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Geology and Mineral Resources of The Quijotoa Mountains.

Pima County

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of the Quijotoa Mountains

PIMA

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INTRODUCTION

Geography

Location of the District

The Quijotoa Mountains[1] are in south-central Pima County in the Papago Indian Reservation in southwestern Arizona. They may be reached from Tucson by the Tucson-Ajo road, a distance of 85 miles. The mountains are about 5 miles to the south of the main road. They are bounded on the east by the broad, gentle, Santa Rosa Valley and on the west by an equally broad and gently undulating flat called Quijotoa Valley. More definitely their limits are defined between latititudes 32°00' N and 32°10' N and longitudes 112°12' W, with their major axis trending approximately N 25°W in an area that is about 14 miles long and 4 miles wide.

During the late eighties and the early nineties, Quijotoa and Weldon, two mining camps that were rather short lived, were located respectively on the eastern and western slopes of Ben Nevis. Covered Wells, an Indian Trading Post with good well water and real western hospitality, is situated on the Tucson-Ajo road which at this point enters the broad pass between the northern end of the Quijotoas and the Brownell Mountains that lie immediately to the north and northeast.

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[1] So called because of a striking semblance of their most prominent peak to an inverted Papago Indian basket. Kee-hoe means basket and toe-ah an eminence.

Physiography

The northerly portion of the range, without specific name, is about 5 miles long. This is a typical sierra that rises by smooth, rolling slopes to a series of summits on a northwest-southeast line. The culminating point, with an elevation of 3850 feet above sea level, is considerably higher than the average crest.

Ben Nevis Mountain, a high irregular mass of rock which rises by precipitous cliffs from the surrounding rolling hills to an elevation of 4000 feet above sea level, forms the central portion.

The extreme southern part of the range consists of South Mountain an oval mass about 3 miles long and 2 miles wide. It rises abruptly from the plains on the west, south, and east sides and is connected to the rest of the range by a series of rolling hills. The cliffs rise 1200 to 1500 feet in almost vertical walls and attain an elevation of nearly 4000 feet above sea level.

The Quijotoa Mountains, more especially in the northern part, present a topography of rather high relief that apparently is the result of stream cutting by the swift torrents that are active only directly after heavy downpours of rain in the higher parts of the range. Steep canyon-like valleys are present at regular intervals on the sides of the range. As the gradient of the streams lessens the topography is subdued; and the canyons are less precipitous though some of them cut through the lower-lying spurs that flank the main range on the east and west. In these flanking areas the country has a monotonous and even sky line, broken only by small hills of slight altitude which increase in number near the main ridge. Near the small canyons the surface is commonly underlain by gravel from 2 to 8 feet thick, but near the crest of the hills and ridges rock crops out. The presence of these canyons or "arroyos", as they will be referred to from now on, has indeed been helpful in working out the geology of the district; inasmuch as many excellent key exposures were found in them. The low lying spurs and the main range define the limits of a narrow inter-mountain valley that roughtly parallels the Quijotoa system on the east; a similar feature is less well defined to the west being more or less obscured by low ridges some of which are still connected with the main range. The narrow inter-mountain valley on the east gradually broadens until it coalesces with Santa Rosa valley to the southeast. Here the stream is depositing rather than cutting as indicated by the omnipresent meanders of the stream beds. On these gentle slopes the swift torrents from the mountains lose their velocity, and consequently their carrying power, and drop their load of rock to eventually sink below the survace entirely in the broad expanses of Santa Rosa Valley.

Climate and Vegetation

The climate of this district is marked by high temperatures and low rainfall. The summer heat is intense; it often exceeds 100^{o} F. and at times reaches 120^{o}F. as measured by thermometers placed in the shade. The dryness of the air and the consequent cooling of the body by evaporation, however, make these high temperatures bearable.

According to records of precipitation kept at Indian Oasis, which were kindly furnished for this report by the Indian Agency, the average annual rainfall is about 12 inches, with most of the precipitation taking place during the months of July, August, and September. With even a small amount of rainfall the desert and lower slopes spring to life over night and in the wet season present a beautiful picture of varying shades of green that are highly contrasted by the bright yellows and reds of the different cactus forms.

This is not a treeless plain, but an arboreal desert, where large shrubs and trees give the country a deceiving verdure that is in marked contrast to its ability to support animal and human life. The seasonal concentration of the rainfall and the high temperature is in all certainty responsible for this desert type of flora.

The common desert trees are mesquite, palo verde, palo fierro, catsclaw, and ocatillo. Mesquite, a thorny legume, is by far the most abundant and is found growing on steep rock slopes where, with the palo verde, it forms the major portion of the vegetation. The palo verde with its green branches and green trunks is particularly striking in appearance, and with its bright yellow locust-like flower in the spring commands a large portion of the beauty of the blooming desert which is only too short lived.

Palo fierro or sonoran ironwood, is a handsome tree with an erect bushy crown and blue-green leaves. It is usually found along the stream channels on the higher parts of the alluvial slopes and is especially noticeable around the base of the mountains where it grows in orchard like groves.

Catsclaw is a shrubby tree rarely over 10 feet high in this district, but makes itself very noticeable by its short, claw-like thorns which in many instances form impenetrable thickets.

The ocotillo, Arizona's state flower, is a striking desert plant, which consists of several wand-like, thorny stems that rise in gentle, outward curves from a common base. At each thorn, leaves appear in the spring and the end of the stem is crowned by a large cluster of beautiful, bright red flowers.

The cactus family is well represented with the giant cactus or sahuaro, and the cholla in greatest abundance, and the bisnaga or barrel cactus occurring in lesser numbers.

The sahuaro has a straight trunk, from 12-20 inches in diameter, that is faced all around with vertical parallel ribs. Many plants attain a height of 40 feet whereas heights to 26 feet are common. Certain types of rocky soil seem to favor the taller cacti, since these are found in belts on the steeper slopes.

Cholla, which grows from a single stalk 3 to 6 inches in diameter, ia a much branched bushy plant not over ten feet high. Traveling through these cholla thickets is in places most difficult and painful. Only the slightest touch is necessary to cause the long yellow spines to penetrate the flesh to depths of a quarter inch. Removing these spines is painful indeed and a very small pair of pliers has proved helpful in shortening the torture.

Field work and acknowledgments

Previous Geologic Studies of the District

The only previous geologic attention that the Quijotoa district has received was in 1922 when Mr. Carl Lausen and Mr. Eldred Wilson paid a visit to gain a knowledge of the general geology for the state geologic map of Arizona, which was then being prepared. I have been unable to find any existing reports that would in any way indicate that previous detailed work had been done on the geology of the district.

Present Investigation

The work on which this report is based is the result of a fund given by Messrs. Ernest E. Slingerland, Larry J. Margulies, and Aaron L.

Fischer, all of New York City. These men were primarily interested in the Morgan group of claims that lie near the center of the range. To gain a better knowledge of the geology of the prospect and of the Quijotoa Mts. in general, they contributed $1000 with which to establish the Slingerland Graduate Scholarship in Geology for 1930-31 at the University of Arizona.

I wish to take this opportunity to express my thanks and appreciation to the donors of the fund for their unceasing interest in the work throughout the year.

As there was no topographic map of the district, the making of one was the first work that had to be completed. Field mapping was begun September 21, 1930, and as only week-ends could be utilized for this work the map was completed in the latter part of December. In this work I was very ably assisted by Mr. Ben E. Peet of the College of Mines and Engineering at the University of Arizona. Plate I represents an area approximately one and one-half miles square. This area was selected to receive the detailed geologic attention; because in it all geologic processes that have affected the district have left their mark on the rocks in a manner that is less obscured here than in other parts of the district.

I am deeply indebted to Prof. B.S. Butler for the abundant and expert guidance under which I was constantly working in this district.

I also wish to acknowledge the kind and courteous assistance furnished by the people in the district, notably among whom were Mr. Keith Knight, local representative for the Larrymade Mines, Inc., Col. J.J. Munsey of the Trading post at Covered Wells, Mr. Fred Brenner, and Mrs. Lottie Morgan.

History of Production in the District

Spanish manuscripts, discovered in Lower California, show that this district shipped ore to Mulaje, Lower California, for reduction as early as 1774.[2] Much of the country around Horshoe Bend shows evidences of

[2] The Guijotoa Guide Book, Bascom S. Stevens - 1884

early mining activities, by whom and at what time the present generation seems to know very little.

In the year 1883 several rich discoveries of silver ore were made on the top of Ben Nevis Mountain which ultimately led to the organization of several mining companies. These were very short lived, however, because the rich ore which at first proved profitable soon gave out, while the leaner ores proved unprofitable and the camp was soon abandoned. The district is credited in Mineral Resources of the United States[3] from 1905 to

[3] Mineral Resources of the United States, U.S. Geol. Survey, 1905-1910.

1910 inclusive with values of production ranging from $214 to $4100 with a total value of $9,123.00. This production was by lessees mainly from the placers but some also came from the old lode workings. Since 1910, production in the district has been at a standstill with the exception of the Silver Screen Mine located at the extreme north end of the range.

GENERAL GEOLOGY OF THE QUIJOTOA DISTRICT

To gain a knowledge of all the geologic relations within the district, we must also know those outside of the main Quijotoa Range. This work has been carried on in detail within the area outlined by Plate II, and in a reconnaissance way for some distance outside of that area.

Not a single fossil has been found in the region or outlying districts to form a basis for age classification. Hence it has been found convenient to sub-divide the formations on the bases of their relations and the character of the rocks into an "Older Broup," a "Middle Group," and a "Younger Group."

The Older Group which, topographically, occupies the relatively low areas in the district consists essentially of a quartz monzonite that has been subjected to all subsequent activities; so that the original rock in many places hardly recognizable. Over wide areas it has been penetrated by dikes and sills of varying composition which seem to follow general zones of weakness and along which there has been abundant shearing and crushing.

The Middle Group series outcrops in a relatively narrow belt partly encircling the low areas of the Older Group. It consists of a series of interbedded shales, arkosic sandstones, and conglomerates that reach an approximate thickness of 150 feet and that lie unconformably on the Older Group, dipping from 25° to 50° N.W. The rocks of this group are usually much distorted and broken and, because of their relatively samll total thickness, are covered in many places by talus from the overlying series of sills and surface flows.

Toward the south end of the area the sedimentary rocks disappear under the later flows. One of the red shale members of the Group, in its lower part, contains rounded fragments of limestone. These limestone fragments predominate in only a very narrow zone (stratigraphically) and seem to represent a short interval during which the supply area of the land sediments encroached upon the thick bed of limestone lying immediately west of the Sierra Blanco Mountains, about six miles to the north and west of Covered Wells. That this bed of limestone to the west is the source of the pebbles seems probable since fragments of untransported material lying at the base of the outcrop of limestone cannot be distinguished from those that have been deposited in the shale, with the exception that the fragments in the shale showed more signs of transportation. No fossils have been found in the limestone; so even its approximate age lacks considerable assurance, but as it has been mapped as Cretaceous on the State Geological Map of Arizona, I shall refer to it as Cretaceous, in this thesis. Hence the rock of the Middle Group will inferentially be Post Cretaceous, because most of the sediments lie above the narrow horizon that consists predominantly of limestone fragments.

The Younger Group, and also the largest group, consists of a series of extrusive, intrusive and sedimentary rocks which form the higher topographic features. These include the Brownell Mountains and the Quijotoa Mountains.

Originally the Brownell Mountains were not to be included in this paper and certainly a detailed study of them has not been made; however, a series of rocks of the Younger Group in the Quijotoa area have features similar to those of the Brownell Range, which makes imperative at least an aftempt to relate the rocks genetically.

Following a period of erosion which was brought on by slight doming of the sediments of the middle series and earlier rocks the Brownell intrusive begain to make its appearance as dacite dikes, sills, and surface flows to the north of the Quijotoa area. This activity, as it continued and became more far reaching in its influence toward the south, covered the exposed portions of the Older Group as well as the slightly tilted beds of the Middle Group with flows of dacitic composition that in some places reaches 200 feet in thickness. This forms the earlier part of the Younger Group. These flows are now found forming the underlying back bone of all the low lying ridges in the district. They show much evidence of brecciation and mineralization wherever large outcrops of them are found. The brecciation in many places is apparently flow breccia, however, fault breccia is also abundant. Hematite, sometimes of the specular variety is found as the cement in many of the outcrops of the mineralized breccia, which is noteworthy;

Inasmuch as over moderately large areas (4 miles apart) the same type of brecciation is found with hematite as the cement. This mineralization by the hematite over large areas, not only in the Brownell flows and intrusives, but also in the sediments, especially a later quartzite (Verde quartzite) may be attributed partly at least to the same activity that formed the veins of specular hematite "iron dikes" that are prominent, especially in the Quijotoa Mts.

Above these flows is a layer of quartzite that contains fragments of the earlier Brownell rocks and which also has been mineralized in some places. This has been named the Verde quartzite. Outcrops of this quartzite were found south of Red Ridge just outside of the southern limits of the area in Plate II, and in the pass west of Ramon Peak, a small exposure of quartzite was found that petrographically is similar to the larger outcrops to the south, but cannot be definitely correlated with it.

The Verde quartzite south of Red Ridge dips steeply toward the southwest underneath a flow that was apparently extruded as the last stage of Brownell activity. This flow is now seen forming the major portion of the low knobs that occur between Red Ridge and the Quijotoa Mts. to the south. Several of the larger knobs to the south of Red Ridge show sharp ledges projecting out from their northern slopes which on closer examination appear to be fault scarps marked by intense shearing and fracturing. The down thrown blocks to the northeast are hardly ever displaced more than 30 feet and attempts to trace this faulting into the underlying Verde quartzite proved negative.

Just how long an interval of time elapsed before the intrusion of the Quijotoa intrusive is impossible to determine because of the absence of later sediments in the district. A comparative study of the Brownell and Quijotoa Mts. suggests a similarity in their sturcture, but reveals a distinct difference in the kind of rock that is found making up the two ranges.

The similarity in sturcture is suggested by the general trend of the two ranges, the direction of which may be observed to roughly parallel that of the general trend of all the mountain ranges of southwestern Arizona, and which makes them an integral part of a portion of the earth's crust that is made up of a series of tilted fault blocks exposing rock of all ages. This would account for neighboring ranges, as for example, the Quijotoa and Brownell ranges, that belong to the same general period of mountain building movement and at the same time present rocks of varying degrees of resistance to erosion.

Whether the intrusion of the Quijotoa intrusive and possibly other contemporaneous intrusions in this region inaugurated the regional block faulting, is an open question. Later faulting which is marked by strong shear zones in the Quijotoa range effect alike both the later intrusive and older rocks of the range.

The Quijotoa intrusive is predominantly of a quartz diorite composition though variations to diorite and grano-diorite occur from point to point.

Definite contact relations of the Quijotoa intrusive and the quartz monzonite of the Older Group have not been found in the field; because of the thick covering of debris.

The relation of the intrusive to the andesitic flows that cap Ramon Peak and Bats Nest Peak and that occupy large areas toward the west, can nowhere be definitely established at the north end of the range, because of their widely separated outcrops; however, a reconnaissance study of South Mountain suggests that the flows found on it are pre-intrusive.

Detailed Features of the Geology of the Quijotoa District

The Rocks of the Older Group

A rock of quartz monzonite composition forms the bed rock of the deeper arroyos in the area mapped on Plate II. Most of the outcrops show intrusion of the monzonite by a fine grained, dark green rock that occurs as sill-like bodies up to five feet thick and as dikes that vary in thickness from a from a fraction of an inch to six feet. Numerous outcrops of the rock are present northeast and east of Covered Wells, while to the south it outcrops less frequently and passes underneath Red Ridge. Immediately south of Red Ridge it may again be seen outcropping in a narrow belt until it is finally covered by the Verde quartzite.

The coarse grain of the monzonite facilitates mechanical disintegration and causes the rock to break up into small fragments. This break down is due to the heating and sudden cooling of the rocks. In summer, at midday, the rocks may be too hat to hold in the hands without discomfort, which are then suddenly cooled by rain and subsequent evaporation. There is also a great change of temperature from day to night. Such changes produce differential expansion in a rock made up of different minerals and cause crumbling. The coarse fragments are easily washed away which accounts for rocks of coarse grain and of varying mineral composition occupying the low areas. This condition is typical of desert weathering.

The fine grained, green intrusive rock and its effect on the quartz monzonite, will be discussed in a later division under Detailed Features.

The unweathered monzonite rock from a distance has a brownish pink color which on closer examination resolves into areas of light pink and light brown feldspars intergrown quite uniformly with clusters of a dark green hornblende. The rock has a granitoid texture with some of the lighter colored areas elongated rectangles which in rare cases attain a length of 1/8 inches, but 1/16 to 1/32 inch lengths are more common.

Under the microscope the cloudy or felty appearance of the section is striking, through which the outlines of euhedral and subhedral crystals of quartz and feldspars are faintly discernible. Accompanying the hornblende are areas of chlorite whose relative freshness suggests alteration products of the hornblende. Small clusters of magnetite grains, associated with the dark green silicates indicate that magnetite also was an alteration product of the hornblende; but some more isolated grains of magnetite with a dark red ring surrounding them suggest oxidation of primary magnetite. Under higher magnification and crossed nicols the cloudiness of the feldspars resolves itself into abundant sericite, which is clearly a product of hydrothermal alteration of the feldspars and seems to be present through-out the rock. Yellowish green epidote is also found in all sections of the rock and its uniformity of occurrence in other rocks in the region is a problem which will receive s special attention in a division under Detailed Geology. Briefly, however, it may be said that much of the epidote owes its existence to alteration of the feldspars in the quartz monzonite and certainly some of it is connected with the formation of the hematite veins in the Quijotoa Range, where the pure mineral occurs in veinlets an inch wide. An attempt was made to classify the triclinic feldspars through the faint twinning laminae but the results are only approximate. Labradorite was found to predominate and orthoclase was not nearly so abundant as the pink color of the hand specimen would suggest. Large corroded euhedral crystals of quartz are present with here and there oriented groups of inclusions.

The Rock of the Middle Group

The Middle Group of rocks consists of a series of land sediments of interbedded shales, arkoses, and conglomerates as shown in the columnar section, Figure 2. The section is compiled from outcrops on the north bank of Covered Wells Arroyo where it swings to within five feet of the north side of the highway.

The lowest member is a fine grained red shale with pebbles of limestone that may have been derived from the large area of Cretaceous, limestone west of the Sierra Blanco range. These pebbles have been found only in the lowest member of the sedimentary series. The pebbles of limestone effervesce strongly in hydrochloric acid. The red shale occurs at four horizons in the sedimentary column, its lowest horizon is directly on the rock of the Older Group, with the other three layers at intervals thru the upper part of the series.

The red shale is a very fine grained, dark brownish-red, brittle rock so highly fractured that the slightest disturbance, as a light kick with the foot, will cause an apparently solid piece to fall into many small sliver like fragments. On closer study of an outcrop numerous parallel fractures not over 4 inches apart are observed cutting through the rock, along which there has been slight movement. Another series of parallel fractures, that are more closely spaced and which make angles of approximately 45 degrees with the first series traverses the rock. This fracturing accounts for the sliver-like fragments that are found covering numerous outcrops of the shale. Northwest of Ramon Peak the thickness of the lower shale bed increases to 100 feet within a short distance at the expense of the conglomerate and the arkoses, but this is not surprising when one considers the formation of land sediments and that such a lens of shale might be a mud filling of a small basin on the old erosion surface.

Grading upwards within a distance of 2 feet the rock changes to a reddish medium grained arkosic sandstone. It is composed of corroded grains of feldspars and quartz in about equal amounts that are cemented by a very fine grained material that resembles the underlying shale. Outcrops of this rock show that it has suffered only slight fracturing as compared with the underlying shales. This is shown by the presence of only a few major fractures in an outcrop approximately 30 square feet in area. Arkose re-occurs in the upper part of the section having the same relation with shale and of about the same thickness.

The conglomerate occurs at two horizons in the section and in each horizon it overlies arkose and forms rather prominent brown resistant knobs where the overlying red shale has weathered back for a considerable distance exposing short dip slopes of the conglomerate. A few fractures traverse the rock but there has been little displacement.

The conglomerate is made up of closely packed pebbles of quartzite, and esite porphyry, vein quartz, and jasper which are all moderately well rounded and range in size from 1/16 inch to 1 inch in diameter. The material between the pebbles, largely feldspar, is very similar to the underlying arkose, which suggests that the deposition of this relatively thin layer of conglomerate represents a short period, perhaps during a time when coarser material was carried from the higher land area. Rocks from which the pebbles in the conglomerate could have been derived have not been found in nearby rocks of the Older Group, but a nearby source is not essential as is shown by a study of land sediments that are accumulating today at the base of neighboring mountain ranges where much of the detritus, that forms relatively thin but uniform layers, has traveled distances that exceed three miles from the apparent source.

Structure in the Sedimentary Rocks

The sedimentary series of the Middle Group of rocks outcrops immediately northeast of the road between the Indian church and the base of Ramon Peak in a belt that averages approximately 400 feet in width and is continuous for over a thousand feet. Another outcrop occurs approximately 1800 feet a little south of west of Covered Wells. The northern and central part of this belt trends nearly due north to the base of the Brownell range which is nearly four miles beyond the northern boundary of the area included in Plate II, while the southern part makes a sharp swing in a general westerly direction south of Covered Wells.

Within this belt the beds strike in a general northeasterly direction and dip to the west and north away from the contact with the rocks of the Older Group at angles that vary from 25° - 35°. The strike varies slightly, and in general parallels the contact of the sediments with the underlying Older Group.

As this belt of sediments is found today, it apparently represents a retreating line of outcrops of beds that were originally domed by laccolithic intrusions at the contact of the Older and Middle Group of rocks. These beds were first attacked by erosion on the highest parts of the domes. This process continued until the underlying more resistant intrusive rock was encountered, and which changed the direction of greatest erosional advance down the dip of the sedimentary formation to their present position. This is shown in the central portion of the area represented on Plate II.

Superimposed on the dip of the sediments caused by doming due to laccolithic intrusion is a later differential tilting of small fault blocks in the sediments, that were formed during a period when the whole region underwent crustal adjustment through block faulting.

Figures 3, 4, and 5 show a possible development, in seven stages, of the present sturcture in the sedimentary rocks.

The Rocks of the Younger Group.

This group comprises a series of rocks that differ not only in composition but also in field occurrence, while age differences within the series is also clearly shown by the rocks themselves.

The Younger Group has been divided into two large classes, namely, the Brownell series and the Quijotoa series. The Brownell series includes the rocks formed in the early part of igneous activity of the Younger Group period, the Verde quartzite, deposited during a lull in the igneous activity of late Brownell age, and a few overlying the Verde quartzite, formed during the igneous activity of the later part of Younger Group time.

The Brownell Series

The rocks of the Brownell series, while they vary slightly in composition and texture from point to point in the field, are mainly of a quartz monzonite composition consisting essentially of quartz, orthoclase and plagioclase. Outcrops of the quartz monzonite are found approximately 2000 feet northeast of Covered Wells, where the rocks form a resistant ridge that trends northwest and southeast. The texture of the quartz monzonite on this ridge varies from coarsely granitoid to medium-granitoid with the difference clearly shown in higher and lower portions of the ridge; that is, the coarsely granitoid rock crumbles easily on weathering, is less resistant to erosion, and forms the lower portions. The medium grained rock weathers less readily and is always found forming the highest portions of the ridge.

The thin section under the microscope shows a rock of xenomorphic texture consisting essentially of quartz and feldspar. The feldspars are represented by orthoclase, the tri-clinic potash feldspar, microcline, and the soda lime felspar oligoclase. These are present in about equal amounts, with the quartz evenly distributed and intergrown with all of them. The twinning lamillae in many of the oligoclase crystals thin out to fine points suggesting dynamic action on the rock. Such dynamic action could possibly also account for the development of the triclinic potash, feldspar, and microcline, since according to Alling,[4] shearing stresses at low temperature tend to cause ortho-

[4] Journal Geology, 1921, pp. 209, 275, and 292.

clase to invert to the triclinic form.

Sericite, kaolin, and epidote occur in small quantities as alteration products. Many of the fractures parallel to the twinning planes in the feldspar grains are filled with sericite. Brownish-green epidote in small groups of subhedral grains is sometimes associated with grains of higher lime feldspar where, with sericite, it apparently is a product of hydrothermal alteration of the feldspar.

The next Younger rock of the Brownell series occurs as an extrusive sheet which covers large areas within the also outside of the district mapped. Lying above the sediments of the Middle Group it reaches a thickness of 175 feet in several places. No flow tops could be found that would indicate the upper limits of the sheet; hence the original thickness of the flow could not be obtained. Extensive outcrops of this rock are found encircling Ramon Peak and it also forms the floor upon which later andesitic flows were extruded between Ramon Peak and the Brownell Range.

The lower half of the sheet is a moderately dark, gray colored porphyritic rock. It has nearly a felsitic appearance, but small phenocrysts of quartz rather uniformly distributed may be seen upon second glance, therefore it has been called quartz porphyry. Many of the fragments from outcrops on the south slope of Ramon Peak show brecciation in which the fragments have been recemented with specular hematite, and after careful search the specular hematite is found to occur in small veinlets that in some places were an inch wide.

A study of the thin section verifies the porphyritic texture of the hand specimen. Corroded grains of quartz and plagioclase occur in a very even, fine grained matrix the composition of which can only be determined with higher magnification. All of the phenocrysts, which vary from .5 mm. to 1.6mm. in cross section, show corrosion in all stages. Higher magnification shows the matrix to be composed of anhedral grains of plagioclase feldspar and quartz in equal amounts. Further classification of the plagioclase was impossible, because the grains were too small to work with, even under high power. Small lathlike crystals of ilmenite appear with sub-rounded grains of magnetite. Sericite is present as an alteration product, but only in the plagioclase in the phenocrysts where it forms a dense layer.

In the central part of the extrusive sheet the quartz phenocrysts of the rock are not nearly so prominent in the hand speciment and gradually disappear entirely toward the upper portion of the sheet. The rock still seems to retain its felsitic texture; however, the thin section shows a distinct increase in grain size of the groundmass.

The Verde Quartzite

The Verde quartzite was apparently deposited during late Brownell time when igneous activity paused long enough to allow the accumulation of approximately 100 feet of sand. A small outcrop of quartzite is found on the upper end of Quartzite Gulch, but no definite relation between this outcrop and the large belt of Verde quartzite 2 miles south of Covered Wells could be established. Unfortunately the mapping of the area in Plate I could not be extended that far south and the scale employed on Plate II did not permit any detailed work on this formation.

South of Red Ridge outcrops of the quartzite are found in a belt that is approximately 200 feet wide and which trends parallel to the direction of the Ridge for a distance of about 5000 feet. The quartzite strikes in a general N 55° W direction and dips south at angles that vary from 45° to 75°. The rock is of a light gray color with variations to a brownish red where the rock is apparently permeated with iron oxide. Detailed field study of this quartzite was difficult and limited; because of a later flow that covered it in many places, while in others only small outcrops could be found among the detritus from the higher slopes of the flow.

Some of the specimens that were picked up contained fragments of the earlier Brownell extrusive and of dard, dense, shaly material. The boundaries between the shaly fragments and the quartzite, in some cases, were sharp; others showed a gradation of the dense texture and dark gray color of the shale to the granular texture and light gray color of the quartzite.

Under the microscope angular grains of quartz, with undulatory extinction, with widely scattered grains of feldspar make up the rock. Much of the cement consists of granulated quartz and small amounts of it consist of quartz deposited in optical continuity with the original grains. The few feldspar grains show alteration to sericitic mica which also forms between the grains of quartz. A thin section of a specimen that is brownish red in color shows iron oxide occurring as a thin film between the cement and the original grains. This film in some places collects in large enough quantities to form interstitial groups of black hematite grains.

Three reasons for a land sediment origin of the Verde quartzite are suggested by a study of the quartz grains that make up the rock. The angularity of all the original grains of quartz is very distinct as compared with the subangular or rounded borders of the grains that make up a water deposited quartzite. Regularity of grain size, which could reasonably be expected in a waterlain quartzite, is absent in the Verde quartzite, the variation in the grain size ranging from 1/20 mm. to 2/10 mm. in an area roughly 10 mm. square. The original grains are not packed as closely as those in a quartzite that has been definitely established as a water-lain sediment.

Unconformably on the Verde quartzite lies the last representative of igneous activity during the formation of the Brownell series. This is a rock of a quartz monzonite composition with the feldspar occurring only in phenocrysts. This gives the rock a distinct porphyritic texture, both in the hand specimen and under the microscope. No outcrops of the quartz monzonite porphyry have been found within the area on Plate II, but extensive outcrops of it occur between Red Ridge and the main range of the Quijotoa Mountains where it is found occurring as low ridges that roughly parallel one another in a general northwesterly direction. The northeastern slopes of these ridges are usually marked by a series of small ledges that seem to have formed as a result of a series of small normal displacements along fractures that parallel the present ridges. This is especially true immediately south of Red Ridge; where the ledges form prominent land marks on the slopes. Toward the Quijotoa range these ridges became much less prominent, disappearing more or less under the detritus from the higher slopes of the mountains; however, outcrops in the arroyos verify the continuation of the quartz monzonite porphyry to the main range of the Quijotoa Mountains.

The hand specimen, on weathered surfaces, is of a light brown color but on a freshly broken surface is of a light pink color which is broken only by cavities filled with yellow limonite or small areas where limonite stain has colored the rock. Quartz and pink feldspar in about equal amounts make up the phenocrysts which vary in size from 1 mm. to 15 mm. in cross section. Whether produced by weatherring or by hydrothermal alteration, some of the feldspar phenocrysts show signs of attack which is causing them to crumble and leave cavities which are now filled with limonite. Lining the cavity walls is, in many cases, a thin film of specular hematite which has resisted weathering so that now it is seen standing out as little, metal walled boxes.

Thin sections under the microscope show, in the approximate order of abundance, orthoclase, oligoclase, and quartz as phenocrysts and in the groundmass an intergrowth of very find grained quartz and orthoclase. Hematite and magnetite make up approximately 90% of the accessory minerals, the remaining portion being titanite.

The orthoclase in the phenocrysts shows evidence of some alteration, but most of the mineral is comparatively fresh, while that which is in the groundmass is of a very clear variety. Further detailed study of the groundmass is prevented by the extreme fineness of the grain size. The plagioclase is mainly oligoclase, as determined by indices of refraction and by extinction or sections normal to the albite twinning plane. All the plagioclase shows some alteration to sericitic mica, although in general this alteration is only feeble.

The quartz in the phenocrysts occur as corroded grains that contain numerous gas and liquid inclusions. One exceptionally large phenocryst showed fracturing of the type that it shown on the cooling of beta quartz to alpha quartz. Holes in the section, produced by cavities in the rock are, in nearly every case, lined with abundant limonite and black hematite. The limonite fills cracks in the hematite and apparently is an alteration product which in some cases has completely replaced the original mineral.

High magnification shows more sericitic mica present than is first observed with a lower power. Not abundant in any one place, it is, however, everywhere present in small amounts in the groundmass.

The Quijotoa Intrusive

Quartz diorite is the principal rock that makes up Morgan Peak, Iron Hill, and Weldon Pass. Outcropping in a roughly circular area, it is bounded on all sides by the quartz monzonite rocks of both the Older and Younger groups.

Hand specimens of the quartz diorite show a moderately coarse grained rock composed of a uniform mixture of light and dark minerals. New fractures generally present a bright, fresh appearance. The light minerals are chiefly white feldspar. In some fresh specimens the shining facets of the feldspars are striped with the multiple twinning of the plagioclases and in others, especially in altered samples, may be discerned fragments of rough greasy quartz. Rarely a pinkish feldspar is mingled with the white feldspar. Of the dark minerals there are two colors, namely, a dark green and a light yellowish green. Chlorite and hornblende make up a very large portion of the dark minerals, however, the light green material, which at first seems subordinate, occurs in abundance in minute fractures throughout the rock, and this is true of all samples of the quartz diorite. Distinct crystals of the hornblende are rare and what few are present do not exceed one-eighth of an inch in length.

Thin sections, under the microscope, show in order of abundance labradorite, microcline, hornblende and quartz as primary essential minerals. The only primary accessory mineral that could be seen was magnetite. Secondary minerals are chlorite, epidote, magnetite, limonite, biotite mica, sericite, and quartz.

Accurate determination of the plagioclase feldspar was impossible because of the very advanced stage of sericitization which showed on every thin section of the quartz diorite. The approximate determination as labradorite was made by reading extinction angles on the 010 face measured from the edge of the 001 plane.

All the labradorite showed alteration to sericite, which on over three-fourths of the grains was so far advanced as to entirely conceal the albeit twinning which, in the remaining grains of labradorite, was also only indistinct at its best. The labradorite occurs in euhedral and subhedral crystals, some of whose boundaries appear very indistinct especially at the contact with adjacent grains of quartz. One large grain of labradorite was found enclosing a grain of microcline. It is noteworthy to see how alteration to sericite has taken place in the surrounding labradorite while the "island" of microcline appears unaltered. The contact between enclosed and enclosing mineral is similar to contacts so common in polished sections where, for example, chalcopyrite is found surrounding and replacing pyrite or sphalerite. Although this was the only example of its kind that could be found, in itself it might suggest an enrichment in calcium of the solutions which accomplished this apparent alteration of microcline to labradorite. A later stage of alteration would be represented by the alteration of the plagioclase to sericite.

Hornblende, in elongated crystals which show alteration to chlorite, occurs only in very minor quantities in masses of biotite and magnetite. Quartz although hardly recognizable in the hand specimen makes up approximately ten percent of the rock. Two ages of quartz are strongly suggested by the two modes of occurrence in which the quartz is found. The primary quartz, when it is present, is found intimately intergrown with the plagioclase and the dark primary minerals. Contacts of the primary quartz with these minerals show a rough, serrated edge all around the quartz grain. In the second mode of occurrence the quartz is found in veinlets that are interstitial with mixtures of chlorite, biotite, and secondary magnetite. Numberous grains of feldspar are found completely enclosed by quartz which occurs in small grains that are connected to one another by minute veinlets of quartz. In every case the contacts of the secondary quartz with adjacent minerals are sharp and well defined in contrast to the serrated contacts of the primary quartz.

Magnetite in small grains occurs intergrown with primary quartz and the feldspars. Fractures in the magnetite show alteration to limonite which is true however in only a few cases, other fractures showing a filling with secondary quartz. Biotite, found only in scattered, small quantities, is altering to chlorite and magnetite.

Sericite as a hydrothermal alteration product of the plagioclase feldspar has a widespread occurrence over the whole intrusive body. Usually the alteration to sericite had advanced so far as to form a nearly opaque layer of seriicte over the entire crystal of feldspar which then could only be recognized by its characteristic form.

Epidotization

The occurrence of epidote in this rock as well as in the rocks outside of the Quijotoa intrusive is noteworthy; because epidote in the quartz diorite is apparently associated with a distinct period of igneous activity, and the earlier quartz monzonite of the Younger group is also found thoroughly epidotized near the contact with later basic dikes. That there is an apparent genetic relation between the activity that produced the specular hematite veins "iron dikes" and attendant epidotization in the Quijotoa quartz diorite, and the activity that produced the lamprophyre dikes and attendant epidotization in the region northeast and east of Covered Wells, will be shown in a later paragraph.

The epidote occurs as replacement veinlets that attain a width of two inches. The veins are numerous, especially near the specular hematite vein. It also occurs in numerous, minute veinlets throughout the rock, which are only visible under the microscope.

The epidote of the replacement veinlets varies in color from yellowish green to olive green. Many of the wider veinlets are apparently pure epidote that on fresh fracture shows a very fine grain, uniform composition, and has a smooth feel to the touch. In two instances veinlets, of apparently pure epidote over an inch in width, were found in coarsely granitoid quartz diorite, where the outlines of the granitoid texture of the original rock were clearly preserved by a slight color change at the boundaries of the original grains. The veinlets grade into the country rock by showing a gradual increasing coarseness of grain and showing epidote which insensibly grades from an olive green color to a very light yellowish green and which finally loses itself in the inherent color of the replaced quartz diorite. Several thin sections were made to study this change.

Under the microscope the veinlets of epidote in the quartz diorite were just as clearly defined as those that were visible in the field, only, of course, much smaller but on the other hand more abundant. Microscopic fractures in the feldspars, in the quartz, in the magnetite, and intergranular spaces were all filled with epidote. The contact at the border of the fractures in the feldspar showed a feathering out of the epidote into the feldspar, suggesting a replacement of the latter. Fractures in the quartz grains showed a clear cut contact. Rarely were magnetite grains found which did not show numerous fractures filled with epidote and suggesting an alteration of magnetite to epidote.

A study of the basic, dike-like intrusions northeast and east of Covered Wells, and especially their effect on the quartz monzonite will show a counterpart of the epidotization just described.

Two series of dikes are found cutting this region with a general northeast southwest trend. Both series attain widths ranging from ten to fourteen feet and in the arroyos and the cuts recently made by highway construction they show a nearly vertical dip.

The first series of dikes to be discussed are of a camptonite composition. In the field the rock presents a drab color on weathered surfaces. Fresh fractures show a very fine grained, greenish brown rock. Under the microscope hornblende, anorthite, and quartz in approximately equal amounts make up the primary minerals of the rock. Augite rarely occurs. The rock has been highly altered to chlorite, calcite, and small amounts of hematite and sericite.

The hornblende occurs in elongated, frequently euhedral, crystals that vary up to one and a half millimeters in length. Many of the larger crystals show nearly complete alteration to chlorite.

The anorthite occurs as a comparatively fresh mineral, considering the amount of alteration which the hornblende has undergone.

The chlorite, showing beautiful, ultramarine birefringence, occurs as large patches in the larger crystals of hornblende. It also appears in innumerable fractures that cut all the minerals in the rock.

The calcite is also found as patches in the hornblende, and is especially well developed in the few crystals of augite which were observed. It also occurs in late veinlets that cut even the chlorite.

The hematite is observed in small patches with the chlorite. The sericite is beginning to form in small amounts, on the anorthite.

The intrusion of these camptonite dikes has had a distinct effect on the quartz monzonite for distances up to twenty feet away from the contact. The rock has been epidotized in a manner that resembles the epidotization of the quartz diorite of the Quijotoa intrusive, with the exception that epidotization in the quartz monzonite is more complete.

The quartz monzonite along the contact with the alpha dikes contains over 60% epidote, and the remaining portion is made up largely of pink orthoclase feldspar with quartz. On fresh fractures the rock presents a very pleasing color combination of the pink and green.

Under the microscope the original plagioclase has completely altered to epidote, while the orthoclase appears comparatively fresh. The magnetite shows oxidation rims of red hematite which apparently is the source of the dark red coloring in the hair-like fractures that cut thru the rock in all directions and rather enhance its attractiveness.

This type of alteration suggests a similarity to that shown to the south in the Quijotoa intrusive; at least the solutions that have effected the alteration have apparently been similar. The large amount of epidote in the quartz monzonite intruded by the alpha dikes suggests an addition of calcium; because the unaltered rock does not contain enough original calcic plagioclase to have contributed all the calcium which is now present in the epidote.

The augite camptonite dikes in hand specimen shows a relatively fresh porphyritic rock with phenocrysts of white feldspar in a dark green, aphanitic groundmass. Outcrops of this rock occur in Covered Wells Arroyo southeast of Covered Wells where the rock is seen cutting the quartz monzonite in vertical dikes and as a narrow sill that seemed to follow a horizontal zone of weakness in the intruded rock.

Under the microscope abundant needles of hornblende with augite make up over half of the groundmass. Labradorite, as determined by the index of refraction, with quartz makes up the remainder of the goundmass and all of the phenocrysts. The fresh appearance of the hand specimen is fully verified by the absence of sericite and chlorite in the thin section.

The intrusive contact of the augite-camptonite dikes with the quartz monzonite is sharp and shows no effect on the intruded rock either megascopically or under the microscope.

Late Andesite Extrusives

Red Ridge, lying south of Covered Wells, and Ramon and Bat's Next Peaks to the northwest, are composed of late extrusives together with the broad lower areas of volcanic rock lying still farther to the northwest.

The flow that caps Ramon and Bat's Nest Peaks is a dark gray, felsitic rock with conchoidal fracture. The hand lens shows clearly a brown mineral which crumbles under the knife point. Much of the finely ground rock is attracted to a small magnet.

Under the microscope the rock shows an abundance of magnetite uniformly distributed in small subhedral grains, many of which show complete alteration to red hematite. Crossed nicols reveal a trachytic texture which is disturbed only by an infrequent, large crystal of bytownite lying transverse to the general direction of the flow lines in the rock. The chief mineral constituents of the rock are bytownite and magnetite, with hematite forming as an alteration product of the magnetite.

Red Ridge consists of a moderately coarse-grained, grayish, red rock. Euhedral crystals of plagioclase feldspar, showing the albeit twinning, are prominent. These crystals attain lengths of two millimeters, but crystals of one millimeter in length are more common.

Under the microscope a porphyritic texture becomes distinct with the phenocrysts, consisting of plagioclase and hornblende, making up approximately two-thirds of the rock. The matrix is very fine grained, cryptocrystalline, anistropic material with low birefringence. Secondary veinlets of quartz are cut thru the rock in an indiscriminating manner.

The plagioclase feldspar is the variety andesine, showing zero extinction measured on the 010 face from the 001 edge. Nearly all of the andesine shows a corroded contact with the groundmass, and under higher magnification shows beginning stages of alteration to sericite.

The hornblende has completely altered to chlorite which is now found with alteration rims of hematite. This is the source of the small, red patches seen in the hand specimen.

Structure in the Quijotoa Mountains

In the main body of the Quijotoa intrusive and outlying portions of the main range several prominent shear zones have been located. All of them parallel the northwesterly trend of the main mountain range.

At the base of Ben Nevis Mountain, a zone of cemented fault breccia over one hundred feet wide closely conforms to the trend of the s teep eastward facing cliff for over one and a half miles. The main specular hematite vein, beginning on Iron Hill and continuing northwestward for over two miles apparently closely follows another shear zone.

The Morgan shear zone, the southeastern end of which ends in Dead Man gulch, trends northwest for a distance of approximately five thousand feet.

A study of the Morgan shear zone was possible; because of the location in it of the Morgan Mine, also because of surface pits that were sunk along the shear zone at intervals over a total distance of eighteen hundred feet in a northwestern direction from the mine shaft. This shear zone which is about fifteen feet wide dips approximately 65 degrees to the northeast. The footwall consists of massive country rock with only a few minor fractures cutting thru it. The hanging wall, to a depth of about one hundred fifty feet, consists of finely sheared rock no fragment of which is larger than four inches across and which are only loosely cemented in place, as indicated by the free caving of the rock in the underground drifts. For the next one hundred fifty feet to the bottom of the shaft the difference in amount of shearing is still clearly shown between the foot and hanging walls, however, the hanging wall shows lesser amounts of the finely ground up rock. Strong slickensiding testifies to the movement that has taken place which is beautifully shown on large areas (4 feet square) of smooth plane surfaces on the footwall where well preserved fault striae indicate a normal displacement. The amount of displacement could not be determined; because of the similarity of rocks in hanging and footwall.

East west faulting seems to have been less important, both in determining the structure of the range and in connection with ore deposition. Some fissuring, which was unaccompanied by important movement but which permitted the circulation of mineral bearing solutions, may also have taken place.

Theory of Origin of the Quijotoa Mountains

Upon an old erosion surface were poured out, probably in Tertiary time, great flows of andesite nearly or quite burying the entire region. Remnants of this flow of andesite are South Mountain, Ben Nevis Mountain and the large field of extrusive rock to the north. Soon after this period of estravasation the region was broken by faulting, mainly along north-south lines, with minor breaks running east and west. At about the same time the region, near the central part of the range, was invaded by a mass of intrusive material forming the stock of quartz diorite. This intrusion was accompanied by faulting and fissuring of the earlier rocks and the quartz diorite intrusive which was immediately followed by ore deposition, both within the intrusive and at a distance, along fissures that furnished channels for the ready passage of the ore bearing solutions, The cooling and crystallization and attendant settling of the intrusive and intruded rock caused more fissuring and along these fissures were injected basic differentiation products, forming dikes. This is the period of formation of the camptonite and augite-camptonite dikes near Covered Wells. At essentially the same period watery solutions excluded from the crystallizing magma at greater depth escaped through the pre-existing fissures in the solidified and still cooling portions, resulting in pronounced alteration of the quartz diorite.

The existing parallelism between prominent shear zones and the present trend of the Quijotoa Mountains suggests the idea that crustal adjustments of large magnitude took place along the main shear zones.

Following the igneous activity there was a general elevation of the region, accompanied by faulting and tilting of the fault blocks which formed the present mountain range. This was followed by a period of erosion. During this period of erosion and down to the present time the rocks covering the intrusive mass of quartz diorite have been in part removed and the region reduced to its present topographic form. The material from the higher portions of the region has been deposited on the broad gentle slopes and the adjoining flats, for the most part as land deposits.

MINERALIZATION

A study of the minerals and their occurrence in the district, so far, has revealed two types of mineralization. These two types are represented by the veins of specular hematite, or so called "iron dikes" in the district, and the gold-silver fissure veins of which the mineralization in the Morgan Mine offers a good example. A careful study of the latter type of mineralization was only possible in the Morgan Mine. The Ben Nevis workings and the Silver Screen Mine were considered unsafe for underground study at the time they were visited, although the dumps, particularly of the Silver Screen Mine, yielded some information that was usable.

Specularite Veins "Iron Dikes"

An outcrop of a specular hematite vein extends in a northwesterly direction from the east slope of Iron Hill through Day's Camp and continuing thus to the vicinity of the Mill on the northeast slope of Morgan Peak. In its widest parts the vein attains a width of approximately fifty feet. The zone of alteration varies in width from seventy-five to one hundred twenty-five feet on each side of the vein, thus making a maximum width of vein and alteration zone of three hundred feet.

The main vein consists of predominantly specular hematite which occurs in sheaves, in curved folia, in large irregular masses and in bands closely associated and intergrown with the products of alteration of the country rock. The zone of alteration consists of quartz diorite now so intensely altered to dark, olive green epidote and chlorite through which grains of specular hematite occur finely disseminated, that the original minerals of the rock ar no more recognizable.

The Fissure Veins

The veins occur as fillings in prominent fissures and shear zones which have a general strike of N 45° W, and dip 65° N.E. Subordinate fissures which strike N 45° E., and dip 70° N.W. have been found with fillings of vein quartz, but so far have not yielded ores in any commercial amounts.

The introduction of mineral bearing solutions along the fissures and shear zones which strike N 45° W has, relatively, been of greater importance from both an economic and geological viewpoint. Considered from an economic viewpoint, by far the largest portion of silver and gold ore mined in the district has been extracted from these fissures. Considered from a geological standpoint, and more specifically, in the light of hydrothermal wall rock alteration, the northwest trending fissures are more important.

The vein filling consists chiefly of coarse, dense, grayish white quartz which forms abruptly ending lenticular masses. At the ends of such lenses the ore body frays out into a stringer lode, consisting of quartz diorite penetrated by a large number of more or less parallel small quartz stringers. The main body of a lens is generally accompanied on both hanging and footwall by a wide zone of quartz stringers, the spacing becoming wider as the distance from the main lens increases.

The quartz filling is not crustified. It is commonly ribboned or banded, however, owing to narrow, roughly parallel, bands of hematite colored breccia zones which extend down the dip in the quartz lenses. This banding effect is probably due as a rule to successive openings and fillings of the original fractures in the quartz, each successive period of opening leaving a wider breccia band in the quartz.

The quartz filling of many of the breccia bands is clearly composite, having been brought in at successive times. This mode of origin is partly suggested by the banded structure in the lenses of original quartz, and more positively indicated in the lenses of original quartz, and more positively indicated in the lens exposed on the first level in the Morgan Mine where dark quartz is cut by a network of veinlets of white quartz.

The quartz veins are generally accompanied by dark red gouge. In places the gouge is spotted with fragments of quartz, most of which have been reduced to a sugary texture. The gouge may occur on the hanging wall or the footwall or on both. In places it passes diagonally through the veins, suggesting that the thicker portions of some of the veins may be due to the telescoping of one part of a vein on another by post-mineral movement along such gouge zones.

The gouge pinches and swells and consequently layers of it vary from one-half to four inches in thickness. A notable habit of the gouge is its tendency to wrap around the bodies of quartz.

When a vein is bordered on both the hanging wall and the footwall by gouge, the quartz of the entire vein is likely to have been crushed to a loose sugary texture. The country rock adjacent to gouge is especially severely sheared and ground to fine fragments many of which are slickensided and have taken on a brilliant black polish.

In the upper levels of the Morgan Mine the effect of this gouge on mining is negligible; but in the lower levels, where water is more abundant swelling ground is common, result-in the sloughing off of large pieces of vein material and country rock and requiring close timbering.

Ore Shoots

Only meager information is available concerning ore shoots due to limited underground workings. Because of this condition I am not in a position to give any hard and fast rule regarding which parts of the fissure filling are ore and which are not ore. I have found that dense, gray, brecciated quartz with the fragments recemented by bands and ramifications of red hematite, usually makes ore. Although the vein filling in the ore shoots consist largely or wholly of quartz, it is not true that all large masses of quartz in an ore-bearing vein are ore. This would apply to the barren, white, quartz vein on the 200 foot level in the Morgan Mine. A vein containing an ore shoot may break up into a stringer lode, then pinch down to a gouge filled fissure, and then expand abruptly to an impressive body of quartz, but this quartz may be barren.

Proposed Hypothesis for the Origin of the Quartz Lenses in the Shear Zone.

An understanding of the cause of the lenticular occurrences of mineralized portions of quartz veins in the fissure, and the apparent selective type of mineralization over a series of lenses is important not only in the light of a study of the structural occurrence of the ore, but also for future prospecting in the district.

The following sequence of events is suggested. As an igneous after effect, following surface fissuring and adjustment of the quartz diorite intrusive, solutions, saturated only with silica from the magma still differentiating in depth were introduced into the fissures. The walls of the fissures were more or less warped and contained minor crenulations which, on subsequent lateral or oblique movement of either wall, would cause an unmatching of the fissure walls forming lens-shaped openings into which the silica solutions were introduced. Subsequent crustal adjustment, due to the ever unstable conditions of the cooling rock at depth, expressed itself in an oblique and possibly a lateral direction rather than at right angles to the strike of the original fissure. This type of movement had a tendency to fracture the enclosed quartz vein and to draw out thin portions of the veins, which finally were severed in many places causing a subsequent isolation of fusiform segments of the quartz vein. Those portions of the fissure where a complete severance of the vein was effected, now had the hanging wall in direct contact with the footwall, and any further movement of hanging wall relative to footwall, or vice versa, would produce a narrow gouge filled fissure, thereby enclosing the isolated segment of quartz vein, on both sides, with an effective solution barrier. It is reasonable to assume that movement, in so many different possible directions through 180 degrees, would develop gouge, not only on the sides of the isolated quartz lenses, but also on the top and bottom thereby completely isolating the quartz lenses with a "solution proof" barrier, the efficacy of which would be upset only by later movement of the fissure walls. Segments of the quartz vein not completely isolated by the gouge would be accessible to later ascending solutions providing the failure of the gouge were anywhere but directly above the segment of isolated quartz vein. During all these periods of adjustment and readjustment the brittle quartz would be intensively brecciated, and be in a physically receptive condition as host rock for any subsequent ascending solutions.

Origin of the Ore Bodies

If this outline of events is true, subsequent, ascending, thermal ore solutions had a rather definite predetermined series of paths to follow within the fissure. Brecciated quartz lenses that were completely isolated by gouge were obviously inaccessible to the ore solutions and those not isolated were cemented and mineralized, a process which turned the original, possibly barren, quartz vein into ore. Lenses, sealed at the top and open at the bottom, acted as solution traps causing relatively rich ore to form near the top; others that were open, both at the top and bottom, merely acted as trunk channels for solutions bound for ore deposition at higher altitudes and were mineralized, owing only to the fact of decreased speed of the solutions when coming in contact with the mass of highly brecciated quartz.

This may be held as one explanation for the occurrence, in close proximity of each other, of uniformly mineralized, breccia quartz lenses, of lenses making ore only near the top, and of lenses which are valueless.

Character of Mineral Veins

Primary vein minerals consist of quartz, hematite, calcite, gold, argentite, galena, pyrite, and very subordinate amounts of chalcopyrite.

The quartz belongs to two periods of mineralization; an earlier period during which the quartz lenses were formed and a later period during which the brecciated quartz lenses were again mineralized by ore minerals.

Hematite, calcite, quartz, and gold are found intergrown in the veinlets that form between fragments of the quartz of the earlier period indicating their later age.

Pyrite formed during both periods; because grains of it are found in the quartz of the earlier period and it is also found in subordiante amounts with hematite, calicte, and gold.

The galena occurs in small masses between the fragments of earlier quartz. Owing to its infrequent occurrence its relation to the hematite, calcite, and gold could not be discovered; although it is clear that the galena belongs to a later age of mineralization.

No argentite nor chalcopyrite could be observed for study.

Therefore two distinct periods of mineralization are indicated; an earlier period during which silica solutions with small amounts of iron and sulphur in solution deposited quartz and pyrite in lens shaped bodies, and, subsequent to brecciation of the quartz, a later period during which quartz, hematite, calcite, galena, pyrite, gold, argentite, and chalcopyrite formed as filling between fragments of the earlier quartz. Argentite and chalcopyrite, were not observed as primary minerals, but their presence in small amounts was indicated by silver chloride and copper carbonate in the oxidized ore.

Alteration of Wall Rock

Hydrothermal alteration of the wall rock has resulted in a replacement of the minerals of the quartz-diorite by calcite and sericite, A thin section of the altered rock under the microscope shows calcite making up at least 65% of the rock. With sericite it is found replacing the labradorite, orthoclase, and hornblende.

Source of vein Minerals

Two sources are suggested for the primary vein minerals. The quartz and pyrite of the earlier period, and the hematite, carbonate, galena, pyrite, gold, argentite, and chalcopyrite of the later period originated in a deep seated, probably magmatic source.

The quartz, associated with the calcite in the vein filling of the later period, has been derived from a decomposition of the original vein quartz and wall rock silicates, by the carbon dioxide contained in the solutions that were introduced during the later period.

Character of the Thermal Solutions in the Fissure Veins

From a study of the vein filling in the Morgan Mine, it is certain that the main mineralizing solutions were distinctly carbonate solutions.

The chemical nature of the solution was first noted during a microscopic study of the wall rock in the Morgan Mine. The quartz diorite is found traversed by a fine network of calside of the fissure. Calcite is the vein mineral which has recemented the breccia fragments of early quartz throughout a large portion of the vein. Some of this carbonate carries considerable amounts of manganese and iron. Near the Morgan shear zone, within two hundred yards east of the Morgan shaft, is a small group of anastomosing veins of carbonate containing iron and manganese in appreciable amounts.

Secondary Alteration of Veins

None of the workings have penetrated the zone of surface oxidation; hence a study of primary mineralization was not possible.

The lowest workings in the Morgan Mine, at a depth of three hundred feet, are still in the oxidized zone with only minor amounts of water. Ore, which has come from the lower workings of the Silver Screen Mine at a depth of five hundred ninety feet, still shows limonitic alteration by waters from the surface.

Small cubic crystals of pearly, gray cerargyrite (silver chloride), were noted in a specimen of ore from the first level in the Morgan Mine.

Small masses of galena in the ore from the first level in the Morgan Mine showed concentric layers of anglesite (lead sulphate) surrounding it. Other smaller grains of galena have now been completely altered to anglesite which in turn is altering to cerussite (lead carbonate) as indicated by white, concentric bands around the anglesite. These bands effervesce vigorously in hot hydrochloric acid.

With a few exceptions the pyrite has suffered complete alteration to limonite which gives the ore its typical, dark red color. Under the microscope, the limonite at first seems to be all derived from the hematite grains, but this is not true. Under higher magnification the limonite is found with veinlets of quartz with hematite cutting through it. Also, on closer study of the individual grains of hematite, oxidation to limonite is not important.

At the bottom of the Morgan shaft, small veinlets of pyrite show only partial oxidation to limonite. Such veins were found to be completely enveloped by a two-inch seam of gouge which possibly prevented access by oxygenated waters, to the pyrite.

Traces of chalcopyrite have been suggested by rare occurrences of malachite in the ore. The gold occurs in the free state. Grains, plainly visible to the naked eye occur in cavities in the ore, associated with wad, limonite, and calcite. In the Morgan Mine a number of these grains were found growing on crystals of calcite which lined a small cavity filled with wad. Much of this black oxide of manganese is loose and friable and when panned yields surprising amounts of very fine, flaky gold. Under the microscope, these grains average approximately .08 millimeters across the widest part.

The usual intimate association of gold, calcite, and manganese dioxide in the ores from the oxidized zone may be rationally explained as follows. The following statements in regard to experimental work along these lines are taken from Dr. W.H. Emmons "Principles of Economic Geology":

"If a crystal of calcite is placed in an acid solution in which gold is dissolved in the presence of manganese, gold is precipitated with manganese oxide on the surface and in the cleavage cracks of the calcite crystal......The reactions may be stated:

$$2\ Au\ Cl_3 + 3Mn\ Cl_2 + 6\ H_2O\ \ 2\ Au + 3\ MnO_2 + 12\ HCl$$

It follows also from this experiment that gold will not be dissolved readily when calcite is present in excess."

The characteristic association in the ores, of free gold, calcite and manganese oxide in the oxidized ores suggests a reaction similar to the one outlined above. The nascent chlorine, necessary for the solution of gold, could possibly be derived from a reaction between the sulphuric acid produced by the oxidizing pyrite; and the chloride in the meteoric waters, evidences of which are indicated by the presence of "hornsilver or cerargyrite." Higher oxides of manganese, necessary to maintain the acidity of the gold solution, are also present in abundance. These may have been derived from a decomposition of the manganese bearing carbonates in the vein filling and oxidation of the liberated manganese. When the solution of gold chloride, descending in association with manganese dioxide, percolated into cavities that were lined with crystals of calcite, there occurred a precipitation of both the gold and the manganese dioxide, due to the alkaline reaction of the calcite crystals on the solution of gold chloride and manganese oxide.

The presence of sulphides as galena, or pyrite may also have been significant in the precipitation of free gold out of its acid solution.

THE MORGAN MINE

The Morgan Mine owned by the Larrymade Mines, Inc. is located six miles off the main Tucson-Ajo highway. A road leads up to the collar of the shaft which is approximately half-way up the east slope of Morgan Peak at the head of Dead Man Gulch.

The mine workings lie in the Morgan shear zone which strikes N 45° W and dips 65° northeast. A timbered, inclined shaft dipping 65 degrees has been sunk to a depth of three hundred feet. There are two main levels and a surface sub-level. The first level consists of a drift one hundred forty feet long in a northwesterly direction from the shaft at a depth of one hundred ten feet. The second level one hundred feet lower consists of drifts of forty and sixty foot lengths in southeast and northwest directions respectively from the shaft. The sub-level is at a depth of thirty feet and leads thirty feet in a northwest direction from the shaft.

Only oxidized ore is exposed in the mine. The ore occurs in lens-shaped bodies that vary in width from twelve inches to four feet. These bodies vary from ten to thirty feet in length along the strike of the shear zone and at their extremities thin out into very narrow, gouge filled fissures. The largest of these lenses has been cut on the first level, where ore has been extracted for shipping purposes. In the main these lenses of ore lie directly on the footwall which in this mine consists of altered quartz diorite. The ore is typically a gold-silver ore. Gangue minerals are quartz, calcite, hematite, limonite, and small amounts of manganese oxide. A carload of ore shipped during March, 1931, averaged per ton:

Gold.................1.39 oz.
Silver...............1.11 oz.
Copper.............. .10%

Primary ore consists of highly fractured quartz, which has bee re-cemented by quartz, hematite, a carbonate containing manganese and iron, galena, gold, and argenitite, named in order of abundance. Pyrite occurs in small amounts.

Oxidation by surface waters to limonite has removed practically all the pyrite and has left its trace in the predominant red color of the ore. The argentite has been altered to silver chloride (cerargyrite) of which small cubic crystals were observed on a specimen of ore from the first level. The small amounts of galena that are present show oxidation to anglesite (lead sulphate) which has in some cases gone to completion and shows the more in-soluble lead carbonate (cerussite) beginning to form around its edges. The hematite, as seen under the microscope, shows some oxidation to limonite, but nearly half of the grains appear fresh. As shown by the microscope the carbonate apparently has recrystallized to calcite, liberating manganese which is now present as wad in many of the cavities in the ore. Oxidation by surface waters has been responsible for the enrichment of gold in the ore. This is clearly shown by cavities in the ore, lined with crystals of calcite, that not un-commonly show grains of gold growing on the calcite crystals. Manganese oxide, mixed with oxide of iron commonly occurs in abundance in these cavities. The gold has been precipitated out of its acid solution by a reaction between the calcite and solution, a process which is more fully discussed on page ____.

At this point it might be well to discuss the possibility of the oxidized ore becoming richer in gold as the water table is approached. This possibility is not recognized for the following reasons:

1. Surface waters, carrying gold in acid solutions, quickly react with the highly reactive calcite gangue mineral. This reaction causes a re-precipitation of the gold before the solutions have descended very far, a process which is discussed more fully on page ____.

2. The presence of sulphides in the ore, as for example the galena and small amounts of pyrite would also prevent the movement of gold to any considerable distances.

3. While solution of gold by descending surface waters is possible under the conditions, its migration for any considerable distances in depth is not likely due to its rapid reprecipitation by the reactive gangue minerals. Such a process therefore can not give a relatively rich oxidized zone near the water table.

To gain some knowledge of the distribution of the lenses of ore along the strike of the shear zone, surface pits were sunk at intervals for a distance of eighteen hundred feet northwest of the shaft. Two of these pits, located approximately one thousand feet northwest of the shaft, at depths of twelve feet showed stringers of ore four inches wide that assayed $53.00 per ton.

The wall rock consists of altered quartz diorite. The hanging wall is highly fractured and consists of small fragments of quartz diorite which make up the shear zone. The footwall is relatively massive and shows only very little fracturing. On the surface the footwall appears as a resistant low ridge, approximately ten feet wide, that closely follows the shear zone. Indeed it has been helpful in locating the outcrop of the shear zone which is usually covered by detritus. This resistance to weathering is caused by abundance of carbonate in the rock.

Under the microscope calcite is most abundant of all minerals shown in the thin section. With sericite it is found replacing the labradorite, orthoclase, and hornblende. Hornblende, chlorite and epidote have been completely replaced and the feldspars show all facies wholly or partly replaced by calcite. Where the feldspars were found being replaced by calcite. Where the feldspars were found being replaced by calcite, the unattacked portion of the mineral had a clear and fresh appearance. The abundance of calcite is verified by strong effervescence of hydrochloric acid when applied to the rock.