning. Most of the heavy mineral fraction recovered was magnetite and much of the pyrite has been altered to limonite. A little SO₂ was obtained on combusting the heavy mineral fraction, but yielded a result of +232 ± 11 per mil, no doubt spurious, under extremely difficult mass spectrometer measurement conditions.
CHAPTER X

ALTERATION AND MINERALIZATION IN THE ABRIGO FORMATION

Significant mineralization is known to occur in association with the Abrigo Formation in many districts in southeastern Arizona and northern Mexico (see fig. 3). In some areas, as at Johnson Camp, the bulk of the ore is contained entirely within specific horizons of the Abrigo Formation. In others, such as Bisbee, the Abrigo Formation hosts substantial ore but is not the only important host rock. There is little question however, that in areas where the rocks of the Abrigo Formation are involved, a conspicuous relationship exists between the type and grade of mineralization and the proximity of the Abrigo Formation. In fact, studies have been undertaken to determine the potential for Carlin Type deposits within the lithologically favorable rocks of the Abrigo Formation. Gillette (1983), for example, sampled and analyzed apparently unaltered material from the Abrigo Formation in an area containing numerous jasperoids for the presence of low grade disseminated gold. The results indicated that gold was not present in amounts above background values (mean gold content was 0.004 ppm).

Overall, the Abrigo Formation can be considered a "dirty" carbonate unit and this no doubt is the reason for
its interest as a possible host for Carlin Type mineralization. When contrasted with most of the Paleozoic section in the region, the Abrigo Formation contains substantially more clastic material. Analyses by Nye (1968), and Cooper (1957) on unaltered rocks from the Naco Group, the Escabrosa Limestone, the Martin Formation, and the Abrigo Formation indicate that the SiO$_2$ component is exceedingly low in the carbonate rocks of the Naco Group and Escabrosa Limestone while the Martin and Abrigo Formation contain substantially more SiO$_2$ ranging from under 10% to as much as 68%. The analyses also show a marked contrast in combined Al$_2$O$_3$ + TiO$_2$ + P$_2$O$_5$ content between the same rock types. Of the three samples taken from the Naco Group and Escabrosa Limestone, none contained these constituents in amounts over 1% but the 16 samples from the Martin and Abrigo ranged from one to over 12%. The Abrigo and Martin Formations were also found to contain significant amounts of iron and sulfur. Some of the Abrigo shales in the study by Nye at Bisbee contained as much as 5% "non-hydrothermal" Fe.

The significance of the clastic component and amount of iron and sulfur present in the rock becomes apparent when the type and intensity of alteration in the various Paleozoic rock types is considered. In many localities in southeastern Arizona, the Abrigo Formation has been
preferentially silicated adjacent to intrusive bodies while the overlying carbonate rocks are only weakly silicated or recrystallized. For example, Cooper (1957) notes that very little contact alteration of the pure carbonate rocks has occurred in the Johnson district. Simple recrystallization of the Escabrosa, Black Prince, and Horquilla Limestones with rare tremolite and epidote are the only metamorphic effects observed. The nearly pure dolomite in the lower Escabrosa Limestone and Martin Formation have been recrystallized to marble while the impure carbonate rocks of the Martin and Abrigo Formations are strongly altered to silicate skarn assemblages. Although the other Paleozoic rocks are altered at Bisbee, calc-silicate alteration in the Abrigo Formation extends much further from the intrusive source suggesting that both increased permeability and reactivity aided in the extensive alteration.

Preferential alteration and mineralization in the Abrigo Formation has been noted by a number of other workers in mining camps throughout southeastern Arizona and northern Mexico. Work by Brittain (1954), Perry (1964), Weitz (1976), Rushing (1978), and Meinert (1982) all make note of the conspicuous preference for alteration or type of alteration in the Abrigo as opposed to rock types higher in the section.
The composition of the original rock strongly influences the type of alteration assemblage produced. The impure dolomites and dolomitic sandstones of the upper member of the Abrigo Formation are altered to an assemblage of diopside + tremolite + actinolite, serpentine, talc, forsterite, and orthoclase. The silty carbonate rocks of the middle member are altered to garnet + epidote + wollastonite + diopside with wavy hornfels horizons replacing the silt layers. The siltstones of the lower member are altered primarily to hornfels with garnet and epidote replacing the carbonaceous material. The hornfelsic alteration reflects the higher aluminum and iron content of the lower member.

Transfer of mineral constituents also may be enhanced between impure and relatively monomineralic horizons within the Abrigo. Cooper (1957) describes a quartzite horizon enclosed by dolomite at Johnson Camp that is partially replaced by diopside that has penetrated inward from both contacts. The SiO₂ needed for formation of diopside was supplied by the quartzite while the Mg came from the enclosing dolomite.

In addition to the influence that original composition has on alteration and mineralization, the structural competency of the Abrigo Formation as compared to other rock types may also play an important role in ore
localization. At Bisbee, the localization of ore is clearly controlled by structurally induced permeability. The more intensely shattered horizons contain the most significant ore bodies. The more competent horizons in the upper Abrigo Formation for example, were easily shattered and hence preferentially mineralized (Nye, 1968). The orientation of the ore bodies themselves generally conforms to bedding, which Nye suggests is due to both the brittle nature of the upper member and the presence of bedding plane faults.

At Johnson Camp the ore bodies are located at the intersection of favorable beds in the Abrigo Formation and fractures associated with faults. In addition, Cooper and Huff (1951) found that ore grade is closely related to the composition of the host rock at Johnson Camp.

The ore at the Abril mine southwest of the Golden Rule is also contained within the Abrigo Formation. Here, the locations of the ore bodies are clearly controlled by bedding plane faults that are particularly well developed in the rocks of the Abrigo Formation.

There are numerous other examples of ore localization within the Abrigo Formation such as the Turquoise District in the Courtland-Gleason area and some of the manganiferous silver ore bodies at Tombstone.

In summary, there are two important lithologic aspects of the Abrigo Formation that contribute to the preferential
alteration and mineralization noted in the section above. The first is the tendency for various members of the Abrigo Formation to shatter easily or otherwise compensate for tectonic stress by movement along bedding plane faults, particularly when certain horizons have been altered to calc-silicate assemblages. The ability for mineralizing solutions to penetrate the wallrocks will be greatly enhanced by the propensity of the rock for brittle failure. In the case of the Abrigo Formation, the alternation of shattered siltstones and sandstones with plastically deformed finer grained material would tend to channel fluids in a manner analogous to movement of oil through a permeable sandstone reservoir. This tendency, when developed within reactive and reduced carbonate rocks such as the Abrigo Formation, is most likely the reason for the extensive and preferential alteration and mineralization of the Abrigo Formation in the region.
CHAPTER XII
DISCUSSION AND CONCLUSIONS

It is clear that the Golden Rule deposit is anomalous in gold when compared to other mineral deposits in the region. While there are other districts that are known primarily for their gold content, production from most of these are of very limited extent. The Dos Cabezas-Teviston District in the Dos Cabezas Mountains is one exception and is credited with producing over 10,000 ounces of gold from numerous workings including the Gold Prince mine. The deposits in the Dos Cabezas Mountains however, tend to be of a considerably lower gold grade than the Golden Rule deposit. Other economically significant gold producing districts include the Bisbee, Pearce, Tombstone, and Turquoise districts that have combined to produce in excess of 3 million ounces of gold, 80% of which came from Bisbee (Wilson, et al, 1967). Although they contain significant gold, these deposits were primarily mined for Ag, Cu, Pb, and Zn. The exceptionally high gold content of the Golden Rule deposit becomes apparent when Ag/Au ratios from the Golden Rule are contrasted with those from the deposits listed above (table II).

What is also unusual about the Golden Rule is the lack of alteration within the Paleozoic section. The other
<table>
<thead>
<tr>
<th>Mining District</th>
<th>Gold/Silver Ratio</th>
</tr>
</thead>
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<tr>
<td>Bisbee (Warren)</td>
<td>0.027</td>
</tr>
<tr>
<td>Courtland-Gleeson</td>
<td>0.02</td>
</tr>
<tr>
<td>Golden Rule</td>
<td>0.64</td>
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<tr>
<td>Pearce</td>
<td>0.102</td>
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<tr>
<td>Teviston</td>
<td>0.25</td>
</tr>
<tr>
<td>Tombstone</td>
<td>0.004</td>
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deposits described earlier such as Johnson Camp and Bisbee all show significant contact alteration of the wallrock. Could the absence of alteration at the Golden Rule just be a function of distance from an intrusive source? Contact relationships with respect to the rhyolite porphyry indicate that the porphyry was probably "dry" and therefore may not have been the causative intrusion. The fact that mineralized quartz veins also cut the porphyry instead of emanating from it also suggest that some other source for the hydrothermal fluids is required.

It is reasonable to speculate that other intrusive phases related to the rhyolite porphyry lie at depth in the Golden Rule area and are not exposed. Possible evidence for a larger intrusive body in the Golden Rule area is indicated by a prominent magnetic anomaly centered in the area just south of Porphyry Hill (fig. 34) (Klein, 1983).
Figure 34. Positive magnetic anomaly centered south of Porphyry Hill in the Golden Rule area (contours at 10 gamma intervals). From Klein, 1983.
The anomaly may be produced by a deeply buried intrusive rock containing magnetite. Klein 1983 suggests that the anomaly may reflect a mafic fraction of a buried intrusion.

The possibility that the Golden Rule deposit lies on the periphery of a zoned system is also cause for some consideration. Zonation studies such as at Mineral Park in western Arizona indicate that gold tends to occur furthest from the implied intrusive source with a lead, zinc, silver zone surrounding a copper-rich core closest to the source area (Lang, 1986). Field work conducted during this study clearly shows that the metal ratios from samples in the Golden Rule area vary enormously from material rich in Ag, Zn, and Pb in the southern portions of the map area to ore from the mine rich in Au and Pb. The scale of the present study, the amount of exposure, and the number of samples taken constrain the applicability of metal zonation studies somewhat, but the contrast in metal ratios from south to north is conspicuous.

It is possible that the composition of the wallrocks along the major structures played a minor role with respect to chemical controls on precious and base metal mineralization in the Golden Rule area. Since the mineralized veins in the Golden Rule area occur as open space fillings along structures and not as replacement bodies, it is obvious that the primary control for ore
deposition was not chemical reaction with the wallrock. A combination of the orientation of the structures and, to a limited degree, host rock composition may have exerted enough chemical control on the mineralizing fluid to preferentially precipitate gold in veins within or adjacent to the Abrigo Formation. Anomalous gold mineralization occurs without exception only in the northern part of the map area in association with the Abrigo Formation. Essentially identical veins occur within the rhyolite porphyry to the south but are barren with respect to gold. The angle of the bedding plane faults at the mine enabled the ore-bearing fluids to penetrate a considerable portion of the Abrigo Formation maximizing contact with favorable horizons. The presence of locally abundant authigenic pyrite and glauconite in the sediments of the Abrigo may have reduced the oxygen fugacity of the system sufficiently to precipitate gold. Local oxidation of glauconite in the Abrigo Formation may suggest that the mineralizing fluids reacted with the host rock.
CONCLUSIONS

The temperatures and pressures inferred from the fluid inclusion studies indicate that a moderately high temperature, CO₂-rich fluid of low salinity produced the Golden Rule deposit. A minimum temperature range of 275-315 °C and pressures exceeding 500 bars suggest a mesothermal environment lying at a depth possibly in excess of 2.5 km. Temperatures in this range are most likely produced by proximity to some intrusive body.

On the basis of results from mapping, sampling, and fluid inclusion studies, the Golden Rule deposit is interpreted to have formed on the periphery an unexposed intrusion, perhaps a more mafic phase related to the rhyolite porphyry. The sporadic mineralization noted along many structures over a relatively large area indicates that fluids migrated throughout most of the section along every available conduit. Intersections of the large faults such as the thrusts with favorable stratigraphic horizons in the Abrigo are likely locations for additional ore bodies in the Golden Rule area.
### APPENDIX A

**Assay Data**

*(H) = data from Hamph (1970).*

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<th>Sample No.</th>
<th>Au</th>
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<th>Zn</th>
<th>As</th>
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REFERENCES


