Geology of the Cactus Mines, Rosamond, Kern Co., California

A thesis presented as partial fulfillment of the requirements for the degree of Master of Science in Geology. California Institute of Technology, Pasadena, California. May, 1941

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Introduction

Location of the Area.

The Cactus ore deposits are located in the western end of Middle Butte hill, about ten miles southwest of the town of Mojave. The hill extends over parts of sections 8, 9, 16, and 17; T 10 N; R 13 W, S.B.B.L. & M. This area is in the northeastern part of Antelope Valley, the westernmost extension of Mojave Desert physiographic province.

The Cactus Mines consist of three orebodies, the Cactus and the Silver Prince, both located on the same structure, and the Winkler orebody, lying roughly 1500 feet east of the Cactus in rhyolite. These deposits mark the present western limit of the Mojave Mining District which has supported considerable mining activity, at various periods, during the past fifty years.

The mines of the district are mostly of the gold-silver sulfide, epithermal type. The total production of all the mines in the district is probably near $20,000,000. Larger producers include the Exposed Treasure, Yellow Dog, Standard, and the Pride of Mojave on Standard Hill; the Queen Esther, Golden Queen, and Lodestar mines on Soledad Hill; the Tropico mine on the south side of the Rosamond Hills; and the Cactus mines in the Middle Butte.

This district, and the Randsburg area to the northeast, account for the greater part of the gold and silver production from Southern California.

Purpose of the Investigation.

The purpose of this investigation was to study and record the geology of the Cactus Mine ore deposit and, if possible, those factors which influenced or controlled the localization of ore.

This report and accompanying maps are presented as a thesis in partial fulfillment of the requirements for the Master of Science degree in geology at the California Institute of Technology; Pasadena, California.

Method of Investigation.

The underground geology of the ore deposits was mapped on each level of the mines on a scale of 1" = 20'. Structures observed were recorded, rock types and general degrees and types of alteration were noted. These maps are on file as a part of this thesis.

Samples for laboratory examination were taken from the vein, every 25 feet, down the main, or no. 2 shaft; and down the stopes and raises north of the shaft to the 800 foot level. A suite from the vein on the 700 foot level was taken at frequent intervals along the strike, and several groups were collected across the vein. The cross vein samples were separated at every change in character of the material from one wall to the other. Alteration suites were collected from crosscuts in the foot and hanging wall areas. To date, these wall rock samples have not been studied in sufficient detail to add much to the knowledge of the geology.

Each sample taken was located and plotted on the underground maps.

The mineralogy of the vein samples was studied and reported in the thesis "The Mineralogy of the Ores of the Cactus Queen Mine" filed with the California Institute in June, 1941 by Mr. Alexander Smith. Mr. Smith studied the sawn surfaces of several specimens from each sample under a binocular microscope, and selected those showing critcal features for polishing and examination in reflected light under a metallographic microscope. The mineralogy, texture, and variations in the character of the gangue were determined and recorded for each specimen. Mr. Smith's investigation forms an integral part of this entire work, and his report should be read in connection with this one.

Acknowledgements.

Mr. Harvey S. Mudd and Mr. Roy W. Moore gave the writer of this paper the opportunity and permission to make the investigation and to present it at the California Institute of Technology as a thesis. The work was done under the supervision of Dr. Horace J. Fraser who gave his time, advice, and encouragement toward it, both in the laboratory and in the field. Mr. Alexander Smith spent several days at the mine collecting ore suites, and worked for many hours on them in the laboratory with the result that much valuable information was made available. The author acknowledges with thanks the assistance of these individuals.

Physical Conditions

Relief and Elevations of the Middle Butte.

Middle Butte is an isolated hill of rhyolitic rock rising abruptly from the surrounding desert which very gradually slopes southward with practically no relief. The desert floor in the Middle Butte area has an elevation on the south side of the hill of 2900 feet, 3000 feet on the west side at the Cactus camp; and 3100 feet at the north end of the hill. The elevation of the top of the hill for nearly all of its extent is between 400 and 500 feet greater than that of the adjacent plain. The highest point, in the central area, is 3480 feet. The crest above the Cactus mine is 3310 feet.

At the southern end, Middle Butte reaches its maximum width of 1½ miles. The hill narrows along a two mile northeast "axis" to approximately ½ mile width in the north.

Several canyons cut nearly across the hill from the south and east sides. Shorter canyons on the northwest side meet the south and east side canyons at low saddles. Most of the hillsides and canyon walls slope between twenty and thirty degrees.

The summits of ridges are rounded and generally narrow, but in a few places have nearly flat areas of five or six acres which have the appearance of a surface only slightly eroded.

The topography of Middle Butte is controlled to a great extent by the degree and nature of alteration of the rhyolite and by large scale faults.* Very little of the rhyolite mass is unaltered. The two principal types of alteration are: 1. silicification of varying intensity including complete replacement of large masses of rhyolite; and 2. alunitization, usually accompanied by sericitization and kaolinization. Alunitization is more widespread than silicification and is most common in the lower and middle parts of the hill, while silicification is usually confined to the upper part. Often, the silicified rock forms a capping for several hundred yards along the crest of a ridge. This resistant rock is responsible for the crags and the lesser eroded highland areas. The softer, alunitized rhyolite is easily weathered and has permitted the cutting of deep canyons wherever the silicified capping has been cut through. Many canyons and low saddles crossing the hill are probably controlled by large faults which permit more effective weathering action.

The summit area of the hill is thus an area of low or moderate relief, composed of either the upper silicified rhyolite layer or of a hard and resistant, flow banded felsite. Weathered from this upper rock are rough, craggy ledges, 50 to 100 feet thick, which have a steep profile. In the lower, alunitized rhyolite from the base of the crag-forming ledges to the

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* Structures herein referred to as large scale are those that are traceable for several hundred feet and thus are relatively large with respect to the dimensions of the hill.

desert floor the surface slopes uniformly at a moderate angle.

Because of several long, deep canyons which cut back into the hill, the summit area is reduced to a small fraction of the total area of the hill. If the term, "butte" is used loosely this hill may be classified as such; but if a butte, it is one which has been eroded to the stage of early maturity with consequent destruction of many of its butte-like characteristics.

Geological Conditions

Regional Geology.

Middle Butte lies near the northern side of Antelope Valley, which is a large structural unit formed by two great faults, the San Andreas on the southwest side and the Garlock on the northwest. The San Andreas fault strikes S.70° E. in this area and the Garlock about N.60° E. They intersect at Tejon Pass, which forms the western apex of Antelope Valley, about thirty miles southwest of the mine. The valley is wedge-shaped, extending eastward into the Mojave Desert region with no definate boundary.

The Tehachapi Mountain range lies north of the Garlock fault and the San Gabriel range is located south of the San Andreas fault. Both mountain masses, which are three or four thousand feet higher than the valley, are composed principally of Paleozoic and older metamorphic rocks and Jurassic intrusives.

The Willow Springs fault is the largest known structure in Antelope Valley. It can be traced along the south side of Rosamond hills from Rosamond (dry) lake westerly through Willow Springs and for three or four miles beyond. Its total length is greater than ten miles. Rosamond hills were probably formed by movement on this fault. No other fault of comparable length is known in the valley.

The rocks exposed in the district form two series. The basement rock is quartz-monzonite and related acid intrusive rocks, considered as part of the Sierra Nevada batholith of Jurassic age. All rocks overlying the quartz-monzonite basement are classed as part of the Rosamond series, of Miocene age.

The Miocene rocks occur as isolated hills in various parts of the valley. They include continental sediments, tuffs, lavas, and intrusive porphyries. The volcanic facies range from felsitic and porphyritic rhyolite to andesite and some basalt. The type locality of this series is the Rosamond hills area, ten miles south of the town of Mojave.

Geology of the Middle Butte.

The regional geology of Middle Butte is still incomplete and will remain so until the area is carefully mapped in detail. Particular energy needs to be directed toward differentiating the various porphyry units, and to determining their general attitude. As yet, it is not known whether they formed as flows, or as a mass of interlacing intrusives, or as a monolith with later intrusive bodies of nearly similar porphyries cutting through it.

Mapping of the various porphyries as individual units is made difficult by their lack of reliable distinguishing features. Alteration has destroyed the diagnostic minerals throughout the major part of the mass. Inconspicuous but determinable differences in texture and grain size remain the only means of differentiation. Another difficulty is the limited extent of uninterrupted exposures.

Middle Butte is formed by a mass of rhyolite porphyry lying upon a quartz-monzonite surface. The surface dips 30^{o} to 45^{o} southeast and strikes N-35^{o} to 50^{o}-E, outcropping along the base of the northwest side of the hill. Faulting with an undetermined amount of movement has taken place along this surface. The contact between quartz-monzonite and porphyry is described later.

The hill-forming porphyries overlying the quartz-monzonite surface contain several different rock units. Rhyolite porphyry is most common. Others include quartz-keratophyre, and quartz-latite porphyries.

Several explanations have been presented for the origin of the hill. As yet none can be wholly accepted and the others completely rejected. The contact between porphyry and quartz-monzonite has been faulted to an undetermined extent. At every place so far exposed the original contact features have been masked by either a heavy gouge layer, a breccia zone several feet in width, or a quartz vein. The amount of movement along this contact fault has a vital influence on any hypothesis concerning the origin of the hill.

The original concept pictured the hill as an eroded mass of surface flows lying on an erosion surface of quartz-monzonite. If this is correct the quartz-monzonite surface and its overlying burden must have been tilted to account for the inclination of their contact. The fault-like features of the contact could have been caused by the porphyry sliding a short distance down the contact at, or after the period of tilting. The different porphyry units should then appear as flows parallel to the plane of the monzonite surface.

Dr. Harrison Schmitt[1] has suggested that the porphyry may represent material solidified within a caldera, or large volcanic orfice of the central vent type, from which there was repeated effusive activety combined with occasional explosive ejections. The contact would be classed as one wall of the caldera. This explanation requires no orderly arrangement of the porphyry units. Only a small movement would have taken place on the contact.

A third alternative postulates the porphyry mass as an intrusive plug, essentially in place, with little movement on the contact after solidification. Recurrent intrusions would be required to account for different units in the porphyry body.

Two other possibilities require large scale faulting along the contact. If the contact fault is normal with a large displacement, the porphyry mass could be a depressed block representing part of a large lava field that may have covered a surface at least a thousand feet above the present desert level. The down faulted part would be less eroded than the rest of the surface, and after the original surface was eroded the depressed block would stand as a fairly resistant mass compared to the more easily eroded quartz-monzonite. Thus the hill would be without roots and would be only a remnant of a more widespread series of flows.

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1. Harrison Schmitt, <u>Geology of the Cactus Queen Mine</u>, Private report, 1939, 1940.

Still another hypothesis postulates thrusting along the fault and the hill as a horst. The porphyry would then have been derived from a thick sill or dike many hundred feet below the present surface. This possibility is perhaps the least adaptable to the known facts.

Petrography and Petrology of the Middle Butte.

Middle Butte is composed of three different rock types. They will be described here in order of greatest age.

The basement rock is a plutonic mass belonging to the Sierra Nevada batholith. At Middle Butte it has the composition of a biotite-quartz-monzonite. Its texture is medium grained with anhedral quartz and feldspar, varying in size from 3 to 5 millimetres, with occasional crystals of subhedral orthoclase as large as 10 or 15 mm.

The approximate proportions of the minerals are as follows:

Essential minerals,

Quartz	:	25 %	of rock
Orthoclase	:	30 - 35%	" "
Plagioclase	:	35 - 30%	" "

Appeliative minerals,

Biotite	:	10%	" "

Accessory minerals,

Rutile	: }	< 1%	" "
Titanite	: }		

The rhyolite and soda-rhyolite porphyry mass are next in age. They lie above the southeast dipping quartz-monzonite surface, and also occur as intrusive bodies within the quartz-monzonite. There are, as mentioned previously, several petrographic varieties. The most common species is rhyolite porphyry. Quartz-keratophyre and dacite have also been identified.

This series has a typical porphyritic texture with variable sized phenocrysts. The quartz phenocrysts are always corroded, irregular in shape, and their maximum diameter ranges from 1 to 12 mm. The orthoclase and albite phenocrysts are generally euhedral crystals with a size range from < 1 mm. to 8 mm. Often the feldspar crystals of a certain porphyry unit will be uniform in size. The phenocrysts are arranged in haphazard fashion through the rock but frequently a flow structure is discernable in the groundmass of an unaltered specimen.

The mineralogy as listed below is similar to that of the quartz-monzonite:

Essential minerals,	Average	
Quartz	: 10 - 15% of rock	
Orthoclase	: 1 - 5% " "	When orthoclase is 1% or less and albite or olig. + 10% the rock is classified as quartz-keratophyre.
Plagioclase, Albite or sodic oligoclase:	5 - 30% " "	
Accessory minerals,		
Biotite	: <1 - 1% " "	
Groundmass	: 60 - 90% " "	

The different facies of this group can be distinguished in hand specimen although they are closely related petrographically.

The youngest rock emplaced in the Middle Butte is rhyolite felsite, which shows a marked flow banding. It occurs as plugs in the porphyry and in several places as a capping above the porphyry. This felsite has also been found in the quartz-monzonite as dikes 1 to 5 feet wide.

The rhyolite felsite is a white colored rock composed mainly of quartz and orthoclase and is lacking in dark or iron bearing minerals. The extrusive felsite exhibits flow breccias in many places.

Ore Deposits of the Middle Butte.

There are three general classes of ore deposits in Middle Butte. They are distinguished by their mineralization or location. As exploring and development progress, these classes show increasing evidence of a close genetic relationship.

The three classes of deposits are:

1. The quartz-sulfide-gold group localized by a contact between quartz-monzonite and porphyry.
2. Quartz-sulfide deposits entirely within the porphyry.
3. Quartz-alunite-gold deposits, which have been found to date only in the porphyry or felsite.

Much of the porphyry-monzonite contact has served as a locus of deposition for quartz bodies. The contact is characterized by frequent veins, lenses and irregular replacement bodies of quartz, separated by areas in which only gouge exists. The Cactus and Silver Prince veins are examples of this type, they lie on the contact and on loci controlled by the contact.

These deposits have been the most important on the hill in terms of ore production.

The localization of quartz along this contact is probably due to structural and physical conditions rather than to any chemical influence exerted by the wall rocks. The contact structure offered a deep-reaching, extensive channel to mineralizing solutions. Any other long, deep fracture within the rhyolite may have been equally favorable for deposition.

The mineralization is quartz emplaced principally by metasomatic processes, accompanied by small amounts of the common sulfides including pyrite, chalcopyrite, and occasionally arsenopyrite. Galena, sphalerite, chalcocite, covellite, bornite, the silver sulf-arsenides, silver sulfides, and gold are found in the commercial ore shoots. Adularia, barite, and alunite occur in small quantities as late mineralization products.

Location of the ore shoots in the quartz will be discussed later.

The quartz-sulfide deposits entirely within the porphyry exhibit a similar form of mineralization to that of the contact type. They are localized by faults, joints, and intraformational porphyry contacts. Generally, they are of limited lateral extent with widths ranging from a few inches to twenty-five feet, or more. Most commonly they are from two to five feet wide.

The Shumake vein is an example of this type. It outcrops on the northwest side of the hill, about 1000 feet north of the Silver Prince no. 1 shaft. From this point it can be traced on the surface 800 or 900 feet northeasterly to the Shumake shaft where it intersects other quartz veins and is cut off by faulting. The strike of this vein is about N-70°-E, and the dip 60° N.W. at the surface. Much of the vein is barren but a few small ore shoots have been discovered. Silver mineralization is of minor importance in these ore shoots, gold being the predominant ore mineral. Recent development indicates that this vein branches from the contact vein. There are several veins of this type in the rhyolite which should be considered in future ore search.

The quartz-alunite-gold deposits are characterized by a gangue containing predominating amounts of alunite. The seat of deposition is in most cases along a fracture in either the porphyry or the felsite. The controlling fracture usually serves as a footwall above which the vein is deposited by replacement of the hanging wall rock. The vein hanging wall is formed by short, intersecting premineral fractures and hence, is quite irregular. The width of the vein may change from four or five feet to as much as forty feet within a strike distance of 100 feet.

The quartz-alunite body now being developed and mined by Cactus Mines is the Winkler vein. It is on a fracture that strikes northwest from the center of section 17 and dips 35° to 50° northeast. This localizing fracture has been drifted on for 900 feet on the 250 foot level and is a strong structure at each heading. The vein deposited on this fracture is about 500 feet long and has been opened to a depth of 450 feet down the dip. Ore shoots are found sporadically along the vein. They are usually less than 200 feet long and from 50 to 300 feet deep. Their terminations are abrupt and often lack even narrow gold-bearing feeders. The largest ore shoot extends from the surface, at the no. 1 pit, for 280 feet down the dip. At the 280 foot level it terminated as a pointed wedge, although the localizing structure continued downward. Another shoot lies about 150 feet farther northwest on the structure. The top of it is about 220 feet below the surface. It continues downward 150 feet with ore of good grade all the way to the lower termination, which is abrupt. The strike length of this ore shoot is less than 100 feet. Below this shoot, on the same structure, the vein is wide and very strong, composed of earthy textured, barren alunite.

The mineralogy of the veins is essentially:

Alunite
Quartz -- predominant gangue mineral.

Sericite
Limonite - in minor quantities.

Arsenopyrite - trace.

Gold --- occurs in shoots, usually of moderate or high grade.

Small success was met in an attempt to relate the occurance and limitation of ore shoots to specific porphyry units. The ore lies in small lenses which cut through various facies of rhyolite indiscriminately, and are entirely isolated on all sides from any other ore pocket.

The only other quartz-alunite deposit from which ore was mined in commercial quantities is the Middle Butte ore body, located in the southeast corner of the hill, in the southwest ¼ of section 16. This vein dips 35° northeast at the surface and ± 20° at depth. It lies in felsite capping the porphyry, and is localized by a normal fault of moderate (less than 100 feet) displacement. Much of the production was from small pockets formed at intersections of fissures with the vein structure. Approximately $250,000 of gold was extracted. In both of these deposits silver mineralization is nil.

Geology of the Cactus Ore Body

Location of the Cactus Ore Body.

The Cactus ore body lies in the western end of Middle Butte hill in the northwest part of the southwest quarter of section 17. The collar of the main or no. 2 shaft, sunk in the vein, is 150 feet south and 720 feet east of the quarter corner of sections 17 and 18, and at an elevation of 3060.0 feet. The shaft is inclined about 40° with a bearing from collar to bottom of S-37°-W. This shaft divides the ore body into approximately equal parts.

Attitude and Dimensions.

The vein has an average strike of N-40°-E and dips 30° to 45° southeast. It pitches in a direction N-75°-E with a pitch length of at least 1500 feet, measured from the top of the S-2-270-Stope, 270feet southwest of the shaft an the 200 foot level, to the N-900-Drift. The breadth, measured along the ore shoot at right angles to the pitch length is 400 feet and the greatest stope length, or horizontal dimension is 600 feet. Widths are 15 or 20 feet in the central area of the vein on the 400, 500, and 600 foot levels. They decrease laterally toward the edges where the vein pinches out completely or terminates against premineral structures. The average width is about 8 feet.

Structural Conditions.

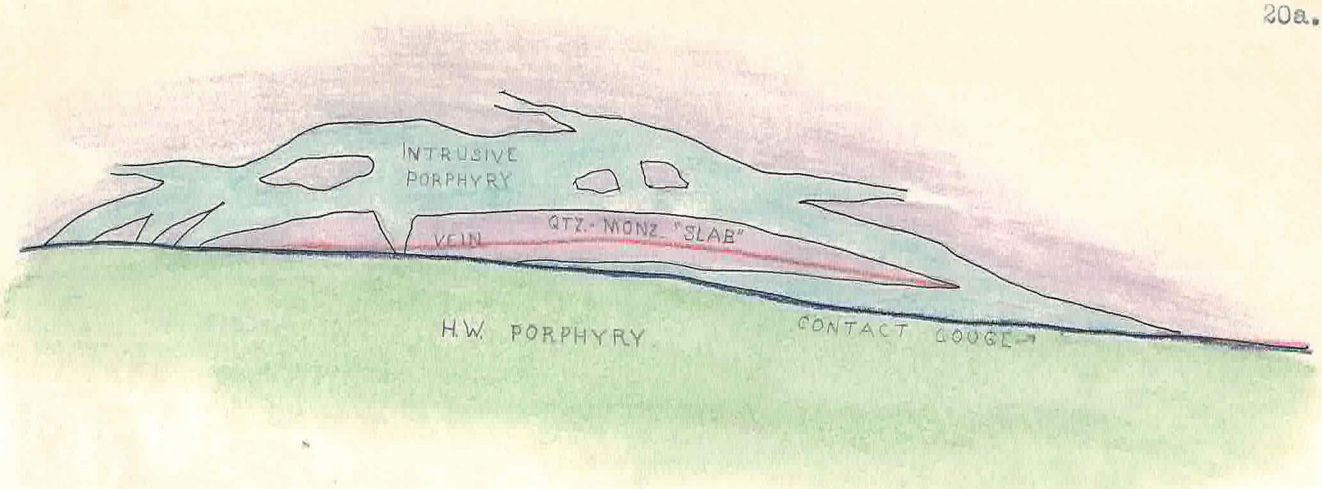
The principal geologic structures associated with the Cactus ore body are as follows.

1. A quartz-monzonite slab separated from the foot-wall quartz-monzonite mass by an intrusive porphyry dike roughly parallel to the contact.
2. The shear zone in which the vein is deposited. This is contemporaneous in part with the contact shear.
3. The contact shear between the quartz-monzonite and the hanging-wall porphyry.
4. Cross faults in the Cactus vein area.
   - A. Intermineral; post first stage and pre third stage mineralization.
   - B. Post mineral.
   - C. Large scale cross faults with 100 to 1000 foot displacement; undetermined age.

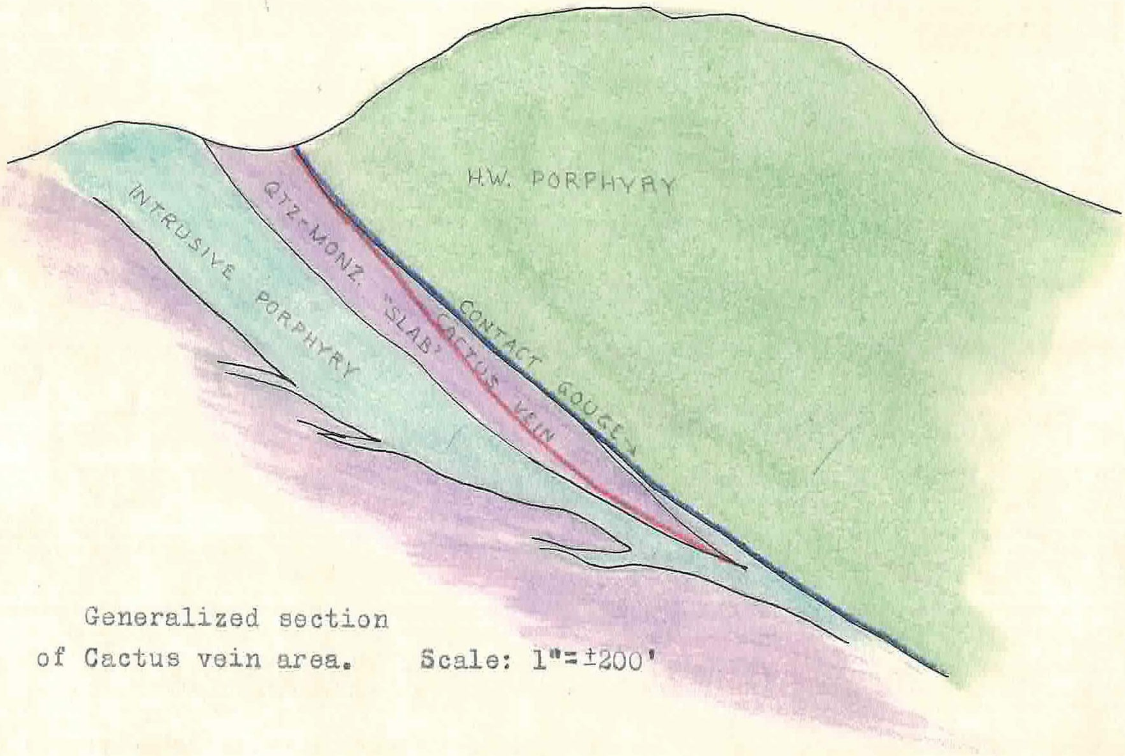
In th vicinity of the Cactus vein a slab of quartz-monzonite is separated from the foot-wall quartz-monzonite by a dike, 10 to 200 feet wide, of rhyolite and soda-rhyolite porphyry. The walls of the dike are irregular but the general strike and dip of it are are about parallel to that of the contact structure. The quartz-monzonite segment is at least 1000 feet in strike length on the 500 foot level and varies in width or thickness from just a few feet to 100 feet. It extends in depth from the surface to below the 900 foot level of the mine.

The dike separating this slab has many branches shooting off into the monzonite in various directions, some of them cutting through the slab. Where the dike is thickest it has included large blocks of quartz-monzonite. These irregularities veil the continuity of the geology from level to level.

At the present time it cannot be determined whether this



Generalized plan of the Cactus vein showing the porphyry intrusive and the isolated segment of quartz-monzonite. Scale: 1"= ±200'



Generalized section of Cactus vein area. Scale: 1"= ±200' slab is completely isolated from the rest of the monzonite by the porphyry or whether it is connected at one end. This slabbing of a section of quartz-monzonite has been observed only in the area occupied by the Cactus vein and may be of some local significance.

A shear or zone of fracture is the locus of the Cactus vein. In certain areas southwest of the main shaft this zone is contemporaneous with the contact shear and the vein is located directly under the contact gouge. This is true from the 200 foot level continuously down to the 800 foot level along the south end of the ore body. At varying distances from the southern termination of the vein on the different levels the vein shear zone leaves the contact shear and passes into the footwall, where it strikes roughly parallel to the contact shear, but twenty to fifty feet beyond it. It dips 5° to 10° steeper than the contact. Where the vein has left the contact shear it is entirely within the quartz-monzonite slab described in the preceding section. At increasing depths the vein lies farther in the foot-wall area. This is seen especially on the maps of the 800 and 900 foot levels.

Why the vein was not deposited continuously against the rhyolite - monzonite contact gouge, which is definately premineral, is difficult to explain. It is possible that a branch fracture was created in the monzonite slab by the force of the foot-wall intrusion of the rhyolite and that this fracture in the monzonite slab may have been more open to mineralizing solutions than the rock against the contact gouge.

Farther north along the rhyolite - monzonite contact, in the Silver Prince ground, the vein lies on the hanging-wall side of the gouge.

The "contact shear" is the structure which marks the main porphyry - monzonite contact. The hanging-wall rock is rhyolite and soda rhyolite porphyry that forms the bulk of Middle Butte hill. The foot-wall rock is quartz-monzonite. This structure and contact should not be confused with those of foot-wall porphyry intrusions in the quartz-monzonite which are common in the Cactus vein area.

The contact shear has developed either a gouge layer or a breccia zone. One or the other has been present wherever the shear is exposed. The gouge varies in width from six inches to five feet and is composed of finely divided rock flour. It has been strongly attacked by altering solutions and is sometimes silicified or strongly pyritized. Where brecciation has occured along the shear there is often a zone ten to twenty feet wide in which the rock fragments are moderately rounded and the various types of rock are mixed together. The breccia zones have in many places furnished a locus for vein deposition, as in parts of the Silver Prince area, particularly above the 600 foot level. In several parts of the Silver Prince and Beery-Shumake areas the contact shear was sharper with little brecciation and no gouge. Here the vein is mostly formed by replacement of the rock on each side of the contact.

This structure is probably the most important of all in Middle Butte from an economic viewpoint. The total movement on it is not known but whether great or little, enough brecciation has occured to furnish an important channel for mineralizing fluids. From the south end of the Cactus ore body to at least several thousand feet north, this contact shear is the locus of vein deposition. Ore shoots in this long vein were formed wherever conditions were favorable.

Two favorable factors affecting ore deposition were opening of the vein during those periods when the solutions were carrying gold and silver, and some force or agent to precipitate these metals in ore making quantities. Since most of the contact vein is barren these conditions rarely occurred simultaneously. However the ore shoots are rich enough to justify considerable exploration expense.

Intermineral cross faulting in the Cactus Vein area is of major geological importance. The Cactus vein is composed of several generations of quartz, with the gold and silver mineralization confined to certain generations. After each period of quartz deposition the vein was closed to mineral-forming solutions until reopening occurred. One of the principal causes of reopening the vein was the brecciation resulting from cross faulting.

Mr. Alexander Smith[2] has described the specific types of mineralization which were related to certain periods of cross

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2. Alexander Smith, Mineralogy of the Cactus Vein, Unpublished Doctor's Thesis, 1941.

fracturing. The sequence of events during mineralization were as follows.

After the development of the Cactus shear zone the earliest silica-bearing solutions passed through it, partly silicifying the country rock on each side of it, and depositing a lusterless, bony white quartz in the breccia. Thus a true vein was established although horses and unsilicified areas were probably common. The replacement quartz has a slightly different appearance from that which filled the space between the fragments. Replacement quartz is light grey in color, semi-transluscent, very dense and fine grained. The open filling quartz is bone white and has very little transluscency. No metallic or other mineral was observed in this quartz. It was called the "bony first stage quartz" by Mr. Smith.

After the channelways were sealed by deposition of bony quartz, the first cross faulting took place. The best example of this first series of faults is the one which crosses the vein and S-400-Drift on the 400 foot level between survey stations 403 and 405, 105 feet south of the no. 2 shaft. It crosses on the 500 foot level 45 feet south of the shaft. This is a normal fault striking N-1° to 10°- W and dipping ±30° toward the east, with a displacement of about fifty feet. It intersects the vein at a strike angle of about 50°. The movement on this fault caused fracturing of the vein on each side of it. This breccia zone reached downward to connect with mineralizing solutions and furnished a channel for their ascent.

Evidence for this can be seen in the bony quartz breccia cemented by gold- and sulfide-bearing quartz of the second stage of mineralization. The quartz of this stage was designated "transparent quartz" by Mr. Smith. The "transparent quartz" solution, after travelling up this cross fault and others of the same series, spread outward along the brecciated vein zone, deposited in the cracks and openings and replaced much country rock that had not been affected by the first stage silicification. The replacement action was more intense in this stage, especially along the vein on the foot-wall side of the cross fault. The fault probably had developed some gouge across the vein zone which diverted toward the south most of the rising solutions. The vein foot-wall south of the fault is irregular, following joints and small faults for short distances until they intersect other similar structures. The vein is two or three times wider than normal in this area. These features are typical where cross faulting has reopened the vein to later deposition.

The transparent quartz is less fine-grained than the first stage quartz and is often of sugary texture. It is usually white, or transparent and colorless, and carries several varieties of sulfide minerals. The sulfides are often very fine grained and when abundant give the quartz a grey or black color. The minerals of this stage as listed by Mr. Smith include pyrite, chalcopyrite, chalcocite, galena, sphalerite, argentite-stromeyerite, ruby silvers, and gold. Pyrite is the most abundant, and in many places the only metallic mineral present. The total amount of sulfides is generally less than 1% by weight of the vein material. This stage of mineralization should be divided into substages to be of use in ore finding because there are several combinations of minerals occurring in the transparent quartz.

The second period of cross faulting that has been differentiated occurred after the major part of the vein was developed. Examples of this stage are definately known only on the 700 foot level because they are recognized by the mineral deposition which followed them, and this is the only level that has been systematically sampled for microscopic ore examination. One fault of this group crosses the N-700-Drift 40 feet north of the N-7-270-Winze. It is a normal fault striking nearly north and dipping 50° east. It has offset the vein about fifty feet. Its age was determined by the minerals coated on the second stage quartz in diminishing amounts away from the fault. These minerals are a green colored, porcelain-like quartz containing gold; small amounts of dickite, barite, and alunite; and minor cinnabar, realgar, and orpiment. These minerals are of the third stage and are called the "soft gangue" type.

In the case of a similar fault where displacement was sufficient to move the two parts of the vein a distance greater than the vein width so that the faulted ends butt against country rock, and so that an impermiable gouge is formed, the vein segment on the foot-wall side of the fault will likely receive most of the new mineralization. This is more true of the less steeply dipping faults because their damming action is effective over greater area. This is borne out by the lack of third stage mineralization in the vein segment adjacent to the fault 40 feet north of the N-7-270-Winze, on the hanging-wall side of this fault. The vein segment on the foot-wall side of the fault is well mineralized.

In the Silver Prince area the third stage type of mineralization was important in the formation of ore shoots. This is true of the ore body opened on the 150 foot level above the 600 foot level, in the vicinity of the "50" raise. The second stage quartz here is poorly mineralized but has been coated and partly impregnated with third stage quartz and soft gangue minerals of high gold content, resulting in a body of several thousand tons of high-average-value ore.*

Many of the first and second period cross faults are now obscured where they intersect the vein, especially if the movement on them was less than the vein width. This is the case because the rift has been resealed in the vein area by later quartz. In a few places the texture of the later quartz shows the trace of the fault. It is usually necessary to examine the wall rock to observe the fault, the offsetting sometimes being mistaken for a simple roll in the vein.

The post-mineral or third stage of faulting occurred throughout the mine. It is best exibited on the 200 foot level, 50 to 120 feet south of the no. 2 shaft; on the 300 foot level 130 feet south of the shaft; and on the entire length of the 900 foot level. In these areas many faults of only a few feet displacement cross the vein at all angles. Most of them are nor-

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* See ore specimens numbered from C.Q. 182 to C.Q. 223 in the Cactus Queen suite.

mal but reverse slips are also present. They are dated as post-mineral because there is no increase in mineral content of the vein where they occur. Their trace is not silicified but is usually marked by a ½ to 2 inch gouge or breccia. The vein quartz in the vicinity of such faults is strongly fractured, and in the upper levels, is more thoroughly oxidized. Some of the areas where fracturing by these faults has broken the quartz into small fragments the oxidation has been thorough to remove much of the silver sulfide minerals so that the grade of the ore is lowered.

In parts of the vein where third period faults are numerous clean stoping is difficult, especially if the economic foot- or hanging-walls are determined by assay. In cases where the offsets are two or three feet the hanging wall limit may be carried from a depressed block across an elevated block, leaving several tons of good ore as a crust on the hanging-wall of the elevated block. This is partly, but not completely, avoided by careful sampling.

Three faults have been mapped in the mines which are unusual there because of their large displacements. No connection has been noticed between them and the mineralization, nor have they been classified as to age. They strike N.W. at angles 60° to 90° to the strike of the vein, and dip 35° to 55° toward the northeast. The southernmost one crosses the S-500-Drift at Cactus coortdinates 990 feet south, and 560 feet east, about 650 feet south of the no. 2 shaft. Its horizontal movement was 150 feet, with the north side depressed. This fault is of little economic interest because the contact shear is unmineralized in this area.

The middle large fault is found in the Silver Prince area on the 500 foot level of the Silver Prince shaft. It crosses the 500 station crosscut at coordinates 260 feet north, 1660 feet east. The strike is about N-20°-W, dip about 45° northeast, and horizontal displacement roughly 100 feet in normal direction.

The northernmost fault has received the greatest attention. It was first encountered on the Silver Prince N-600-Drift at coordinates 1010 feet north, and 2015 feet east. The strike is northwest and the dip ±50° northeast. The horizontal offset is 500 feet on the 600 foot level. The contact vein has not been exposed at the foot-wall side of this fault, having either died out or passed into the hanging-wall area beyond the contact, into the rhyolite.

The intensity of the vein silicification decreases in the last 100 feet approaching the hanging-wall side of the northernmost fault, and the vein on the foot-wall side of the middle cross fault narrows rapidly in the vicinity of the fault. No evidence was found which could definately relate this diminishing deposition to the presence of the faults.

The middle and northern faults line up fairly well with the saddles on the hill surface but they could not be definately located during surface mapping. However, they probably control the northwest trending canyons in Middle Butte.

Conclusion

The Cactus Mine represents an interesting example of epithermal gold-silver mineralization in sheared igneous rocks. Much remains to be learned before the process and controls affecting deposition are completely understood but it is hoped that the observations presented in the preceding pages will be of some assistance.