Hager, Dorsey, Practical Oil Geology, McGraw-Hill Book Company, 370 7th Ave., New York City—$3.00.

Lilley, E. R., The Geology of Petroleum and Natural Gas, D. Van Nostrand Co., Inc., 8 Warren St., New York City—$6.00.

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ARIZONA BUREAU OF MINES

G. M. BUTLER, *Director*

GEOLOGY AND ORE DEPOSITS OF THE OATMAN and KATHERINE DISTRICTS ARIZONA

BY

CARL LAUSEN

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PREFACE

The Arizona Bureau of Mines considers itself fortunate in being privileged at this time to publish this report on the "Geology and Ore Deposits of the Oatman and Katherine Districts." A mere descriptive paper would doubtless prove valuable in attracting attention to these districts, but Doctor Lausen has written something much more significant. While it has long been known that some of the veins could be mined profitably, while others could not, the reason for the differences in mineralization has been a mystery, and, as a result, much money has been wasted in exploring veins which it is now known do not contain the type of vein filling that is associated with good gold values in these districts. Doctor Lausen has, apparently, solved the problem, and has succeeded in discovering certain facts as regards the vein fillings that should prove extremely valuable when applied in subsequent operations. Recognition of the fact that only fourth or fifth stage quartz and associated minerals, as described herein, contain enough gold to be minable at a profit is an achievement of great potential value.

It is recognized that the descriptions of mines and prospects are not in every case as complete as might be desirable, and that some meritorious properties may not even be mentioned, but the time available for the preparation of this paper did not suffice to gather the data required for a really detailed report. Because of the existing keen interest in gold properties, it was thought best not to delay publication until additional information could be collected and compiled.

Suites of specimens representative of all the different stages of vein fillings described herein are possessed by the Bureau and may be examined by anyone. Furthermore, the geologists of the Bureau will be glad to assist prospectors or miners by determining to which stages of vein filling samples submitted for examination belong, if it is possible to do so. June 1, 1931.

G. M. BUTLER, *Director*.

GEOLOGY AND ORE DEPOSITS

OF THE

OATMAN and KATHERINE DISTRICTS ARIZONA[1]

BY CARL LAUSEN

INTRODUCTION AND ACKNOWLEDGEMENTS

The Oatman and Katherine districts have produced more than thirty million dollars worth of gold and silver yet no complete report on the geology and ore occurrence of this interesting region is available though numerous short papers on various phases of its geology or the mining operations conducted there have been published from time to time. A thorough study of the Oatman District was made by Dr. F. L. Ransome and a preliminary report[2] based on that study was issued by the United States Geological Survey in 1923. The detailed descriptions of the rocks and the excellent map of the district accompanying this report have been of great value to the operators in this district. As Dr. Ransome has left the Geological Survey, it is hardly likely that a complete report will be written by him and published. Among the earlier accounts of the district, that by Mr. F. C. Schrader[3] is, by far, the most complete. Although Schrader's report is based upon a reconnaissance examination of the district, as stated in the introduction, it served a useful purpose until superseded by Ransome's more detailed studies. Schrader's work, which preceded Ransome's by fifteen years, was done at a time when a large number of the properties were operating. The bulletin, therefore, contains much information on the character of the vein fillings and the grade of the ore mined. Both Ransome's and Schrader's bulletins have been drawn on freely for infor-

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[1] Submitted as a thesis in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Arizona, May, 1931.

[2] Ransome, F. L., Geology of the Oatman Gold District, Arizona: U. S. Geological Survey Bull. 743, 1923.

[3] Schrader, F. C., Mineral Deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Arizona: U. S. Geol. Survey Bull. 397, 1909.

mation on the underground workings of properties now inaccessible. Frequent short notices in the technical press deal chiefly with mining or metallurgical problems, and rarely make more than a brief mention of the geology, and then usually treat of the geology of some particular mine rather than of the district as a whole.

The writer, while a member of the staff of the Arizona Bureau of Mines, visited the region at various times while the geologic map of the state was in preparation. Later, he examined the Oatman and Katherine districts for the United Verde Copper Company. Since then, additional trips have been made, chiefly in connection with special problems on general geology, faulting, and ore deposition.

A laboratory study of ores and associated country rocks has yielded results, some of which are not only of scientific interest, but also of considerable economic importance.

The operators in both districts have given freely of the data accumulated during the years of operation in the district. Among them, may be mentioned in particular, Messrs. Victor Light and Chas. Waters of the Tom Reed Gold Mining Company, Mr. J. W. Bradley of the United Eastern, and Mr. R. H. Dimmick of the Katherine Mine. Numerous others in both districts have been obliging enough to take the writer to their properties.

Mr. J. B. Tenney, of the Arizona Bureau of Mines, kindly compiled the information on production records.

To the staff of the Department of Geology of the University of Arizona, the writer is under obligations for aid in the laboratory investigation of ores and for suggestions during the preparation of this report.

GEOGRAPHIC FEATURES

LOCATION AND ACCESSIBILITY

Local names were at one time applied to parts of the mining district of the Black Mountains, such as Gold Road District, Vivian District, Union Pass District, and others. In reality, these localities comprise what is officially the San Francisco Mining District. A local concentration of veins occurs around Oatman and another from Union Pass westward, while the intervening country, particularly north of the Moss property, and south of Thumb Butte, although not entirely devoid of veins, is more sparsely mineralized. On this basis, an arbitrary subdivision into the Oatman District and the Katherine District is made in this report for the sake of clearness, as those acquainted with the region are more familiar with the particular area under discussion when the terms Oatman District or Katherine District are used rather than when the broader term, San Francisco Mining District, is employed.

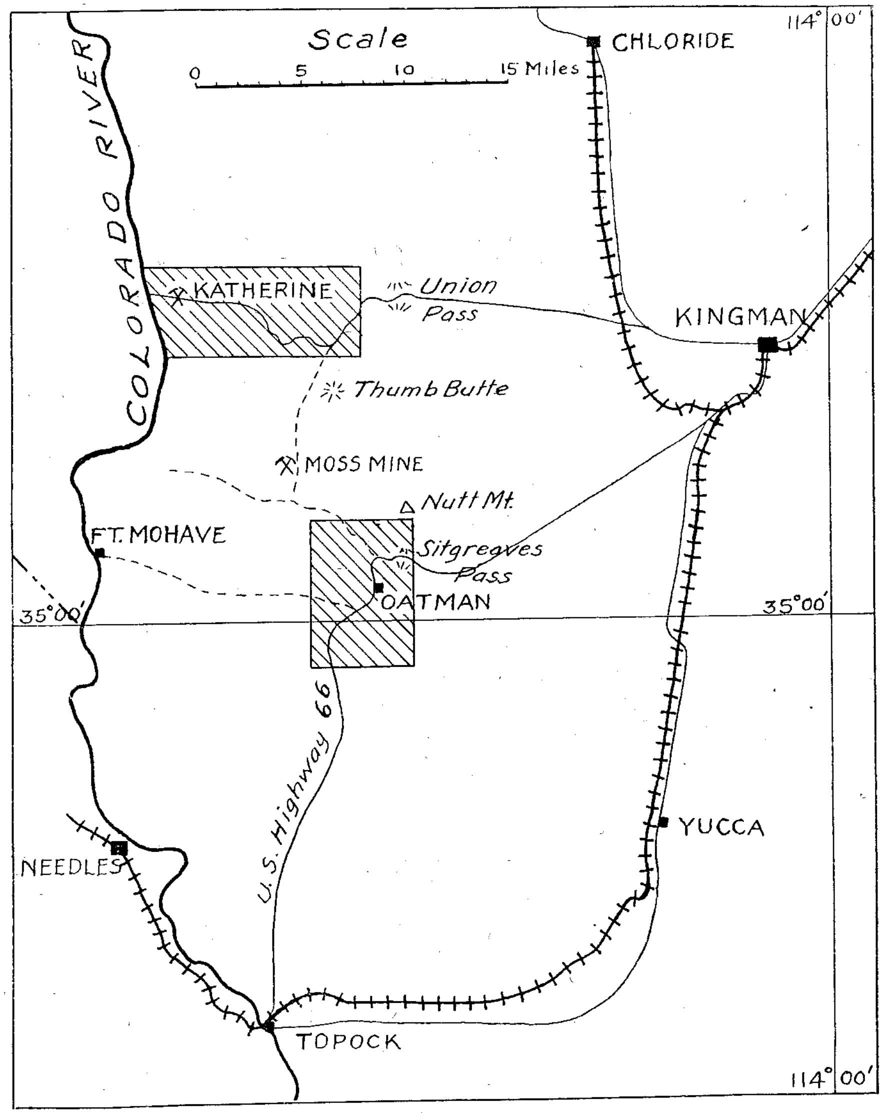


Fig. 1.—Index map of the Oatman and Katherine Districts.

All the important veins in both districts occur on the west slopes of the Black Mountains, in the western part of Mohave County. Highways connecting the mining camps with Kingman, the county seat, traverse the mountains through low passes. U. S. Highway 66 in northern Arizona crosses the Black Mountains at Sitgreaves Pass; the distance from Kingman to Oatman by this road is 29 miles. The road from Kingman to the Katherine Mine crosses the range at Union Pass; the distance between the two points is approximately 35 miles. Still farther north, several other roads cross these mountains. The position of these camps relative to Kingman is shown on the index map, Fig. 1.

Kingman is the nearest shipping point on the Atchison, Topeka, and Santa Fe Railway, and power for the Oatman District is generated there. To the southwest of Oatman is Topock, a station at the bridge across the Colorado River, and about eighteen miles to the northwest of Topock is Needles, a division point on the railway.

In the early days of Oatman, a narrow-gauge railroad extended from the Vivian and Leland mines to Fort Mohave on the Colorado River. At that time, a ferry was operating at Ft. Mohave, and supplies for the mines were brought in from Needles, California.

Numerous short roads lead from the main highways to the individual groups of claims, but many of them are now impassable. One of these roads leads off of the main highway about midway between Oatman and the Gold Road Mine and follows Silver Creek to the mines in the northwestern part of the Oatman District. A branch from the Silver Creek Road turns north and connects with the Union Pass Road just north of Thumb Butte.

CLIMATE

The region is characterized by an arid climate, with high temperatures prevailing during the summer months, and a relative low humidity. Cloudy days are rare and even in the winter a sunny day may be quite warm. Extremes of temperature are shown in Table 1[4] for Ft. Mohave, about fourteen miles to the west of Oatman, and for Kingman 29 miles to the east. The extremes of temperature do not picture accurately the climatic conditions, and for that reason the mean monthly temperatures are also given. The average monthly rainfalls at Ft. Mohave and Kingman are also given. No records are available for Oatman, but the temperature can be expected to be somewhat lower than at Ft. Mohave and higher than at Kingman. A diurnal change in temperature of 50° to 60°F. has frequently been recorded, and a

[4] Smith, H. V., The Climate of Arizona: Bull. No. 130, Agricultural Experiment Station, University of Arizona, 1930.

TABLE I

TEMPERATURE RANGE AND RAINFALL AT FT. MOHAVE—ELEVATION 604 FEET

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total rainfall inches
Extreme max.	81	92	98	105	117	127	124	120	117	104	90	81	
Extreme min.	18	24	24	30	37	52	52	61	42	35	24	3	
Mean temp.	51.6	56.5	63.1	70.9	79.1	88.5	94.5	92.8	84.8	72.6	60.4	53.2	
Rainfall in ins.	0.63	0.96	0.47	0.26	0.11	0.05	0.22	0.73	0.12	0.28	0.47	0.91	Total 5.21 inches

Ft. Mohave temperature record period of 13 years. Rainfall 44 years

TEMPERATURE RANGE AND RAINFALL AT KINGMAN—ELEVATION 3326 FEET

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total rainfall inches
Extreme max.	78	81	88	102	106	110	110	117	107	99	89	77	
Extreme min.	8	11	16	20	30	34	35	43	31	27	13	11	
Mean temp.	43.8	47.8	50.4	58.5	65.2	73.5	78.6	80.5	73.7	62.5	53.3	43.4	
Rainfall in ins.	1.39	1.46	1.24	0.67	0.39	0.18	1.12	1.41	0.89	0.74	0.75	1.26	11.50

Kingman temperature record period 25 years. Rainfall 25 years marked drop of temperature usually occurs where a bright, sunny day is followed by a clear, star-lit night.

The elevation above sea level is an important factor in determining climatic conditions. The elevation at Ft. Mohave is 604 feet above sea level, at Kingman it is 3,326, while at Oatman it is 2,700 feet.

Rainfall is also dependent, in a measure, on elevation. Table I shows the average annual rainfall at Ft. Mohave to be 5.21 inches, while at Kingman it is 11.50 inches. At Oatman, it is between these two figures. In Arizona, the rainfall is seasonal; the heaviest showers occur during the summer months, particularly during July, August, and September. During these months, the showers are nearly always accompanied by violent electric storms which are of relatively short duration, but, during these brief storms, a large volume of water may fall. For the remaining months, the rainfall is chiefly concentrated in December to March, inclusive. Gentle showers are then the rule, but heavy showers may occur.

The rainfall record at Ft. Mohave, shown in Table I, represents an average of 44 years, while the temperature record is based on 13 years of observation. The figures given for Kingman, both temperature and rainfall, are based on a 25-year record, and have been compiled from official government sources.

HISTORY AND PRODUCTION

Much of the early history of discovery and mining in these districts is obscure. According to Ransome's bulletin[5], Gen. J. H. Carleton and the 5th California Volunteers were stationed at Ft. Mohave in 1862. As some of the soldiers were experienced gold miners from California, they prospected the surrounding country when not on military duty. Some of these soldier-prospectors probably discovered the Hardy vein and established the settlement on Silver Creek. Fragments of old stone walls are still standing as a monument to these pioneers.

About 1863, John Moss located the Moss vein. Some reports state that he was led to this deposit by friendly Indians who showed him specimens of quartz which contained free gold. The outcrop of this vein is said to have contained considerable free gold, particularly at one place. About this time, the Mossback vein about two miles to the east was located. Considering the prominence of some of the veins as features of the landscape, particularly the silicified portions of the Tom Reed and Gold Road veins, it is surprising that ore shoots in them were not discovered earlier.

[5] Op. cit. p. 3.

Very little reliable information is available concerning activities in the district during the seventies, eighties, and early nineties. Apparently, work continued on the veins in the vicinity of Silver Creek, and, as interest waned, the prospectors migrated to areas of greater promise. It is possible that the discovery of rich silver-gold ores in the Cerbat Range to the north of Kingman, in the early seventies, drew the attention of prospectors away from the region of Silver Creek. Such ore as was mined along Silver Creek was hauled to Hardyville on the Colorado River for treatment. The reason for so doing was the general absence of water in this region, although a small seep occurs near the old settlement on Silver Creek where bedrock is exposed at the surface. That some of the ores, perhaps the richer ones, were treated near the settlement, is suggested by the presence of an old arrastre cut out of solid stone.

From such information as is available, it seems probable that the earliest locations in the Katherine District, the Sheeptrail and Boulevard mines, were made in the early eighties. The ore from these two mines was hauled to the Colorado River for treatment in the Pyramid mill. A teamster hauling this ore to the river had passed a small granite knob about midway between the mines and the river many times. Examining this outcrop, he noticed numerous stringers of quartz traversing the granite, and, on panning a sample, he obtained a string of colors. This led to the discovery and locations of the present Katherine Mine about 1900 or 1901.

Prospectors from the settlement on Silver Creek, searching the hills to the southwest, located a number of veins. There, the Leland and the Vivian were located prior to the year 1891, the Pioneer about 1896.

A discovery which led to a more thorough prospecting and development of the region was the finding of free gold in the outcrop of what was later termed the Gold Road vein. According to Schrader[6], the locations were made by Joe Jeneres in 1902. Jeneres was grubstaked by Henry Lavin of Kingman. The discovery was said to have been accidental.. A sample taken from the outcrop is said to have carried forty ounces in gold per ton. The announcement of this discovery led to an influx of prospectors and many claims were located.

The Tom Reed vein was located about 1900 and changed hands a number of times before the present company took over the holdings in 1908. In 1901, the Gold Road Company put down

[6] Op. cit. p. 154.

two shafts to a depth of 100 feet and discovered some ore in each shaft.

At the time of Schrader's examination of the district, in 1906 and 1907, a number of companies were operating; some were producing gold, others were developing their holdings.

Additional claims were located from time to time after the earlier discoveries, among them the Grey Eagle and Bald Eagle, in 1904, that were destined to play an important part in a lawsuit at a later date. These claims are to the southeast of the Ben Harrison shaft of the Tom Reed Company and are now a part of the holdings of that company.

In March, 1913, McIver and Long obtained an option on ground which later formed the main holdings of the United Eastern. According to some statements the U. E. vein was first recognized in the Tom Reed Mine. Miners, working in the Tom Reed Mine, noticed that the vein split into two branches, the main fracture continuing its trend to the northwest, while the split, which also contained some vein filling, had a more nearly north-south trend. Development work continued on the main or north-west branch, but, at the time, the branch was not developed. In 1915 the United Eastern Gold Mining Company was organized, and the shaft started by McIver and Long was continued by the company. By the end of 1916, a considerable tonnage of ore with a value of about $22 per ton had been blocked out, and a 200-ton mill was completed.

The next important discovery was the finding of ore on the Big Jim claim to the east of the Tom Reed vein. This claim was later (1917) acquired by the United Eastern Company, and led to litigation with the Tom Reed Company.

In 1917, the Telluride vein was discovered, and, although the ore body was relatively small, it was rather rich. This discovery was the latest important one made in the Oatman District although some rich ore was found in a winze at the Sunnyside vein below the 500-foot level in 1927. The ore shoot was comparatively small and soon played out in depth.

Both the Oatman and Katherine districts, like so many of the bonanza gold districts of the west, have had a checkered history. The spectacular character of some of the rich ore and the possibility of fortunes being made quickly appeal to the imaginative mind. Each new discovery led to a period of excitement during which many new claims were located, or old ones relocated; additional capital was brought in to try out new ventures; activity increased by leaps and bounds and prosperity reigned; but, in time, the excitement slowly subsided. As the value of the ore decreased or production dropped off, interest waned, and a period of stagnation set in. Many of the new ventures failed to find ore and, unable to raise additional capital to carry on, the claims were often abandoned. The cycle is then complete, and may be repeated over and over again as new discoveries are made.

Following the discovery of the United Eastern ore body in 1915, it is said that fully 200 properties were operating at one time in the Oatman District. During 1916, eighty different shafts were being sunk at various properties. Of this large number, only a few encountered new ore bodies, usually near the surface in the zone of enrichment where higher values could be expected. Such enriched ores seldom continued in depth more than a few hundred feet below the point of discovery.

The ore at the United Eastern was first encountered at a depth of 300 feet below the surface. This discovery led to the belief that it was necessary to attain this depth before ore could be expected. The number of shafts eventually sunk to depths ranging from 300 to 600 feet thoroughly exploded this fallacy.

A record of the production from the Oatman and Katherine districts has been compiled by Mr. J. B. Tenney of the Arizona Bureau of Mines and is given in Table II. As shown in this table, the production from the various mines prior to 1907 is more or less uncertain, and is based on such records as are available. This table is also interesting because it shows the years during which the different large mines were the main producers of the district.

Production prior to 1908 is given as $2,500,000. This figure is probably low, as $2,250,000 is credited by Tenney to the Gold Road Mine for the period of 1904 to 1907 inclusive; and the Moss vein is said to have produced $250,000 from the original discovery. The estimate does not cover the production from the Hardy and other mines along Silver Creek; nor does it include the early production from the Katherine District or the various properties around and including the Vivian.

Table II shows that the main period of production from the Gold Road Mine was from 1904 to 1915, inclusive. This mine was shut down in 1918, reopened in 1922, and again closed in 1924. The Tom Reed Company produced from 1908 to 1921, and from 1922 to May, 1924, gold production was entirely by lessees whose ore was treated in the Tom Reed mill. Production, by the company, began again from the Black Eagle shaft in 1927. The total production credited to this company includes also, in the later years, a small production from outlying properties.. Pro-

TABLE II.—GOLD AND SILVER PRODUCTION OF THE SAN FRANCISCO DISTRICT, ARIZONA

COMPILED BY J. B. TENNEY

Year	TOM REED MINE		UNITED EASTERN		GOLD ROAD		TOTAL PRODUCTION a			
	Tons Ore	Bullion Value	Tons Ore	Bullion Value	Tons Ore	Bullion Value	Total Tons Ore Treated	Total Gold in dollars	Total Silver in ounces	Total Value in dollars
1897					1904 to	$ 2,250,000				
to					1907 incl.					$2,522,000
1907										
1908						739,400	72,757	266,254	6,522	269,711
1909		$1,037,911					18,106	300,036	7,118	303,737
1910						676,600	89,284	1,103,221	26,254	1,117,398
1911	43,924	835,048				665,783	110,699	1,458,639	33,834	1,476,571
1912	55,663	1,154,559			109,070	676,515	174,319	1,794,847	41,456	1,820,342
1913	48,111	1,141,907			103,629	843,991	159,948			1,818,522
1914	46,995	1,002,407			107,846	651,761	160,469			1,846,398
1915	29,916	661,871	Discovered		96,273		132,579			1,499,033
1916	46,170	486,678	Developed				95,245	892,681	23,812	908,349
1917	81,884	620,179	84,548	$1,827,670			167,258	2,310,270	57,353	2,357,529
1918	88,525	794,383	92,339	2,072,359	Mine closed		182,824	2,772,991	70,432	2,843,423
1919	89,537	679,986	97,325	1,970,509			184,490	2,556,197	71,833	2,636,650
1920	93,970	705,657	102,926	2,233,819			197,629	2,830,731	92,806	2,931,890
1921	69,832b	377,992	97,413	1,910,054	Mine		179,013			2,388,050
1922	43,072	463,118	117,687	1,643,909	reopened		169,240			2,138,546
1923	42,814	538,366	104,800	2,085,075	31,109		186,686	2,796,830	68,551	2,853,042
1924	14,586	181,936	Closed June	1,000,000‡	Closed.Oct.		96,788	1,617,196	39,097	1,643,391
1925	35,448	494,829	Dump ore	60,000‡			46,638			568,131
1926	21,261	283,595	treated				89,391			647,172
1927	17,259	161,461					102,979			530,866
1928	7,672	118,275					43,300			296,926
Total	876,639	$11,740,158	697,038	$14,726,895	447,927	$ 6,504,050	2,659,642			$35,417,926

a. Includes production from small mines.
b. From 1921 to 1928 includes ore from lessees.

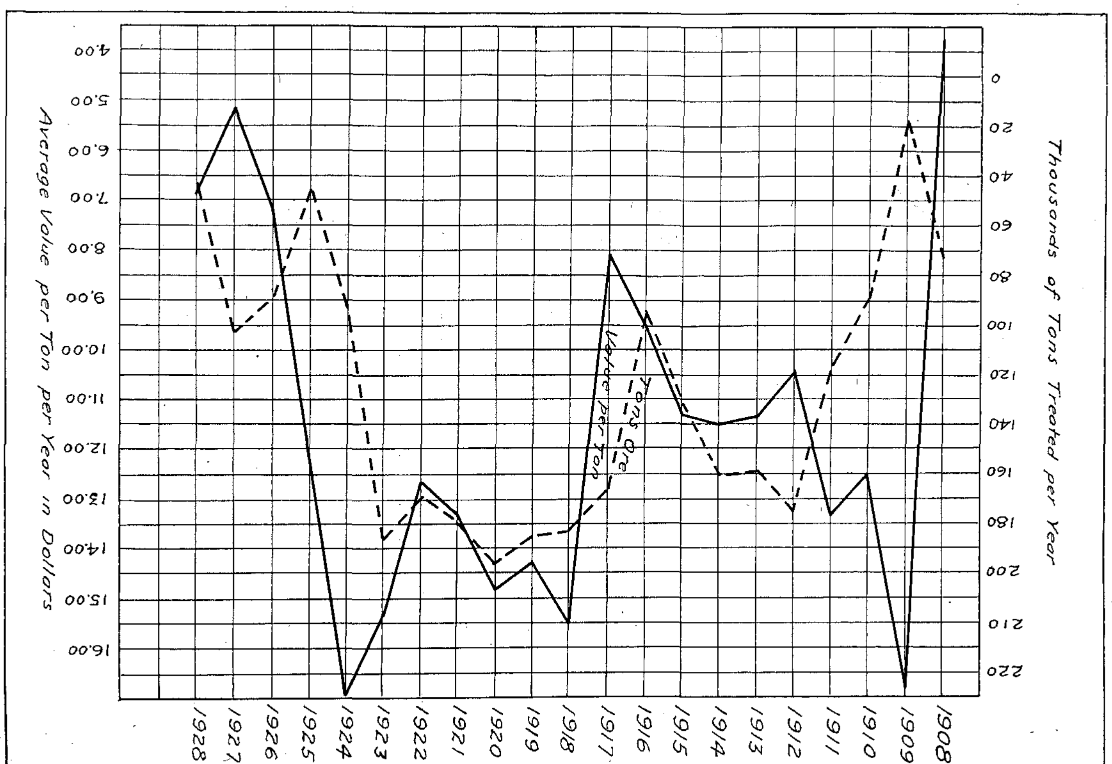


Fig. 2.—Chart showing the relation between tons of ore mined and the value per ton for the years 1908-1928 inclusive.

duction from the United Eastern began in January, 1917, and continued until June, 1924, when the mine was closed. Ore mined at the Big Jim by lessees in 1926 is included in the production of the Tom Reed as the ore was treated at that company's plant.

PHYSIOGRAPHY

In both the Oatman and Katherine districts, all the veins so far located occur on the west slope of the Black Mountains or in the lower country to the west, between the range and the Colorado River. The mineral-bearing area may be subdivided on the basis of topographic relief into three belts or units with a north-south trend. These are, 1st, the rugged uplands, 2nd, the foothill belt, and, 3rd, the detrital slopes.

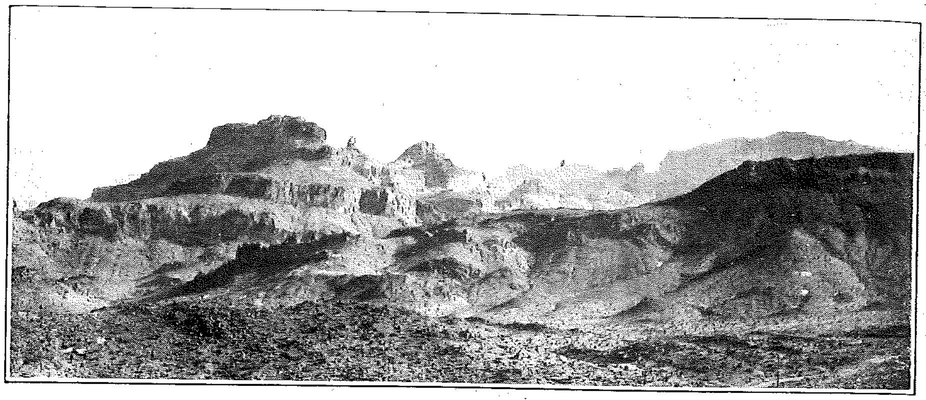


Fig. 3.—Topography of the higher slopes of the Black Mountains to the east of Oatman, Arizona.

Rugged Uplands: At Sitgreaves Pass, where the main highway between Oatman and Kingman crosses the mountains, the elevation is nearly 3,600 feet above sea level. South of this pass, the mountains, as viewed from a distance, present a mesa-like appearance due to what appears to be nearly flat lava flows. In reality, these flows are deeply dissected by streams which flow to the east or south. Antelope Creek, within a mile of its head at the crest of the range, just east of the town of Oatman, has cut a canyon into these lavas, which is nearly a thousand feet deep. Basalt flows are present less than two miles south of Antelope Canyon and there the mesa-like relief is even more apparent. The drainage is to the south through Warm Springs Canyon. This particular part of the range is frequently referred to as the Ute Mountains.

North of Sitgreaves Pass, the topography is much more rugged. In this area, Nutt Mountain, with an elevation of 5,065 feet above sea level, forms the highest point in the Black Mountains. Surrounding Nutt Mountain on all sides, the relief forms a terraced topography of cliff and slope. In some places, the more massive flows form cliffs, from 300 to 500 feet high. Be-

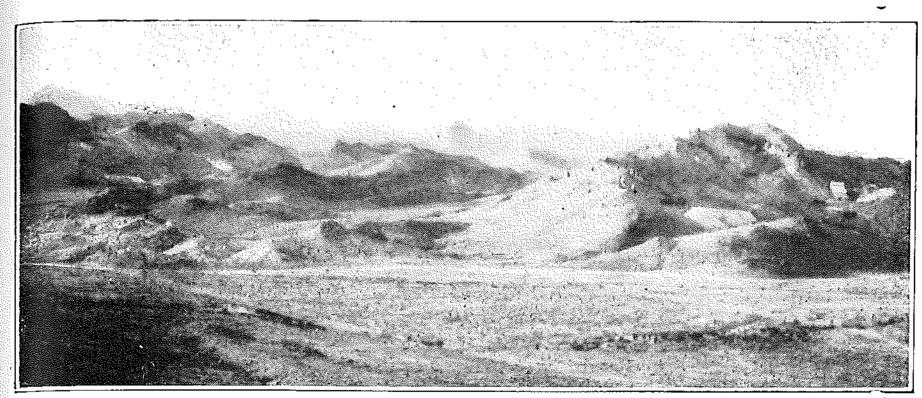


Fig. 4.—Topographic relief in the foot-hill belt to the west of Oatman.

tween the massive flows are softer tufaceous members that in places weather to form more gentle slopes. At several places, the continuity of these nearly vertical cliffs is interrupted by faults. Side canyons, although of a steep gradient, make the higher region accessible. Cottonwood Creek, which heads in this portion of the range, in its upper reaches, has formed a canyon of wild scenic beauty. This rugged type of topography continues in the higher portions of the range northward for many miles, even beyond Union Pass.

Foothill Belt: In places, the rugged topography of the mountains proper merges imperceptibly into the foothill belt; in other places, the change is more abrupt. Flanking the range on the west side, a region of lower elevations and gentler slopes forms the foothill belt. Its width is quite variable, ranging from two miles to six miles. The relief consists of a more mature topography intricately dissected by stream erosion. The hills rarely rise more than a few hundred feet above the stream bed. The hill tops are well rounded and the slopes are usually gentle. Here and there, however, particularly in areas in which the Esperanza trachyte is exposed, a more rugged topography exists. This condition is particularly notable in areas around the Boundary Cone.

Intrusive plugs of rhyolite form prominent features of the landscape. Two such plugs occur in the Oatman District. They are somewhat lighter in color than the lavas which they invade, and Boundary Cone, in the southwestern part of the district, is the most prominent. This conspicuous feature of the landscape is visible for long distances, especially from the west. This plug rises 1,400 feet above Esperanza Gulch in a horizontal distance of somewhat less than a half mile. The Elephant's Tooth, east of the town of Oatman, another plug of rhyolite porphyry, is the erosional remnant of a dike with a local increase in width.

Intrusive porphyry forms a rugged area to the northwest of Oatman. The highest point, Mt. Hardy, attains an elevation of 3,231 feet above sea level and a thousand feet above Silver Creek, immediately to the north. The rock is traversed by a large number of joint planes along which erosion has cut numerous rugged crags.

In the southeastern part of the Katherine District is Thumb Butte, a prominent feature of that region. The rock from which this butte is carved is a thoroughly consolidated volcanic agglomerate. Erosion has cut the upper part of this agglomerate into a series of sharp pinnacles and crags.

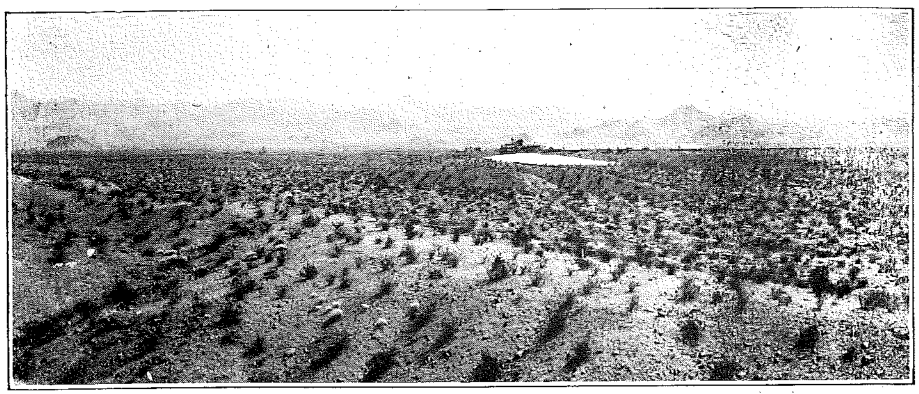
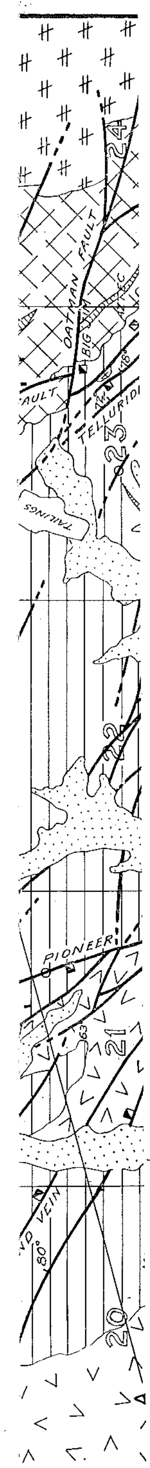


Fig. 5.—The detrital slopes to the west of the Katherine Mine.

Detrital Slopes: Recent gravels and sands form long detrital slopes which extend from the foothill belt westward to the Colorado River. The general uniformity of this slope is its most striking feature. In its upper reaches, the surface slopes at the rate of 200 feet to the mile, but, nearer to the banks of the river, the slope has decreased to somewhat less than 100 feet to the mile. Long, dry washes, broad and shallow, drain the region. These washes rarely carry water except after heavy storms, but, the streams carry large quantities of sand, gravel, and even large boulders when in flood. At present, the streams have cut their beds to depths which rarely exceed 50 feet below the old surface.

The down-cutting of the streams has developed a series of terraces. Particularly good examples occur on Silver Creek near the



GEOLOGIC MAP OF THE

KATHERINE DISTRICT

MOHAVE COUNTY, ARIZONA.

PLATE II

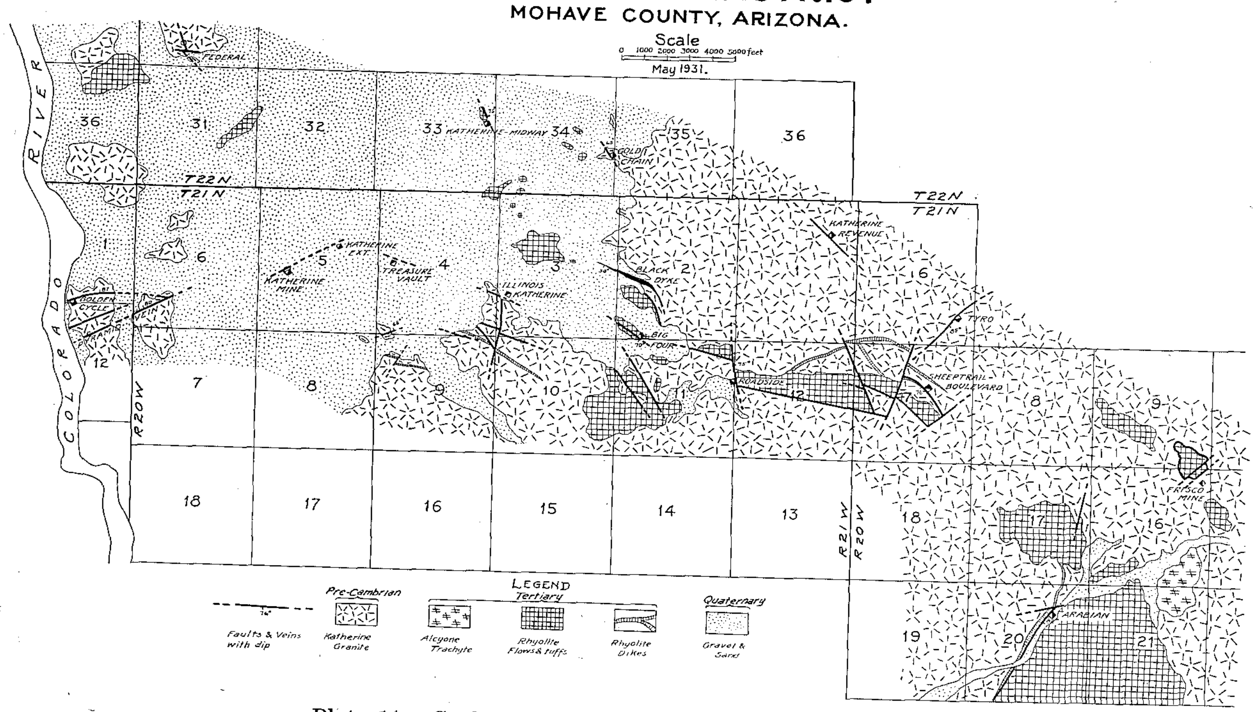


Plate 11.—Geologic Map of the Katherine District.

Oatman Amalgamated Mine. Only a few isolated remnants remain, and the shifting of Silver Creek from side to side has cut deeply into the few remaining remnants.

GENERAL GEOLOGY

PRE-CAMBRIAN FORMATIONS

The underlying rock on which the Tertiary lavas rest is exposed in several small areas in the western part of the Oatman District. Deep diamond drilling at the United Eastern Mine shows that the andesites at that mine rest directly on the old, highly sheared granite. A small exposure of sheared granite is present on the east side of the range opposite Oatman, only a short distance south of the highway.

Granite is the prevailing type of rock in the Katherine District. A prominent ridge, which extends eastward to the base of the range, just south of the Katherine Mine, is composed of granite with local, small patches of lavas. About a mile south of Union Pass, a belt of this granite crosses the crest of the range and extends eastward an unknown distance. Shafts sunk through the surface gravel at various properties near the Katherine Mine have penetrated the granite in depth. The intervening country on the west side of the Black Mountains, between the Oatman and Katherine districts, also contains isolated exposures of the older rocks.

Although the formation as a whole is essentially granitic, in reality it is a complex of various old rocks, such as schist and gneisses, highly sheared and altered. At least two different granitic intrusions occur in these districts with marked differences in mineral composition and texture. Both, however, are younger than and intrude the schist-gneiss complex.

There is no positive proof in either the Oatman or Katherine districts that this complex is pre-Cambrian in age, but its highly sheared and altered condition suggests that it belongs in the older divisions of geologic history. Not far to the north-eastward, in the lower slopes of the Grand Wash Cliffs, are extensive exposures of a coarse-grained, highly sheared granite, remarkably similar in appearance to the granite in the Katherine District, which is overlain unconformably by Paleozoic sedimentary rocks the oldest member of which is a sandstone of Middle Cambrian age. The older rocks in both the Oatman and Katherine districts are therefore assigned to the pre-Cambrian division of geologic time.

There is a small exposure of these older rocks near the Murdock shaft in the southwestern part of the Oatman District. This brownish, somewhat schistose rock may be a partly recrystallized sediment. It is rather fine-grained in texture with abundant mica flakes on parting planes. In this vicinity, also, is an exposure of fine-grained diorite. The rock is somewhat altered, but appears to consist essentially of feldspar and a ferromagnesian mineral, perhaps hornblende, together with a small amount of accessory magnetite.

The older rocks occur a short distance to the west of Fortuna Hill, in the western part of the Oatman District, where a small exposure of biotite gneiss is cut by granite. The granite is uniform in texture, the large feldspars rarely exceeding two-tenths of an inch in length. The minerals are potash feldspars, both microcline and orthoclase, some acid plagioclase, and quartz. Ferromagnesian minerals are rare, but the form of some iron-stained patches suggests derivation from biotite. A little magnetite may also be seen in the hand specimen. The rock is cream-colored on fresh fracture and weathers pale brownish. It is somewhat altered and seamed with veinlets of calcite, and the feldspars are kaolinized. In texture and mineral composition, this granite closely resembles the rock cut in deep diamond drilling at the United Eastern Mine, but the granite from the mine contains a small amount of chlorite.

The prevailing rock in the Katherine District is a coarse-grained granite. On a weathered surface, it is brownish due to the decomposition of the ferromagnesian constituents. Surface exposures are highly altered and crumbly. Even in the deeper workings of the mines, it is practically impossible to obtain specimens that do not show intense alteration. Specimens from the mine workings have a greenish-gray color due to abundant chlorite. Intense shearing has crushed the large crystals of both quartz and feldspar, and has produced a gneissic structure. The rock is rather coarse-grained and somewhat porphyritic in texture, with large phenocrysts of microcline rather common. These phenocrysts are rounded in outline and measure up to two inches in diameter. The matrix of the rock in which the large phenocrysts are set consists of quartz and feldspar grains rarely less than one-quarter inch and frequently over one-half inch in diameter. The quartz is of an opalescent, bluish color and translucent rather than transparent. The feldspars are nearly all more or less kaolinized. Between the quartz and feldspar grains is abundant chlorite to which most of the dark color of the rock is due. Associated with this chlorite are grains of pyrite, and it is possible that the solutions that deposited the pyrite also changed the original ferrogamnesian minerals to chlorite.

An examination of thin sections of the freshest granite available shows the rock to consist essentially of anhedral grains of feldspar and quartz together with aggregates, irregular in outline, of small hornblende grains. Both feldspar and quartz show wavy extinction, which suggests that the rock has been subjected to considerable pressure. This suggestion is further borne out by the study of quartz grains. Rounded outlines of quartz grains which appear in ordinary light to have been, originally, a single grain are found, when examined in polarized light, to comprise an aggregate of smaller grains. Such quartz grains are always traversed by numerous trains of dusty inclusions. The most abundant feldspar in the slides is orthoclase, usually as twinned crystals. Some decomposition product occurs along cleavage cracks as small scales, perhaps sericite. Although most of the microcline is present as large phenocrysts, as mentioned in a preceding paragraph, a subordinate amount is present as smaller grains. It shows the usual twinning according to the Pericline law, and is remarkably free from decomposition. Crystals of acid plagioclase, either with subhedral outlines or in well-defined crystals, are quite common in the rock. The effect of polysynthetic twinning, very fine, narrow striations on cleavage faces, is a characteristic feature. By optical means, this mineral was found to be albite. Aggregates of small scales of a micaceous mineral (sericite or paragonite) occur in the feldspar. As a rule, the albite shows more decomposition than any of the other feldspars. Frequently only small areas of a grain remain free from alteration. Hornblende is present as an aggregate of grains, rounded or irregular in outline. The hornblende is of the greenish variety, strongly pleochroic, with the characteristic cleavage. It shows some alteration to fibrous shreds of chlorite.

Among the accessory minerals are magnetite, pyrite, apatite, and zircon. The magnetite occurs as veinlets traversing the hornblende or moulded around grains of this mineral, indicating that its period of formation was slightly later than that of the hornblende. Associated with magnetite are occasional grains of pyrite. Apatite occurs as rather large, stout crystals, usually enclosed in the magnetite or the hornblende. Smaller crystals of this same mineral, as slender needles, may be observed in both feldspar and quartz. Well crystallized individuals of zircon are also common, but no titanite was found. Very small needles of a yellowish brown mineral in the feldspars may be rutile, but it was not positively identified.

The order of crystallization of the constituents of this rock appear to be zircon, apatite, hornblende, magnetite, pyrite, plagioclase, orthoclase, microcline, and quartz.

The texture may be described as allotriomorphic with a tendency towards idiomorphism for the grains of plagioclase feldspar.

The rock may be described as a hornblende-microcline granite. A striking feature of the rock is the entire absence of micaceous minerals such as biotite or muscovite.

Dikes of pegmatite and pegmatitic quartz are quite common in the granite of the Katherine District. They do not present any features of special interest.

Near the road leading west from Union Pass is a small exposure of rock which is weathering to an olive drab soil. Decomposition is so far advanced that it is impossible to get a specimen for accurate determination. It appears to have been diorite or gabbro. Certain dark dikes cutting the granite are hornblende diorite porphyry and may be related to this diorite or gabbro intrusion.

MURDOCK BRECCIA

Near the Murdock Mine, in the southwestern part of the Oatman District, is a detrital deposit which is here named the Murdock breccia. It consists very largely of granitic detritus together with angular fragments and boulders of granite, gneiss, schist, vein quartz, and some dark rocks, perhaps diorite. The matrix in which these more resistant rocks are set is composed of angular grains of quartz and feldspar derived from the disintegration of exposures of granite. More or less red mud occurring in the matrix was probably formed from the decomposition of the feldspar.

The material at this locality shows little or no sorting, and a mixture of large and small boulders is a common characteristic. From a distance, however, a rude stratification is discernible and the deposit near the Murdock Mine appears to dip to the west at about 25°.

About two miles west of the Leland Mine are extensive exposures of this formation. The material of which it is composed is very much the same as that near the Murdock Mine, but the color, particularly in the upper portions of the deposit, is greenish rather than brown. A closer examination shows more distinct bedding. The greenish portion appears to consist partly of volcanic ash, and may represent material derived from the first outbursts of volcanic activity.

No substance of this nature was observed anywhere in the Katherine District. Although it may have been present beneath the lavas at one time, it has probably, like the lavas, been removed long ago by erosion.

The absence of sorting, the angularity of the boulders and smaller grains, and the freshness of some of the feldspar suggest the materials of which this formation is made up were transported by streams, torrential in character. It is possible that arid or semi-arid climatic conditions prevailed at the time of decomposition.

The age of this breccia is uncertain. No Paleozoic or Mesozoic sedimentary rocks occur in the region. The nearest exposures of Paleozoic rocks, which are of marine origin, is approximately sixty miles to the northeast in the Grand Wash Cliffs. It is possible that these sediments covered this region at one time. The upper Cretaceous sediments of eastern Arizona with their contained coal bed indicates a humid climate. If, therefore, the assumption is correct that the Murdock breccia was formed under semi-arid conditions, and cannot be correlated with any of the formations already mentioned, it was, most probably, deposited at some time during the Tertiary, perhaps early Tertiary.

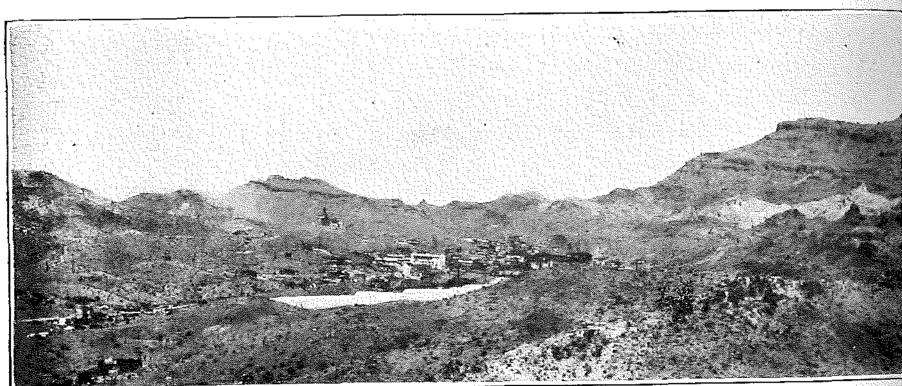


Fig. 6.—General view of the town of Oatman from the south. The white area in the lower central part is the tailing pile of the Tom Reed mill.

TERTIARY LAVAS

In the Black Mountains of western Mohave County is an extensive series of volcanic flows, agglomerates, and tuffs which show considerable variety in composition and texture. These flows and associated tuffs are of such diverse types as olivine basalt at the basic end of the series and rhyolites at the acid end. Between the extremes are various intermediate types.

The lowest member of the series was described by Schrader as the "basal andesite" or the "older andesite."[7] Above, is an andesitic flow to which Schrader gave the name "green chloritic andesite," and still higher in the series is his "undifferentiated volcanic rocks."[8] Ransome, however, mapped the district in detail and separated the various members of the volcanic series; and to these members he gave formational names. His terminology, based on more detailed studies, gives a more accurate classification of the rocks of this interesting series.

In the western part of the Oatman District, the basal member of this volcanic series rests on the pre-Cambrian rocks or on the Murdock breccia. In the southeastern part of the Katherine District, a flow of trachyte, correlated with the Alcyone, rest in places on the Katherine granite. At other places in this district the flow is underlain by a bluish-gray tuff, which in turn rests on the granite. Exposures fail to indicate the topographic relief at the time volcanic activity began. It appears to have been somewhat hilly with some of the depression filled or partly filled with the detritus that forms the Murdock breccia.

A search of the various tuffs intercalated in the flows failed to yield fossils. In many parts of the Great Basin Province, from northern Nevada, southward to the Mexican boundary, volcanic rocks are commonly found. At some places, the occurrence of fossils in associated tuffs shows the volcanic rock to belong to the Tertiary period, and the various flows and associated rocks at Oatmaan are also believed to be Tertiary in age.

The volcanic rocks dip to the eastward at a low angle; the oldest members, therefore, occur to the west and form irregular belts with, roughly, a north-south trend. To the eastward and forming the crest of the range, are the younger members of the series.

Alcyone Trachyte: The basal member in the Oatman District has been named by Ransome the Alcyone trachyte.[9] In general the color of the Alcyone trachyte, when viewed from a distance, is a delicate lavender tint; occasional areas are pale greenish gray. Some flows are reddish, perhaps due to the oxidation of the ferromaganisan silicates, while others, more basic in composition, are of a rather dark gray. Interbedded with the flows

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[7] Op. cit. p. 34
[8] Op. cit. p. 37
[9] Op. cit. p. 17.

are beds of ash and volcanic agglomerate. The differences in color give a banded appearance to the formation in some places.

The Alcyone trachyte is composed of rather thick, massive flows, but in places they show a platy structure. In a hand specimen, the rock invariably shows an abundance of stubby feldspar crystals and, occasionally, ferromagnesian constituents in a dense groundmass. Some of the flows are really flow breccias formed by the breaking up and inclusion within the moving magma of the thin solidified crust. This type is particularly well exposed to the south of the Boundary Cone rhyolitic plug.

The maximum thickness of the Alcyone trachyte was estimated at about 2,000 feet for exposures in the vicinity of Fortuna Hill, to the west of the Leland Mine. The flows are little disturbed by faulting, and the estimate is believed to be close to the actual thickness. The thickness varies from place to place, probably due to erosion. At the United Eastern Mine, as shown by diamond drilling, the andesites rest directly on the old granite.

When examined in thin sections, the Alcyone trachyte shows some variation in mineral composition. The phenocrysts of feldspar are commonly orthoclase, but in the more basic members the phenocrysts are andesine. Smaller plagioclase crystals are always of a more acid variety of andesine than the phenocrysts. The groundmass contains an abundance of small feldspar laths, which, in specimens not too intensely altered, were determined as orthoclase. The ferromaganesian constituents also vary in the different flows; the more acid members show biotite, somewhat altered, and outlines of what appears to have been hornblende. The basic flows contain augite and occasional remnants of hornblende. Magnetite grains and apatite needles occur as accessory minerals. The groundmass is glass crowded with minute crystals of feldspar and dusted with grains of magnetite. The texture is vitrophyric with well-defined flow lines.

The larger orthoclase crystals are commonly altered along cracks to a white, opaque substance, perhaps kaolin. The plagioclase shows more intense decomposition than the potash feldspar and consists of aggregates of small scales of sericite, some calcite, secondary quartz, and, less commonly, a little epidote. Of the ferromaganesian constituents, the augite shows the least alteration.. The hornblende is usually entirely replaced by calcite, serpentine, bastite, and secondary quartz. These minerals are frequently surrounded by a rim of magnetite and hematite which outlines the original crystal. The groundmass is clouded with kaolinitic dust.

Ransome[10] gives the chemical analysis of a specimen of the Alcyone trachyte, as follows:

CHEMICAL ANALYSIS OF ALCYONE TRACHYTE

R. C. WELLS, *Analyst.*

SiO_2	65.26
Al_2O_3	16.39
Fe_2O_3	1.98
FeO	1.21
MgO	.83
CaO	2.16
Na_2O	4.23
K_2O	6.30
H_2O above 110°C	.34
H_2O below 110°C	.47
TiO_2	.55
P_2O_5	.14
MnO	.05
CO_2	.14
	100.05

As shown by the small amount of water and carbon dioxide, this analysis was of an unusually fresh specimen of the trachyte. The lime is somewhat higher than is common in typical trachytes and results from the abundance of plagioclase found in the slides. This feature was recognized by Ransome.

The framental members, in part, show sorting and distinct stratification, but larger fragments of rock are to be seen here and there mixed with the finer debris. A microscopic examination shows an abundance of glass shards together with angular fragments of the minerals commonly found in these rocks.

Exposures of stratified sands, grayish in color, with a thickness of sixty feet, are present less than a quarter mile due south of the White Chief Mine. Part of this material is coarser in texture and is composed of angular fragments of the Alcyone trachyte, which may be the products of explosions.

In the narrow valley south of the Vivian Mine is an exposure of detritus derived by weathering from Alcyone trachyte and transported by stream. The bedding, in places quite distinct, dips to the east at 17° to where it is overlain by the Oatman andesite. At this place, the measured thickness is 310 feet.

In a saddle immediately east of the Boundary Cone, the Alcyone trachyte has a brownish color, and is overlain by the tufaceous member at the base of the Esperanza trachyte. No sedimentary material occurs at this point.

It appears, therefore, that the Alcyone trachyte was subjected to some erosion before the tuffs and flows of the Esperanza trachyte were formed. How extensive this erosion was is not

10 Op. cit. p. 17.

known, nor is it definitely known that actual disturbances took place after the volcanic activity that gave rise to the Alcyone trachyte.

Esperanza Trachyte: Exposures of this formation are confined to the southwestern part of the Oatman District, and rocks of a similar character were not observed anywhere in the Katherine District. The limited distribution may be due to the original small areas covered at the time the flows were erupted rather than to erosion following their solidification. Where the Oatman andesite may be seen resting on these trachytes, a small thickness of ash beds is present, but no evidence of extensive erosion. East of the areas of Esperanza trachyte shown on the map of the district, the rock is known to extend beneath the andesite to the Sunnyside Mine where it forms one wall of the Sunnyside fault on the 500-foot level.

The maximum thickness in the block to the northeast of Iowa Canyon, based partly on measurement and partly on estimate, is between 800 and 1,000 feet. This block, apparently is not cut by transverse faults. It is uncertain whether this section contains more than one flow. In hand specimens, the rock is everywhere remarkably uniform in texture and mineral composition, but a banded structure which is evident in cliff sections, may mark the divisional planes between flows; if it does, there are at least three flows and one bed of volcanic agglomerate. An interesting feature of this rock is the manner in which it weathers into thin slabs, usually somewhat curved. It is not uncommon to find such slabs up to twelve inches or more in length and nearly as broad, but only a half inch in thickness. As the rock is quite dense, such slabs give out a metallic ring when struck with a hammer. This has frequently led prospectors erroneously to refer to this rock as a phonolite.

The base of the Esperanza trachyte near the Boundary Cone is a fifteen-foot bed of well stratified, cream colored ash. No fragments of foreign rocks occur in this tuff, but some layers are largely made up of angular fragments of pumice, somewhat lighter in color than the remainder of the ash. Just south of the White Chief Mine, the tuff is between fifteen and twenty feet thick and has a pinkish color with a mottled appearance due to the presence of fragments of white pumice. Here the tuff rests on the sandy beds that form the top of the Alcyone trachyte at this locality.

When examined in thin sections, the tuffs are found to consist largely of glass shards, angular grains of clear feldspar (sanidine), and an occasional grain of plagioclase. Biotite is surprisingly scarce in the tuff, considering its abundance in the flows.

The glass shards may have been decomposed by hot vapor or solution, for locally a microscopic thin section contains an abundance of calcite, some small veinlets of quartz, and a sprinkling of iron oxide.

The Esperanza trachyte is a rock which varies in color from purplish brown to bluish gray and contains small crystals of feldspar, rarely exceeding one-tenth of an inch in length. Abundant flakes of biotite, or black mica, are common in a dense groundmass.

When examined in thin sections under a microscope, the phenocrysts of feldspar were found to be mostly the clear variety of orthoclase, sanidine, with an occasional grain of acid plagioclase. The biotite is present as long flakes rather than as the more common hexagonal plates. The groundmass, which contains very little glass, is closely crowded with long, slender, twinned crystals of feldspar together with minute grains of magnetite. It shows a trachytic texture with the flow lines in the lava indicated by the more or less parallel arrangement of the small feldspar laths.

No analysis is available of this type of rock. The mineral composition, however, indicates that the flows of the Esperanza trachyte are, perhaps, more nearly true trachyte than those of the Alcyone. The tuffs at the base of the flows contain considerable calcite, however. It is possible that this calcite is from an extraneous source, and should, therefore, not be considered in estimating the probable composition of the rock. If, however, it was actually derived from the decomposition of the glass then the rock must approach a latitic trachyte in composition rather than a true trachyte.

Oatman Andesite: The Oatman andesite is the most important of the various groups of flows from an economic standpoint, for it is in this formation that most of the ore in the Oatman District has been found. It forms a continuous belt from the southern limits of the area mapped northward to the Oatman Amalgamated Mine, and exposures of the andesite were again observed at the Mossback Mine. No rocks of this kind occur in the Katherine District. The belt attains its greatest width just west of the town of Oatman where the greater width, along this east-west line, is due in part to duplication in the section by faulting, but it is here also that the Oatman andesite attains its greatest thickness. As shown by diamond drill holes, the thickness must be around 2,000 feet, perhaps even 2,200 feet. There is a thinning to the southwest, for, near the Highland Chief Mine, the andesite is not over 600 feet thick. North of the Mossback Mine, the andesite is also rather thin.

Surface exposures of this rock weather to disintegrated grains or fragments of an olive drab to brownish color. Exposures of harder rock are usually dull green or greenish gray while fresh rock is of a dark gray to black color. As much of the Oatman andesite is altered at the surface, it is frequently difficult in places to distinguish the andesite from certain more basic phases of the Alcyone trachyte. It is particularly difficult to do so near the eastern margin of the Times porphyry.

Where the Gold Road latite has been altered by mineralizing solutions, as near the Gold Ore Mine, or near the Big Jim, it closely resembles the Oatman andesite; but the latite always contains abundant flakes of brown biotite, and remains of this mineral, even though much altered, can nearly always be found. This is a useful criterion in distinguishing the Gold Road latite from the Oatman andesite.

Near the head of Iowa Canyon, the andesite may be seen resting on the Esperanza trachyte with only a few feet of reddish ash beds between the two. Northwest of the Pioneer Mine are well-bedded layers of sandstone and shale which appear to be made up largely of material derived from the weathering of volcanic rocks. Some thin layers of dark limestone, rarely more than a few inches thick, occur in the shaly portions. No fossils were found in these limestones which are probably of fresh water origin.

Although the flows which make up the Oatman andesite are quite uniform in texture and color, some portions show an unusual development of large, porphyritic feldspar crystals. It is possible that this rock may occur as an intrusive sill. Ordinarily, the feldspar crystals visible on a fresh fracture are less than a quarter of an inch in length. With a hand lens, some pyroxene may be seen, but in none of the rocks examined was biotite found in a hand specimen. The groundmass in which the crystals are set is quite dark in color and dense in texture.

The individual flows rarely have a thickness of over 100 feet. This fact is brought out in the examination of diamond drill cores. An amygdaloidal texture is well developed at the tops of the flows and perhaps, also, to some extent at their bases. The vesicular portion at the tops of the flows not only has a greater thickness than that at the bases, but in most flows is stained reddish due to the oxidation of the iron. Some of the cavities in such vesicular portions are lined with a thin film of greenish chlorite, and, resting on the chlorite, is a thin film of scaly hematite. When the cavity is filled with introduced matter these irregularly rounded lumps of mineral are referred to as amygdules, and the texture of the rock is then known as amygdaloidal. The amygdules are commonly composed of calcite which is usually surrounded by a rim of chalcedony. Some of the smaller cavities are entirely filled with chalcedony. The vesicular portions of the flows are more altered than the main body of the rock.

A microscopic examination of these andesites shows little diversity in mineral composition. In many thin sections, the minerals are too altered for accurate determination. The larger crystals of plagioclase vary in composition from andesine to labradorite with the central portion of the crystal more basic than the margins. Much of the feldspar is altered to calcite and secondary quartz. The ferromagnesian minerals are pyroxene (augite) and brown biotite, both of which are largely altered to serpentine or chlorite. No hornblende was noted in any of the sections. Grains of magnetite and slender prisms of apatite occur as accessary minerals. The groundmass is rather dense and is closely packed with microlites of feldspar some of which show twinning and have a low index of refraction. It is possible that some of these microlites are orthoclase which would account for the rather high potash content found by analysis in some of these rocks.

The porphyritic texture is quite pronounced, but there is considerable variation in the proportion of phenocrysts to groundmass. In some specimens, the large crystals are embayed, suggesting resorption by the magma, but most of them still show well-developed crystal boundaries. This is true also for some of the pyroxene crystals, but occasionally the augite occurs as a cluster of irregular grains. In the groundmass of some specimens, the microlites of feldspar show a more or less parallel arrangement, indicating flow lines. Perhaps these varieties of the andesite are more acid in composition.

The analyses below are from Ransome's[11] bulletin and from Schrader's[12] report.

ANALYSES OF OATMAN ANDESITE

	1	2	3	4
SiO_2	56.37	53.55	53.13	56.33
Al_2O_3	15.99			
Fe_2O_3	2.56			
FeO	3.41			
MgO	2.97			
CaO	6.81	5.60	7.96	4.00
Na_2O	2.99	2.62	2.43	2.60
K_2O	2.89	3.14	3.13	5.19

[11] Op. cit. p. 23.
[12] Op. cit. pp. 36-37.

H_2O below 110°C	0.38
H_2O above 110° C	1.66
TiO_2	1.16
P_2O_5	.41
MnO_2	.07
CO_2	2.18
Total	99.85

No. 1 is given by Ransome as an analysis of the specimen from the No. 2 shaft of the United Eastern. R. C. Wells, Analyst.

Nos. 2 to 4 are partial analyses from Schrader's report. No. 2 is from the west Gold Road Mine; No. 3 from the Pasadena Mine; and No. 4 is from the lower east tunnel of the Leland Mine. E. C. Sullivan, Analyst.

In these analyses, the alkali content is somewhat higher than is to be expected in typical andesites. This is particularly true of the specimen from the Leland Mine. This rock is classed by Schrader as latite, and correctly so, although he recognized it as forming a part of his "green chloritic andesite." The others should be classed as latitic andesites.

Volcanic agglomerates are intercalated in the flows at various places. Near the head of Iowa Canyon is an excellent exposure of such material which consists of angular fragments of andesite, decidedly vesicular in texture and stained reddish due to the oxidation of the iron compounds. Some material of this nature was also noted on Silver Creek, near the Nigger Head.

Ransome[13] mentions the occurrence of tuffaceous sandstones to the southwest of the Argo Mine, and somewhat similar sandstones were found on the 900-foot level at the Black Eagle shaft where the tuffaceous member has a known thickness of 270 feet. An interesting feature is the occurrence of angular fragments of rhyolite up to ten inches in length. This rhyolite contains visible crystals of quartz and feldspar in a groundmass showing pronounced flow banding. No flows of this character older than the andesite are known in the Oatman District, although it is possible that such a flow may be covered by some of the later rocks. The source of these fragments is, therefore, unknown.

Gold Road Latite: Above the Oatman andesite is the Gold Road latite which is a part of Schader's "Undifferentiated Volcanic Rocks"[14] to which Ransome [15] gave the formational name Gold Road latite. The higher members of the series are rhyolites which Ransome proposed to map separately for his final report.

[13] Op. cit. p. 22.
[14] Op. cit. p. 37.
[15] Op. cit. p. 23.

These flows form the rugged cliffs to the east of Oatman and a part of the surface rock of the mesa extending for some distance to the east. To the south of Oatman, the latite is covered by the basalts of Ute Mountain. These flows are extensively exposed north of the Gold Road fault, and extend an unknown distance to the north. South of the area mapped in the Katherine District are some flows belonging to this period of volcanic activity. They are well exposed a short distance to the west of Thumb Butte.

The Gold Road latite shows some variations in thickness. What appears to be the thickest section exposed occurs to the east of Oatman. Here, however, there is considerable faulting, and the true thickness is not known as the throw on the various faults has not been determined. These flows dip to the east from 8° to 12°. In the cliff section alone, the flows and associated tuffs have a combined thickness of over 1,000 feet. The minimum thickness is estimated at 1,600 feet. Part of the variation in thickness may be due to a rather limited distribution of individual flows at the time they were poured out. At Iowa Spring there is not over 600 feet of latite in the cliff section. There has been some erosion of the original surface, for the tuff at the base of the overlying rhyolite may be seen occupying depressions. An excellent example may be seen to the southeast of the Sunnyside Mine, and similar, pre-rhyolite erosional features occur near the head of Antelope Canyon. Some flows, rather distinctive in appearance, which are abundant in other parts of the district, do not occur here. As a rule, the flows are rather massive, and many individual flows have a thickness measured in hundreds of feet.

The contact of the Oatman andesite and Gold Road latite is not always well exposed. A few feet of ash beds are usually all that separated these two types of rock. At Iowa Springs, the base of the latite is a volcanic agglomerate about eighty feet thick that contains an abundance of large and small boulders set in a matrix of finely divided ash. Nowhere was any definitely sedimentary material noted between the two formations. The andesite does not appear to have suffered much erosion, which would suggest that perhaps the interval of time between the erupting of the andesites and latites was rather short.

As a rule, the various flows are some shade of gray or brown, and the dull greenish color so characteristic of a weathered surface of the underlying andesite is entirely absent. It is only where the latites have been intensely altered by mineralizing solutions that they cannot be distinguished from the andesites.

The basal member of the latite is well exposed in a small hill to the south of the Texas shaft. It is darker in color than most of the flows, being a dark gray with a lavender tint. Somewhat higher in the series the latite flows are a light gray, and, toward the top of the cliff, the latite is brownish. Such flows are difficult to distinguish from the rhyolites.

The latites always contain large, well-developed, transparent crystals of feldspar. These phenocrysts are larger than is common in either the andesite or the rhyolites. Many of these large tabular crystals are rounded in outline. Sparkling flakes of biotite are always present. Pyroxene may be seen with the aid of a hand lens, and a glassy variety of latite, near the top of the mesa, contained visible crystals of hypersthene. The groundmass is always either stony or glassy.

Examined in thin section, these latites show only slight differences in mineral composition. The larger phenocrysts visible to the unaided eye are predominantly andesine, a plagioclase feldspar intermediate in composition. The euhedral crystals of plagioclase show very little zoning. A second generation of plagioclase is somewhat more acid in composition and has been determined as oligoclase. Some orthoclase also occurs as large crystals, but is not common. Among the ferromagnesian minerals, biotite of a deep brown color is a constant constituent of these lavas. Common augite, pale green in section, is also nearly always present. It frequently shows well-developed crystal boundaries both in section parallel to and perpendicular to the vertical axis. In some slides, the augite occurs as an aggregate of rounded grains. One slide showed green hornblende partly surrounding the pyroxene. A glassy variety of latite contained hypersthene in addition to augite. Grains of magnetite and slender crystals of apatite occur as accessory constituents. The groundmass may be closely crowded with minute, untwinned feldspar laths, or it may be composed largely of glass in which incipient crystals, trichites, are visible with higher magnification. Perlitic cracks are common in the glassy varieties of latite.

Analyses of the latites show greater differences in composition than are apparent in a study of thin sections. The two analyses given below from Schrader's report are classed as trachyte,[16] although they were collected from underground at the Gold Road Mine. To the northeast of this mine, Ransome has mapped two trachytic lavas which are later in age than the latite. The specimens collected by Schrader may be intrusive sills formed at a

[16] Op. cit. p. 39.

time when the later trachytes were erupted. Again, they may be the result of alteration by mineral solutions as suggested by Schrader.

ANALYSES OF GOLD ROAD LATITE

No. 1, R. C. WELLS, *Analyst.*

Nos. 2 and 3, E. C. SULLIVAN, *Analyst.*

	1	2	3
SiO_2	62.96	58.74	66.46
Al_2O_3	15.36	15.09	14.14
Fe_2O_3	2.57	4.66	4.07
FeO	2.09	.84	.40
MgO	2.50	2.75	.67
CaO	4.26	2.68	.78
Na_2O	3.84	.25	1.26
K_2O	3.96	8.05	9.26
H_2O below 110° C	.23	2.08	.78
H_2O above 110°C	1.37	3.09	1.28
TiO_2	.72	.98	.83
P_2O_5	.28	.40	.25
MnO	.04	.09	.03
ZrO_2	....	.02	.05
CO_2	....	.61	None
BaO	....	.07	.06
SrO	....	.04	.03
TOTAL	100.18	100.44	100.35

Sample No. 1 was collected by Ransome from the base of the cliff, one mile southwest of the Sunnyside Mine.

Samples No. 2 and No. 3 were collected by Schrader from the Gold Road Mine.

Antelope Rhyolite: In the Oatman District, the rhyolite flows and tuffs are confined to the higher portions of the range. The map of this district includes only the western edge of the higher country, consequently only erosional remnants of these acid lavas remain. North of Sitgreaves Pass are extensive exposures of rhyolite which have been separately mapped and named by Ransome as the Cottonwood rhyolite. The Sitgreaves tuff which underlies the black glassy flows of rhyolite to the north of the pass are not present south of this pass. No rock resembling the Sitgreaves tuff occurs in the upper reaches of Antelope Canyon, and the rhyolitic tuffs to the east of the town of Oatman are quite different in appearance. It is not definitely known, therefore, that the Cottonwood rhyolite and the Antelope rhyolite were erupted at the same time. The southernmost exposure of the rhyolites noted was about a mile to the northeast of Iowa Spring.

Rhyolite tuffs are abundantly exposed in the range to the north of Oatman and extend even beyond Union Pass. In the eastern part of the Katherine District are erosional remnants of both flows and tuff. There the tuffs attain a much greater thickness than in the Oatman District.

The rhyolites show some differences in appearances; in some places, they are black obsidian with transparent crystals of sanidine and shiny flakes of biotite; in other localities, the obsidians are pale gray glass with bright red spherulites. Very commonly these glasses show a streaked appearance or flow banding. Many of the flows are of a reddish brown color with crystals of feldspar, quartz, and biotite in a stony groundmass.

Examined in thin section, these rocks show crystals of sanidine, acid plagioclase, and brown biotite. Clear crystals of quartz are common and usually show resorption by the magma. Occasional crystals or grains of green hornblende or of nearly colorless augite may be seen. Grains of magnetite or needles of apatite occur as accessory minerals. Small, rounded crystals of zircon were found in the flakes of biotite.. The groundmass of the stony varieties contains a second generation of minute feldspar laths in glass. The glassy varieties show an abundance of perlitic cracks. Frequently, hair-like incipient crystals or trichites are present.

At some localities, the tuffs are well stratified. The lines of stratification are more apparent where fragments of foreign material are abundant. The tuffs may be cream, pink, or dark brown in color. Fragments of pumice or of lithoidal rhyolite are embedded in an aggregate of glass shards. Grains of feldspar and quartz are also present.

Ransome [17] gives an analysis of a specimen collected three-fifths of a mile south of Sitgreaves Pass. This particular area has been included by the present writer with the rhyolites. Ransome classed it with the Gold Road latite, but recognized that it was much more acid than the typical latite. He planned to map these rocks separately at a later date for his final report on the district.

ANALYSIS OF RHYOLITE

R. C. WELLS, *Analyst.*

SiO_2	68.94	H_2O below 110°C	0.28
Al_2O_3	13.36	H_2O above 110°C	3.43
Fe_2O_3	1.29	TiO_2	.47
FeO	1.04	P_2O_5	.12
MgO	.79	MnO	.03
CaO	2.02		
Na_2O	2.20		99.86
K_2O	5.89		

[17] Op. cit. p. 26.

Sitgreaves Tuff: Exposures of this tuff are confined to the northeast corner of the Oatman District, and no rock resembling it occurs in the Katherine District. As shown by Ransome's map, this tuff underlies the Cottonwood rhyolite. At Sitgreaves Pass, the tuff rests on the Gold Road latite, and to the northeast it rests on trachytes younger than the latite. Exposures to the north of the highway to Kingman, just east of Sitgreaves Pass, form prominent, light colored cliffs, and there the beds of tuff are quite massive and compact.

On a fresh fracture, the tuff is light-gray in color and weathers buff. The rock is somewhat porous, and consists of fragments of pumice together with crystals of sanidine, biotite, and occasionally hornblende. Some rounded grains of quartz may be seen under the microscope.

The Sitgreaves tuff would make an excellent building stone. Because of its porous nature, it is the water-bearing formation of the district. It is from this rock that nearly all the springs of the district issue.

Olivine Basalt: In the southern part of the Black Mountains are extensive flows of olivine basalt. Only a small portion of these flows is shown in the southeast corner of the map of the Oatman District. A few erosional remnants occur a short distance south of Sitgreaves Pass, capping the rhyolite flows. Exposures of these basic flows also occur to the north of this pass. At the base of the flows are beds of bright red volcanic ash.

The basalts are dark gray to black in color and fine-grained in texture. Some of the flows are quite vesicular in texture, and the cavities in places are filled with calcite. With a hand lens both plagioclase feldspar and olivine may be identified. In thin sections, the rocks show no unusual features, and the minerals present are basic feldspar, olivine, augite, and magnetite.

Just north of Union Pass, and capping the higher points, are also basaltic flows. They are slightly east of the limits of the area mapped as the Katherine District. The flows are black, quite dense in texture, and are interesting because they are slightly different in mineral composition from those in the Oatman District. They are the olivine-free variety of basalt.

ALTERATION OF THE LAVAS[18]

Volcanic eruptions, particularly of the more violent type, are always accompanied by the emission of great quantities of gas, among which water vapor is the most abundant constituent.

[18] The alteration of the rocks produced by the solutions forming the veins will be discussed in the section on ore deposits.

Even the quiet outwellings of basalt from fissure eruptions are accompanied by such vapors. Volcanic explosions and their after-effects have long been an interesting subject of scientific investigation. Clarke[19] gives an excellent summary of the literature on volcanic emanations, including the classical studies about the middle of the 19th century. These early investigators noticed that even the surface of flowing lava gave off white vapors. Some such vapors sublimed to anhydrous salts. The temperature of such flowing lava varies somewhat depending partly on the composition of the magma. Measurements made at different places indicate 1100°C as an average.

The gases enclosed in the magma are, therefore, at high temperatures and under great pressures. As the magma rises in the conduit to the surface, the pressure is released, and the violent explosions accompanying volcanic eruptions are due to the sudden expansion of these gases. So powerful are these forces of explosion that, in many eruptions, large quantities of the rock lining the conduit are disrupted and thrown high into the atmosphere. Great quantities of liquid lava are also ejected, and the expansion of the gas within this liquid gives rise to a froth of glass on cooling. In this manner are formed the fragments of pumice which settle out of the air to form the beds of volcanic ash or tuff so common around volcanic vents. Much of the material of which the tuffs are composed is rather light in weight and porous in texture, and such ash beds are usually very permeable to vapors and solutions.

Even the slow-moving flows of lava may develop a vesicular texture in the upper portion of the flow. In the acid lavas, vesicles are generally less abundant, and this condition may be due in part to the more viscous nature of the magma. The more basic flows, such as andesite and basalt, appear to have been much more fluid, and the tops of such flows are usually so filled with cavities that fragments of this vesicular lava will float on water. To the east of Oatman, the rhyolites often contain lithophysae or stone-bubbles which are spheroidal objects which consist of thin, concentric shells, separated from each other by air spaces. Cavities also exist which are more or less filled with chalcedony or opal. In the Oatman andesite, a vesicular texture is often well-developed, and, although not commonly seen on a weathered surface, is clearly and abundantly shown in diamond drill-cores.

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[19] Clarke, F. W., The data of geochemistry: Bull. 770, U. S. Geol. Survey, pp. 261-292, 1924.

The after-effects of volcanic activity are fumeroles or vents from which great quantities of gas issue. This feature was well exemplified following the eruptions of Mt. Katmai in Alaska in 1912. The floor of a valley about eight miles from the crater was filled to a variable depth with layers of ash. Through these beds of pumice, numerous fumeroles issue. The gases in this valley, now known as the Valley of Ten Thousand Smokes, have been studied by Allen and Zies.[20]

Clarke[21] divides the after-effects of volcanic activity into four

[21] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey, Bull 770, p. 292, 1924.

stages which depend largely on the temperature, as follows:

1. The gases issue at a high temperature and are practically dry. In addition to superheated steam, they may contain hydrogen, carbon monoxide, vapors of metallic chlorides, nitrogen, sulphur vapor, and gaseous compounds of fluorine. Some oxygen may be present.
2. The hydrogen burns to form water vapor which in turn reacts with the metallic chlorides to form hydrochloric acid, and acid fumeroles result. The sulphur burns to form sulphur dioxide, and carbon monoxide to carbon dioxide.
3. These acid gases traverse and penetrate the rocks through which they pass and react with the minerals of the rock, producing various reactions..
4. The dying stages of fumerolic activity emit only steam and carbon dioxide.

That the vapors of fumeroles are capable of producing intense alteration in the rocks traversed has been shown by study at numerous places.

In both the Oatman and Katherine districts, the lavas often show intense alteration which does not appear to have been brought about by the solutions that formed the veins. Such alteration is not due to surface weathering and oxidation. for it occurs at considerable depth below the surface. It appears, therefore, that the alteration may have been caused by the gases which passed through the rocks. Some members of the volcanic series show more pronounced alteration than others. This alteration is best exemplified in the Alcyone trachyte, while the overlying Esperanza trachyte is remarkably free from alteration. In the Oatman andesite, this type of alteration is confined to a narrow edge along joint planes or other fractures in the rock and to the vesicular portions of the flows. Both the latite and rhyolite show little evidence of decomposition except along joints, but

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[20] Allen, E. T. and Zies, E. G.. Nat. Geo. Soc. Tech, paper, Katmai series No. 2, 1923.

the tuffaceous members associated with these flows invariably show some change.

A geologist who examines the Alcyone trachyte is immediately impressed with the extent of the decomposition that has affected this rock. Specimens coming from a depth of over 500 feet below the surface show these changes to the same degree as do pieces from nearer the surface. A hand specimen of this rock usually appears to have been bleached; the feldspars are kaolinized, and the ferromagnesian constituents are either altered to chlorite or else the iron is abstracted and segregated as magnetite. The outline of original hornblende crystals is usually well shown by a narrow rim of magnetite which also contains, in some cases, hematite; and within this rim of iron oxide is pale greenish chlorite or serpentine with some calcite. Feldspars are largely changed to aggregates of kaolin, secondary quartz, and small amounts of calcite. The groundmass of the rock is frequently so clouded with kaolin that portions of the slide are quite opaque. There is no evidence in the thin sections to indicate that the feldspars were first altered to sericite and this mineral in turn changed to kaolin, although a little sericite was found in some slides.

The interesting fact that the overlying Esperanza trachyte has suffered no such decomposition indicates that the alteration was produced prior to vein formation. It is possible, therefore, that the mineral changes in the Alcyone trachyte were produced by hot gases shortly after the consolidation of the lavas.

The most interesting changes in the Oatman andesite occur in the vesicular portions of the flows. Where the vesicles are abundant and close together, the wall of rock between individual bubbles is quite thin; consequently, when such rock has undergone more or less decomposition, it is so soft that it can readily be crushed in the hand. The altered rock is nearly always of a pale greenish color except in those portions in which the iron has been oxidized, and then the rock is reddish.

These altered rocks, when examined with a microscope, show intense changes in the original minerals. Of the feldspars, the orthoclase, which is not abundant, always shows less alteration than the plagioclase. In the orthoclase, some kaolin may be seen along cracks in the mineral, but the plagioclase is largely replaced by calcite and a little quartz. The ferromagnesian constituents, unlike these constituents of the Alcyone trachyte, are not outlined by magnetite; instead, the change has been largely to serpentine. Now and then unaltered remnants of either biotite or augite may be seen.

Where the vesicles have been filled with mineral matter they show a definite sequence. The partly filled vesicle is lined with a thin film of a scaly green mineral, chlorite. Resting on the chlorite are scales of bright red hematite. This mineral is not, however, always deposited. If the cavity is of small size, it may then be entirely filled with chalcedony, but usually the central portion is composed of calcite. The groundmass, invariably, contains an abundance of kaolin.

Alteration of the rhyolites is confined to a thin film along joint planes. Along these joints, chalcedony and, in some cases, opal is deposited. As the tuffs are more pervious to hot vapors or solutions, they contain an abundance of kaolin, and, in part, this kaolin has been formed from the decomposition of the glass shards.

To sum up: The important changes are hydration and carbonation. This fact is indicated by the abundance of chlorite and serpentine, both hydrous minerals formed from biotite, augite, and hornblende, and the presence of kaolin formed from feldspar. No analyses of the altered rocks are available, and it is, therefore, not possible to say to what extent certain constituents like soda and potash have been abstracted and carried away. The fact that orthoclase is replaced by kaolin indicates that potash has been removed; and, similarly, in the plagioclase, soda has disappeared. That constituents have been transferred is clearly shown by the film of chlorite and, sometimes, hematite which lines the vesicles in the andesite. There is no evidence in slides that silica has been introduced, and such irregular aggregates of secondary quartz as occur within or surround altered minerals may have been formed by the breaking down of silicates; nor can one definitely say that lime has been introduced. Such lime as is now found in the form of calcite could easily have come from the breaking down of hornblende, augite, and plagioclase feldspar. Carbon dioxide was, however, certainly introduced, for it is hardly possible that the fresh rock contained sufficient of this gas to form the amount of calcite existing in the altered rock. Carbon dioxide is abundant in fumerole gases, particularly in the later phases of their acivity.

TERTIARY INTRUSIVE ROCKS

Two major intrusions are associated with the volcanic activity of Tertiary age that gave rise to the flows and tuffs in the Oatman and Katherine districts. Numerous dikes and sills showing nearly as much variation in composition as the flows themselves occur as minor intrusions in the flows. No dikes which correspond in composition to the Alycone and Esperanza trachytes were found, but dikes of andesite are common; such andesite dikes are, however, difficult to trace where they cut the andesite flows. Only a few dikes were observed which appear to have been the feeders that gave rise to the latite flows. Dikes of rhyolite-porphyry are common in both the Oatman and Katherine districts. In some instances, there has been movement along these dikes after consolidation, and vein filling is frequently found in such fractured zones.

MOSS PORPHYRY

Exposures of the Moss porphyry occur about a mile to the north of the Hardy Mine and extend northward to beyond the Moss Mine. The average width of this intrusion is about two miles, and it has a known length of somewhat over four miles. The general trend is towards the northwest.

Just west of the Moss Mine, this porphyry intrudes the Alcyone trachyte and the flows have been tilted to the west at angles as steep as 40°. North of the Oatman District, the porphyry was observed cutting the Oatman andesite. Where the Moss porphyry is in contact with the flows of Gold Road latite, the rocks are so thoroughly altered that the relations are not absolutely clear. The Moss porphpry consolidated, therefore, after the flows of anadesite were poured out, and perhaps later than the Gold Road latite.

Fresh exposures of the rock are of a grayish color due partly to the ferromagnesian minerals present and also to phenocrysts of palgioclase feldspar which are of a dark gray color. Altered rock varies from a creamy white, freqently iron-stained, to a pale greenish gray. The rock is porphyritic in texture with phenocrysts of plagioclase crystals up to one-quarter of an inch in diameter. These phenocrysts, somewhat rounded in outline, are thin plates of a dark grayish color. Polysynthetic twinning may be observed with the aid of a hand lens. The groundmass is uniformly fine grained in texture, pinkish in color, and appears to be largely orthoclase. A little biotite and quartz may also be seen in the rock.

A thin section of the rock examined under the microscope shows more alteration than is apparent in a hand specimen. The plagioclase, which has the composition of acid andesine, is altered along cleavage cracks and fractures to an aggregate of scales of sericite. The orthoclase is quite turbid and has been replaced almost entirely by a felted mass of sericite. Biotite is partly altered to chlorite. Quartz is not abundant in the rock

and occurs either interstitially or intergrown with orthoclase, forming a micropegmatitic texture. Magnetite, zircon, the apatite occur as accessory minerals.

A chemical analysis of the Moss porphyry made on a sample collected by Ransome north of the Moss Mine is as follows:[22]

ANALYSIS OF MOSS PORPHYRY

R. C. WELLS, *Analyst.*

SiO_2	62.54
Al_2O_3	14.42
Fe_2O_3	3.51
FeO	2.57
MgO	2.41
CaO	4.26
Na_2O	3.83
K_2O	3.98
H_2O under 110°C	.29
H_2O above 110°C	.84
TiO_2	1.05
P_2O_5	.36
MnO	.07
Total	100.13

As was noted by Ransome, this analysis of the Moss porphyry is similar to that of the Gold Road latite. Both the chemical analysis and the mineral composition, as shown by microscopic examination, show the rock to be a quartz monzonite-porphyry. The amount of quartz in the rock is somewhat less than is commonly found in this class of rocks.

TIMES PORPHYRY

The rugged country, of which Mt. Hardy is the highest point, consists of a fine-grained porphyritic intrusion to which Ransome has given the name Times porphyry. The rock weathers to a dull brownish color, but fresh exposures are light gray with a slight pinkish tint. The rock is not conspicuously porphyritic although a close examination discloses phenocrysts of orthoclase rarely more than one-quarter of an inch in length. Occasional thin flakes of biotite may be seen, as well as some pyrite which was introduced after the magma solidified. The groundmass is uniformly fine grained, and, in this groundmass, quartz is visible under a lens.

The most striking feature observed in a thin section is the intergrowth of quartz and feldspar of the groundmass, forming a micropegmatitic texture. Where this intergrowth surrounds a phenocryst of orthoclase, the feldspar of the intergrowth has the

[22] Op. cit. p. 27.

same optical orientation as the phenocryst. A little acid plagioclase was seen in one slide, but the mineral is rather scarce. The feldspar is usually clouded with kaolinitic material, particularly around grains of pyrite. The biotite is more or less altered to chlorite. Scattered grains of magnetite occur as an accessary mineral.

The Times porphyry has a rather limited distribution. To the north, this rock does not extend beyond Silver Creek, and the southern boundary is Times Gulch. To the westward, the Alcyone trachyte has been intruded by the porphyry, but, along the eastern margin, the lavas have been faulted against the intrusive. Along Silver Creek, the Times porphyry appears to intrude the Moss porphpry, but at this locality, the latter rock is so thoroughly brecciated and altered that positive identification is impossible.

An analysis of the Times porphyry given by Ransome is as follows:[23]

ANALYSIS OF TIMES PORPHYRY

R. C. WELLS, *Analyst.*

SiO_2	72.85
Al_2O_3	13.45
Fe_2O_3	1.11
FeO	.54
MgO	.24
CaO	1.13
Na_2O	4.01
K_2O	5.40
H_2O under 110°C	.08
H_2O above 110°C	.40
TiO_2	.39
P_2O_5	.04
MnO	.06
CO_2	.27
Total	99.77

The small amount of acid plagioclase found in thin sections would not account for the high percentage of soda shown in the analysis, and it is possible, as suggested by Ransome, that some of this soda is combined with potash in the orthoclase. The analysis is therefore that of a sodic granite-porphyry.

RHYOLITE-PORPHYRY

Dikes of rhyolite-porphyry are common in both the Oatman and Katherine districts and also in the intervening country. In some instances these dikes are connected with intrusive plugs, notably the Boundary Cone. The white knob east of the town

[23] Op. cit. p. 29.

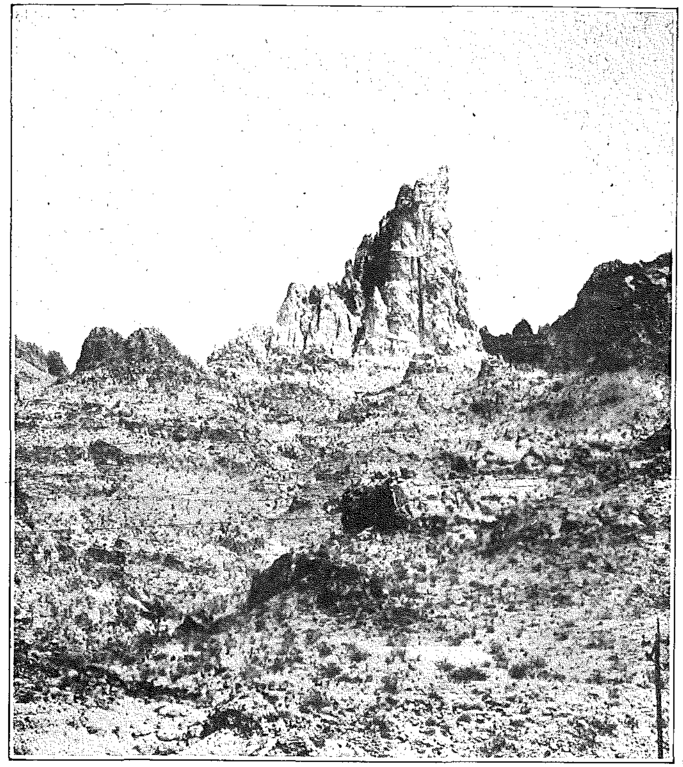


Fig. 7.—The Elephant's Tooth, a rhyolitic plug to the east of Oatman.

of Oatman, known locally as the Elephant's Tooth, is the erosional remnant of a dike of rhyolite porphyry at a point where it is unusually thick. The trend of these dikes is in all directions, but the prevailing strike is either northwest-southeast, or nearly east-west. The dikes have been injected along fractures, for in some instances the brecciated wall rock may be seen frozen to the dike. Fragments of the wall rock are included in the dikes, but such fragments are not abundant and usually correspond to the volcanic rocks exposed in the district. The dikes, as may be expected, vary considerably in size, and only the more prominent ones were mapped. These minor intrusives are particularly abundant near the Times porphyry intrusions, and a local concentration of them occurs near the Boundary Cone.

The prevailing color on a surface exposure is pale brown to pinkish and is due to finely disseminated iron oxide, but, on a fresh fracture, the rock is a creamy yellow. The rock is porphyritic in texture with about an equal development of both quartz and orthoclase. The quartz phenocrysts are frequently irregular in outline, but the feldspar crystals show well-defined crystal boundaries. These crystals are rarely more than two-tenths of an inch in length.

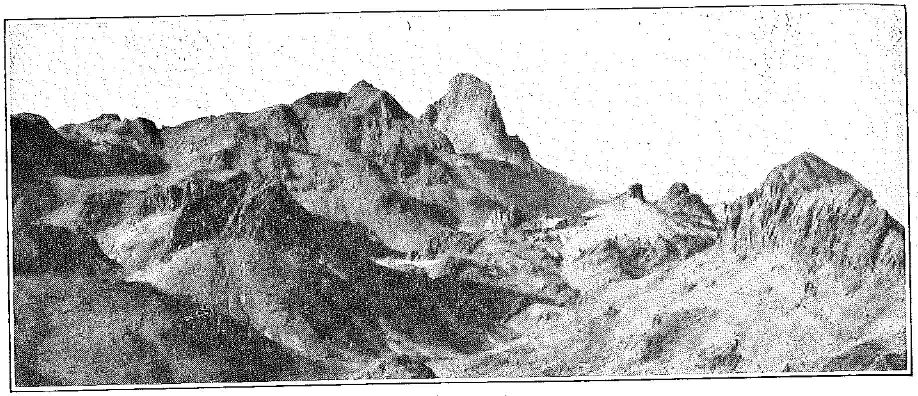


Fig. 8.—A general view of the southwestern part of the Oatman District. The Boundary Cone, a volcanic plug, may be seen in the center of the picture.

The phenocrysts of quartz, when examined with a microscope in a thin section, show a rather stubby development along the prismatic axis. The quartz often shows crystal boundaries, but here and there it is resorbed and embayed by the magma. Frequently a darker border of a finer grain surrounds the crystals and, if examined with higher magnification, is found to consist of a micropegmatitic intergrowth of quartz and feldspar. The groundmass is of uniform grain and consists of quartz and orthoclase. It is interesting, in this connection, to note the occurrence of such an intergrowth surrounding some of the feldspar crystals in the rhyolites. Dikes of the rhyolite porphyry have been traced to the very edge of the Times porpryhy intrusion, and, in other instances, dikes pass up to the contact of the rhyolite flows. The assumption is reasonable that the Times porphyry, the rhyolite-porphyry dikes and plugs, and the rhyolite flows all came from the same magma reservoir at about the same time. This observation is important as it throws some light on the time of intrusion of the Times porphyry as related to the age of other igneous rocks. As no flows younger than the Oatman andesite are in contact with the Times porphyry, its age as compared with the age of the Gold Road latite and younger rhyolites could not be definitely ascertained. The dikes may be, however, connecting links, between the Times porphyry and the rhyolite flows.

Dark-colored dikes are fairly common in the western part of the Oatman District, and they are particularly abundant at Fortuna Hill. Specimens from this hill were found to be andesite-porphyry. A similar dike was found near the Red Lion shaft, cutting the Oatman andesite. As a rule, such basic dikes are difficult to trace in the andesite, and no effort was made to map them.

Dikes, corresponding in composition to the olivine basalt flows, were not observed in the Oatman District. It is possible that they occur beyond the limits of the area mapped, or they may even be entirely covered by the flows.

QUATERNARY DEPOSITS

GRAVEL AND SAND

Deposits of gravel and sand are not important in the Oatman District except in the extreme western portion where they cover the older rocks from which they were largely derived. Here and there, small knobs stand out above the gravel cover, and one such knob in the Katherine District contained the outcrop of the Katherine Mine. The gravel deposits are more widespread and have a greater thickness in the Katherine District than at Oatman. At both the Katherine Extension and the Treasure Vault mines, it was necessary to sink through the gravel to reach the unlerlying granite. In both cases veins were found..

The thickness of the gravel, as might be expected, is quite variable. In the flat to the east of the Sunnyside Mine in the Oatman District, a prospect shaft shows the gravel to be 60 feet deep. Mining operations in the Katherine District penetrated beds of gravel as much as 100 feet or more in thickness. Between the Katherine and Pyramid mines, holes drilled by the Reclamation Service are said to have located an old river channel in which these deposits are somewhat more than 300 feet thick.

The gravel is composed of angular and subangular to rounded boulders of rock which show considerable variation in size. As a rule, the coarse deposits show very little sorting, but the sandy layers are sorted and cross-bedded. The pebbles and boulders comprise all types of rock common in the district, and their derivation has been local, largely from the mountains to the east. On the banks of the Colorado River, however, pebbles of quartzite and limestone are quite common, and, as no such rocks occur in these districts, it is possible that such pebbles were brought down by the river.

Part of the gravels and sands are well consolidated and somewhat cemented with thin films of lime. Locally, such deposition of calcium carbonate is in bands which have a thickness measurable in inches, and, in the Southwest, such lime is frequently referred to as "caliche."

No fossil remains have been found in either the gravel or sand. As the deposits are clearly younger than the lavas, they are here assigned to the Quaternary.

STRUCTURAL GEOLOGY

TILTING OF THE LAVAS

In a general way, the Black Mountains may be considered as a tilted block with a fault or series of faults along the western side. The range may also be considered as the eastern limb of a broad arch, the central portion of which lies to the west of the Colorado River. If arching of the earth's crust has taken place, the volcanic rocks that occur on the limbs of the fold may be considered as the erosional remnants of a vast volcanic field which originally extended for many miles in all directions. Such arching would give rise to a tilting of the lavas on the limbs of the fold. There is, however, some evidence against the idea of arching, for, at the Needles, on the Colorado River and a few miles south of Topock, there is no evidence of such arching and the disturbance in the flow can all be explained by faulting. North of the Katherine District and just west of the Colorado River, the volcanic rocks of Eldorado Canyon dip towards the river. This occurrence would suggest that the volcanic rocks of Eldorado Canyon have been faulted against the pre-Cambrian rocks to the east.

The best available evidence suggests that the Black Mountains are a fault block tilted to the east. As the major fractures in the Oatman District dip to the east at steep angles, and as these faults are of the normal type, the crest of the range would be depressed relative to the western portion of the district. If the Black Mountains are a tilted fault block, the main fracture or series of fractures lies to the west of the Oatman District. No evidence of such a fault was found in the Katherine District, but much of this area is covered with Quaternary gravels.

Another possibility that must be considered is the likelihood of a fault along the eastern margin of the range. The one occurrence of pre-Cambrian rocks found there lies at a higher elevation than the exposures on the western side of the range, and it is not impossible that the block may have been tilted

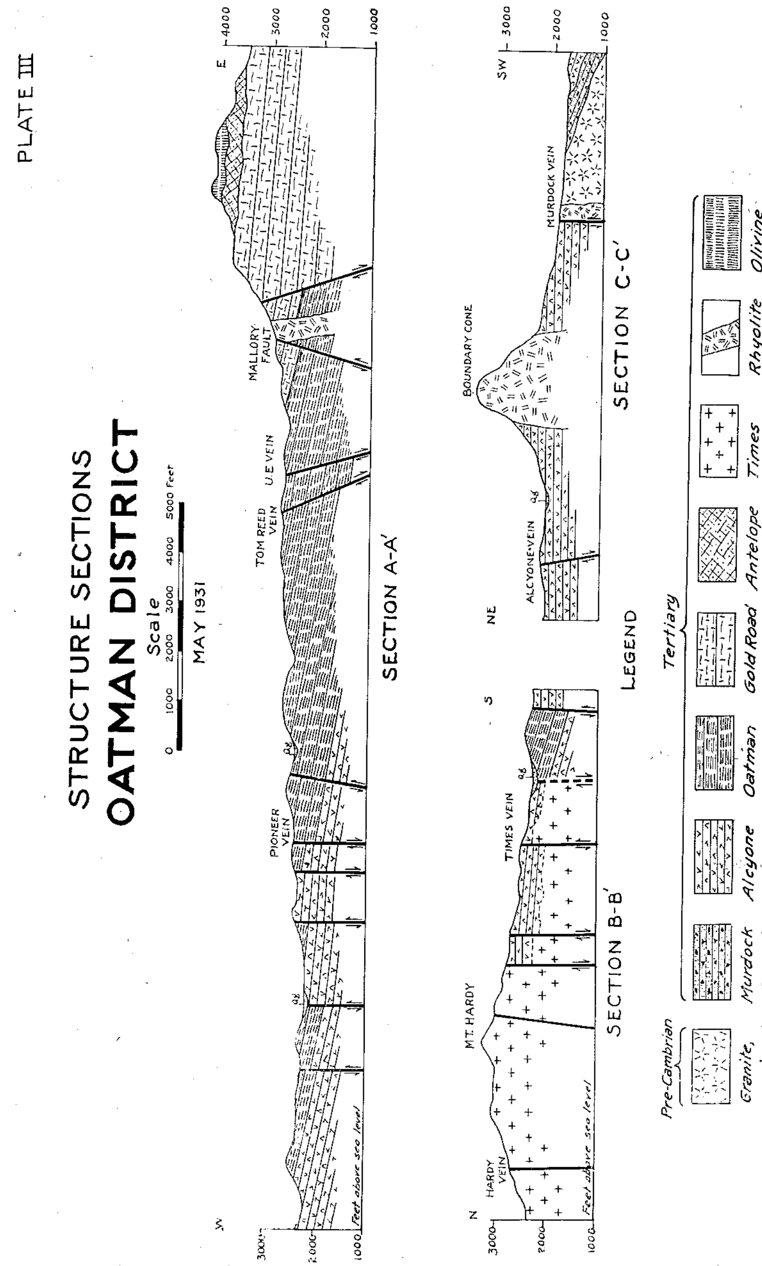


Plate III.—Structure sections of the Oatman District.

along this fault and later modified to its present form by erosion. Pre-Cambrian granite forms, however, a part of the crest of the range a few miles to the south of Union Pass, and the old surface on which the lavas were poured may, therefore, have been quite irregular.

The general dip of the lavas is to the east at low angles. South of the highway to Kingman, the basaltic lavas which form the very highest parts of the range to the southeast of Oatman are here at the base of the range. The eastward dip is less than five degrees. In the immediate vicinity of Oatman the average dip is about twelve degrees, but, to the west, it becomes steeper. Small fault blocks may show high dips. In the southwestern part of the Oatman District, the prevailing dip is more nearly south than east, but here again it is at gentle angles. At Union Pass, the dips observed in the tuff are, in general, similar to those farther south, but in the region surrounding the Sheeptrail-Boulevard Mine the small fault blocks dip at various angles.

MINOR STRUCTURES AROUND INTRUSIVE MASSES

West of the Moss Mine, the lava dips to the west at various angles up to 24°, and the local westward tilting appears to be due to the intrusion of the Moss porphyry. A somewhat similar feature occurs around three sides of the Times porphyry. It is not certain that the eastward dip of the andesite and underlying trachyte along the eastern margin of the Times porphyry is due to intrusion of this rock, for here the dip is normal. To the west of Times Gulch the dip is, however, to the south, and, in the extreme western part of the district, the tilting is to the west. Here again, there is a suggestion that the tilting is due to intrusion.

To the southwest and also to the west of Mt. Hardy, the Alcyone trachyte rests on the Times porphyry. The contact is an intrusive one, and the overlying lavas are frequently disturbed and displaced by the igneous rock. Many faults with a small displacement occur here, and, on some of them, the displacement is large, as at the main break on which the Times Mine is located. These remnants of Alcyone trachyte are parts of the original cover over the intrusion.

The flows surrounding the Boundary Cone, which is an intrusive plug, have also been disturbed as a result of intrusion. A more interesting feature is the brecciation produced in the surrounding rocks, which suggests that the magma was injected under considerable pressure and perhaps in a semi-plastic condition. No such features are to be seen in connection with the dikes.

TREND AND DISTRIBUTION OF FAULTS

The general trend of the faults in the Oatman District is northwest-southeast, but in the southern part of the district they are more nearly east-west. A few faults near the Times Mine (see Plate I) have a northeast trend, but examples of this kind are rare. There is no such regularity to trend of faulting in the Katherine District. Some faults like the Pyramid, Katherine, Arabian, and Tyro have a northeast trend; others, like the Treasure Vault, Gold Chain, and Big Four have a northwest strike. It is possible that a number of other faults occur in this district, but, unless such fractures have been mineralized, they are not likely to be prospected, and, where such fractures have granite in both walls, they are difficult to trace. The fractures that occur in the underlying rock in much of the district are effectively covered by gravel, as at the Treasure Vault and Katherine Extension mines.

In the Otaman District the faults are grouped in zones, each zone having a slightly different trend. Plate I shows a concentration of faults between the Tom Reed vein and the Gold Road vein. In this zone, the average strike is approximately N. 45° W. Another area in which faults are abundant lies to the south of the Lucky Boy fault and extends westward to include the Vivian and Leland mines. The average strike in this zone is about N. 60° W. To the east of the Boundary Cone is a third concentration of faults with a trend approximating N.70° W. These three zones converge toward a point a few miles to the southeast of the Oatman District. At this point, the surface is covered by flows of olivine, basalt, and, as much of the faulting is earlier than the effusion of this basalt, the interesting junction of these faults is effectively covered.

Another interesting feature in connection with these faults is the prevailing dip. To the east of and including the Tom Reed fracture, the dip is generally to the east; while, in the western and southren parts of the Oatman District, the prevailing dip is to the southwest.

There must be some underlying cause for this change of dip feature. An arching of the lavas in a northwest direction across the district with consequent breaking down of the arch on each limb of the fold by normal faulting would account for the difference in dip, and may also account for the convergence of the fault zones. It is conceivable that such arching might have been brought about by the intrusion of the Times porphyry which may have been injected at a low horizon in the volcanic series, and may rest on the old granitic rocks. If the magma moved upward at an angle in a northwesterly direction, it might readily take the form of a laccolith, and such type of intrusion is known to produce an arching of its cover. Remnants of Alcyone trachyte which rest on the Times porphyry are parts of such a cover, but the base on which the porphyry rests was not seen. There is, therefore, no conclusive field evidence to show that the intrusion is a laccolith.

AGE, TYPE, AND DISPLACEMENT OF FAULTS

Among the earliest faults definitely recognized are the fractures occupied by the rhyolite porphyry dikes. These dikes show a radical arrangement around three sides of the Times porphyry and appear to be a direct result of the intrusion of this porphyry.

Many of the dikes are offset by the mineral-bearing fractures as is well shown in the northern part of the district where the two nearly parallel dikes are cut by the Pasadena vein. In some cases faulting prior to the formation of the veins followed these dikes, and the vein occurs on one wall of the dike. Examples of this phenomenon occur in the southeast corner of Section 23, and also at the east end of the Esperanza vein.

Renewed movements on the faults after some of the vein-filling had been deposited, and before the last stages of quartz and calcite were introduced into the veins by the mineral-bearing solutions, resulted in a crushing of the earlier deposit of vein materials. This period of faulting is important and will be discussed more fully in connection with the ore deposits.

Faulting later than ore deposition is well illustrated by the Mallory fault which in its northern extension follows along a rhyolite-porphyry dike (see Plate I). It cuts across the Tom Reed vein near the Big Jim shaft, follows the course of this vein for a short distance, and then takes a rather sinuous course past the Sunnyside shaft and up the cliff to the south. Near the Big Jim shaft, the Mallory fault is offset about 300 feet by the Oatman fault. Some of the faults which cut the basalt flows may represent a post-mineral movement along pre-existing fractures, for none of such faults cutting basalt was found to carry vein-filling.

All of the faults described above appear to be of the normal type; that is; the hanging wall has gone down with respect to the footwall. Some reverse faults occur, however, in the Katherine

District. At the Katherine Mine, the ore body is cut by a series of low-angle faults which appear to have pushed the hanging wall segment upward. A longtiudinal section of the mine which shows this feature will be found under a description of this mine.

The absence of good horizon markers makes it difficult to determine the displacement of the individual faults.. Many of the mine workings are comparatively shallow, and only in the producing mines are depths of a thousand feet or more attained. Many shafts have been put down to depths of 300 to 500 feet, but such shafts are commonly in only one kind of rock and yield no information on the amount of displacement. Quite frequently, two kinds of rock, such as andesite and latite or andesite and trachyte, are brought in contact by faulting, and, in some such instances, it is possible to determine the minimum vertical component of faulting. On the Mallory fault, the vertical displacement of the Tom Reed vein between the Big Jim and Grey Eagle is about 500 feet. Very likely the displacement on similar fractures, such as the Tom Reed or Gold Road, is of about the same magnitude. Many of the faults have a much smaller displacement—measurable in tens rather than hundreds of feet.

The vertical displacement on a fault may vary from place to place along its length. This certainly appears to be the case with the Gold Road fault. Where this fault cuts the rhyolites, the displacement is under 300 feet, but to the northwest, beyond the No. 1 shaft, it is certainly 500 feet and may be even more.

Branching of the faults is a common feature in the Oatman District. Near the Red Lion shaft, the Telluride fault appears to be a west branch of the Tom Reed fault, and a similar branching on this fault occurs a short distance to the northwest of the Ben Harrison shaft. On the east branch of this fault, the United Eastern ore body was formed. Still farther northwest, the Tom Reed fault again branches into two parts..

ORE DEPOSITS

DISTRIBUTION OF VEINS

The veins occupy fault fissures or fractures in the enclosing rocks; no exceptions were noted. The distribution of the veins, therefore, bears an intimate relation to the distribution of the fractures or faults which have been described in a preceding section of this report. Certain features of the occurrence of the vein-filling in these fractures are important.

It will be well, perhaps, to state now that many of the faults which have a length, as shown on the map, of thousands of feet are not filled for their entire extent with vein materials; on the contrary, there are frequent interruptions in the vein. In following a vein along the strike from one prospect pit to another, the vein-filling is often found to diminish, and, in places, entirely to disappear; but the fault continues as a crushed zone. Farther along this same fracture, the vein-filling will again come in. During the field mapping, an effort was made to show the width and extent of the vein-filling along the fault, but, as a strong vein may end in a few small stringers, it was found difficult to show these features on a map. An insignificant stringer at the surface has been found to lead to a solid vein of quartz and calcite three feet thick at a depth of only thirty feet on the dip, and similar variations in width may be observed along the strike of the vein.

Fig. 9.—View showing the structure of the Gold Road vein vith nearly vertical stringers of quartz.

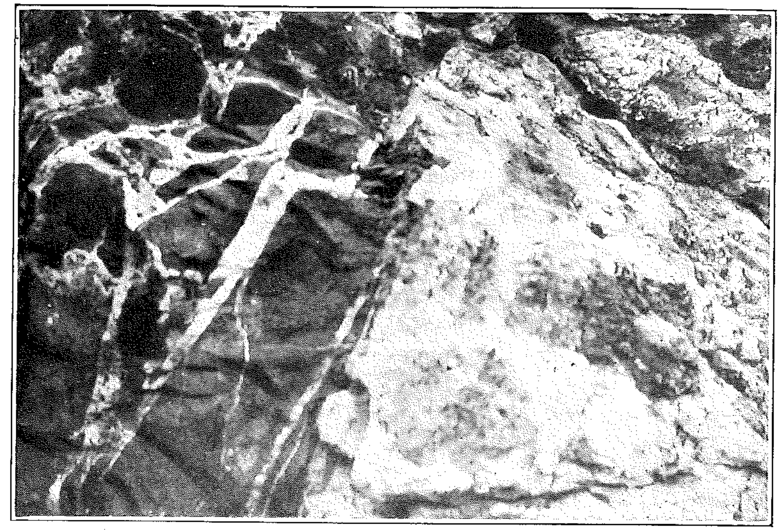


Fig. 10.—The hanging wall portion of the Gold Dust vein, showing stringers in the wall rock.

STRUCTURE OF THE VEINS

The structure of the vein is sometimes quite simple and consists of a tabular body of quartz and calcite with well defined walls. Most of the deposits, however, are lodes which consist of a large number of stringers or veins variable in width and separated from each other by barren rock. Where there has been no post-mineral faulting, small ramifying stringers branch from the main vein into the wall rock. Such side stringers are mineralogically similar to the main vein from which they branch, and may consist of either quartz or calcite, or an intergrowth of both minerals. Frozen contacts are common, particularly in those veins on which there has been no post-mineral faulting. Even in the veins showing late faulting, one wall may be frozen to the country rock.

Some veins or lodes consist entirely of a great number of reticulating stringers which traverse the country rock. This type of deposit is well shown in portions of the Gold Dust vein in the Oatman District and in the Frisco vein in the Katherine District. Compound veins, which consist of two or more veins of solid quartz and calcite separated by country rock, are common in both districts. The intervening country rock is commonly traversed by stringer veinlets, and, when these stringers are sufficiently abundant, the country rock which contains the veinlets may constitute ore.

The ribbon structure, so common in the Mother Lode of California, was not seen in these districts; but a paralled sheeting, simulating such ribbon structure, occurs in the ore at the Katherine Mine, and to a lesser extent in the Gold Road vein.

Fragments of wall rock are frequently enclosed in the veins, and such fragments are in most cases quite angular in outline. Many of these fragments are surrounded by concentric layers of quartz. Where the calcite surrounds rock fragments, the banded structure is less evident, but, if the calcite is fine grained, banding may occur. Many of the small stringers in the walls occupy joints and irregular fractures, and these veinlets appear to have filled open fissures rather than to have replaced the wall rock, although it is possible there may have been some metasomatic replacement, but the extent of this replacement cannot be determined. During the process of ore deposition, open fissures must have existed; otherwise the thin plates of calcite could not have formed as they did.

MINERALOGY OF THE ORES

The mineral composition of the veins is comparatively simple and consists essentially of quartz and calcite with smaller amounts of adularia, fluorite, and gold. During the process of oxidation, but few additional minerals were formed, and, among them, gypsum, hematite, and pyrolusite are the most common. Sulphides are rarely found in the veins, but are commonly encountered in the walls of the veins.

Gold: Gold is the most valuable constituent of the ore, and is always alloyed with more or less silver. In most of the ore having a value of less than $20 per ton, silver exceeds gold by weight, but, in such ore, the precious metals are so finely divided that they are rarely recovered by panning. High-grade ores frequently show free gold. When such gold is primary in origin, it occurs as aggregates of small, hackly grains, as slender curved wires resembling trichites in volcanic glasses, or as thin plates between grains of quartz. Coarse gold is rarely found. Such gold is of a pale, brassy yellow color and contains approximately 20 percent by weight of silver. Gold, believed to be of supergene origin, occurs as loose flakes and wires in vugs with the oxides of iron and manganese. This secondary gold is almost always in larger particles than the primary gold. Its color is a deep, brassy yellow and it may contain as much as 10 percent by weight of silver, or much less.

Visible particles of primary gold in the richer ore is most commonly found embedded in quartz grains, less commonly in adularia, and, in a few cases, notably at the Moss Mine, in fluorite. Nowhere was visible gold found in calcite, although many samples of calcite which are heavily stained with iron and manganese oxides carry gold.

Visible gold in quartz, particularly in the higher grades of ore, is usually confined to layers less than one-tenth of an inch in thickness. When examined microscopically, some isolated grains show crystal outlines. The oxidized ores which carry visible particles of gold are embedded in iron oxides.

Gold in adularia is rather uncommon, but was observed in a specimen from the United Eastern ore body. A thin section of some rich ore from the Gold Road Mine showed a parallel intergrowth of quartz grains and plates of adularia. Free gold as thin wires in this specimen traversed both minerals.

A specimen of fluorite from the Moss vein contained some rather stout wires and heavy plates of gold between the grains of fluorite. Some of the fluorite from the Hardy vein also contains visible gold.

Silver: Silver, as already stated, always occurs alloyed with gold, and, in some ores, the silver predominates by weight, but never in value. Silver Creek takes its name from the fact that the ores from mines along this stream carry considerable silver. The general impression among prospectors is that these ores contain the silver sulphide, argentite, but this mineral was not observed in any of the specimens examined. It is possible the pulverent manganese oxide, pyrolusite, may have been mistaken for a silver mineral. According to R. H. Dimmick, an assay of copper-stained quartz from one of the lower levels of the Katherine Mine gave a high return in silver. The sample contained some chalcocite and may also have carried some argentite.

All persons questioned agree that horn silver does not occur in these gold ores, and none was seen by the writer. It is possible that this mineral may be present in small quantities in the oxidized ores and yet not be visible. A specimen of wire silver received at the Arizona Bureau of Mines was said to have come from the San Francisco Mining District, but the exact locality is unknown.

Copper Minerals: Ransome[24] found a little chalcopyrite and chalcocite at the Gold Ore vein, and the writer found specks of chalcopyrite in ore at Big Jim. The oxidation of these sulphides has given rise to copper-stained quartz. No malachite was found, but chrysocolla is common in such quartz. Similar copper-stained quartz occurs to a limited extent at the Katherine Mine.

[24] Op. cit. p. 33.

Lead Minerals: A pulverent, bright red mineral was found in cavities in ore from the Big Jim Mine, by J. W. Bradley. At first, it was thought this red powder might be cinnabar, but blowpipe tests indicate lead rather than mercury. It is possible this mineral is the red oxide of lead, minium. Several specimens collected on the dumps at the Big Jim and also at the Aztec shaft contained a thin film of a bright yellow mineral. Blowpipe tests show it to contain lead and molybdenum, and it is probably wulfenite. Similar material was collected from the Pioneer vein.

Pyrite and Marcasite: Pyrite, as already stated, is rarely found in the veins although it is quite common in the wall rock adjoining the veins. In a few instances, it was observed embedded in quartz, and a specimen of quartz from the United American Mine contained small cubes of this mineral. Irregular grains and crystals of pyrite were also identified in a specimen from the Moss vein. A sample of the altered wall rock which contains pyrite, from the United American Mine, was crushed and the pyrite was concentrated by panning. These concentrates were then examined microscopically, but no gold was seen. An assay of this pyrite-concentrate gave only a trace of gold and silver.

Marcasite was found with pyrite in quartz at the Moss vein. The mineral occurs as groups of thin plates which diverge slightly at each end. It could not be separated readily from the pyrite for assay, and, consequently, it is not known whether or not the mineral is gold-bearing.

Hematite and Limonite: These two minerals are quite common in the oxidized ores of both districts, and have been derived from the oxidation of pyrite and perhaps, also, from the breaking down of ferromagnesian silicates in the wall rocks. Porous quartz which contains an abundance of hematite frequently also carries small flakes and wires of free gold. Such gold is of a deep, brassy color and is believed to be supergene in origin.

Psilomelane or Pyrolusite: Pulverent, black oxide of manganese is rather widespread in distribution. It appears to be particularly common, though never abundant, in the western part of the Oatman District where it is associated with ores containing fluorite. Chemical tests show some of the calcite to carry manganese, and it was probably from this source that the manganese oxide was derived.

Quartz: Quartz is the most abundant and widespread constituent of the veins and shows considerable diversity in both texture and color. It occurs in several generations, always associated with calcite, and, in some specimens, with adularia.

The first deposition of quartz in some veins was a coarse-grained, colorless variety in crystals up to an inch or more in length. Some quartz is mostly white, but shows some bands which possess an amethystine tint crossing the crystals. In most cases, however, this early quartz consists of an aggregate of interlocking grains instead of crystals.

Yellow quartz is most common in the higher grade ores and has a decidedly greasy luster in some specimens. A microscopic examination of sections of this yellow quartz shows that the grains are filled with an aggregate of minute plumose inclusions; but these tiny scales are too small for optical determination. A fusion of this yellow quartz gave a definite reaction for iron, and it is possible that the yellow color is due to some iron silicate.

Banded quartz, chalcedonic in texture, is abundant at the Gold Road vein and also at the Gold Ore vein. Such quartz may be white to cream, or even pinkish or some shade of brown.

Calcite: Calcite is next to quartz in abundance in the veins. Much of it is white to grayish in color and rather coarse grained in texture, forming large rhombs with curved cleavage faces. Some varieties of the calcite have grown as thin plates perpendicular to the base, and well-developed crystals of this mineral show the rhombohedral faces around the edges of the crystals.

Chemical tests give a trace of magnesia, sometimes a little iron, and a specimen from the Pioneer vein, pinkish in color, gave a test for manganese.

Adularia: Adularia is a common constituent of the higher grade ore, and, in such ore, it is invariably associated with the yellow quartz. The adularia usually occurs as white bands between layers of quartz, but, in some specimens, plates of adularia and grains of quartz are intergrown. Gold is frequently found as an aggregate of grains in such intergrowths, and thin plates of gold were found in adularia.

Bands of pure adularia vary in width from a small fraction of an inch up to nearly two inches. Cleavage faces on these broad bands show the crystals to be quite large. Frequently, the larger crystals have well-developed terminal faces; and the forms identified are the base and clino-domes. Adularia also occurs as a microscopic constituent of the ores as isolated grains and crystals surrounded by quartz.

An analysis of the adularia from the Oatman District, made by Dr. R. J. Leonard of the University of Arizona, yielded the percentages shown in column 1.

	1		2
SiO_2	65.81		64.7
Al_2O_3	17.64		18.4
CaO	0.32		....
Na_2O	1.76		....
K_2O	15.08		16.9
	100.61		100.0

In column 2, is given the theoretical composition of pure potassium silicate, $KAlSi_3O_8$, for comparison. Adularia frequently contains small amounts of soda which replace the potash in the adularia molecule. As may be seen from the above analysis, the Oatman material contains also a little lime.

Fluorite: Fluorite is common only in the northwestern part of the Oatman District, although a little was found by Ransome[25] at the Aztec Mine. At the Times and Hardy mines, fluorite is intergrown with or occurs as veinlets in the quartz, and also lines cavities. It occurs in a similar manner at the Moss Mine. Fluorite also occurs in the Moss vein as segregations which sometimes enclose stout wires and plates of free gold. From its occurrence in various veins, it appears to be of late introduction, but whether it was deposited earlier or later than the adularia is not known as the two minerals have not been found associated in the same specimen. Apparently, fluorite was not an important or abundant constituent of the larger ore shoots of the Oatman District.

The fluorite is white to pale green in color and is usually present as an aggregate of interlocking grains; but, where it lines cavities in the quartz, it forms octahedral crystals. Occasionally a little of the purple variety is found, but it is less common than the pale green fluorite.

Gypsum: The variety of gypsum known as selenite is quite common in the Oatman District. It occurs in the outcrops of those portions of veins where the wall rock was originally impregnated with pyrite. The oxidation of this pyrite formed sulphuric acid, and the acid, in turn, reacted with the calcite in the veins to form gypsum.

Gypsum is quite abundant north of Silver Creek where extensixe exposures of the Moss porphyry outcrop. This rock was originally mineralized over wide areas with pyrite. The significance of gypsum in the outcrop of veins and its relation to ore shoots will be discussed in a following section on outcrops.

Kaolin: Kaolin occurs in the oxidized ores, associated with hematite. Part of this kaolin was undoubtedly derived from the decomposition of adularia in the veins, and, in, part, it may have come from the alteration of the wall rock by surface waters.

[25] Op. cit. p. 33.

Asbestos: A variety of asbestos known as mountain leather was found in a specimen of ore from the Big Jim by J. W. Bradley. It occurred as a thin, flexible sheet between layers of quartz.

STAGES OF MINERAL FILLING IN THE VEINS

Tn interesting characteristic of the ores of both the Oatman and Katherine districts is the rhythmic alteration of quartz and calcite. In each vein, deposition begins with quartz and closes with calcite. Five stages have been recognized; each of which has its distinctive type of quartz, and they can usually, although not always, be distinguished from each other. The calcite shows no such distinctive features, although coarse-grained, gray calcite occurs only in the veins following the first stage of quartz deposition.

Neither the color nor the texture of the quartz is alone a safe criterion in distinguishing the stage of mineralization to which it belongs. For example, yellow quartz with a greasy luster is always looked upon as indicating high-grade ore, but assays of carefully selected samples of such quartz gave low value. Yellow quartz which shows a pseudomorphic texture after platy calcite is, however, always commercial ore, and such ore invariably contains microscopic crystals of adularia. Transparent crystals of quartz may belong to any stage of deposition, but only in the first stage are such crystals large.

It should be apparent from what has been sold that the recognition of the different types of quartz may be of commercial importance. For instance, quartz of the fourth or fifth stage of mineralization, taken from the outcrop of a vein, although carrying no gold, would be worth following to depth. The identification of these different stages is not always easy, but the ability to differentiate them can be acquired with practice; and, as an aid, illustrations of the more distinctive types are included in this report.

The evidence on which this sequence was determined was collected in both the Oatman and Katherine districts. At no mine were all stages observed, but, by piecing together evidence from different veins, a more complete story was obtained. Some veins are filled almost entirely with calcite, but, in most veins, the walls are lined with quartz and the central portion is filled with calcite. Stringers of later quartz cut across both the calcite and earlier quartz. The earlier quartz and calcite from the Aztec vein and also from the Big Jim was crushed by later faulting, and, on this crushed vein-filling, a later stage of quartz and calcite was deposited.

There is an interesting relation between the stages of quartz deposition and the ratio of gold to silver. In the earlier stages, silver predominates over gold by weight, while in the last stage the gold exceeds the silver. There is also a progressive increase in the total value of the gold and silver from the earlier to the last phases of mineralization.

Although quartz stringers traverse previously deposited minerals, or follow periods of faulting in which the veins were reopened, there is no reason to believe that the various stages of mineral deposition were separated by long intervals of time.

A detailed description of the various stages in the deposition of the ores is given below:

First Stage: The quartz of the first stage of deposition shows the most variation in texture, and, for that reason, it is often difficult to identify it with certainty. The coarse-grained, transparent variety which occurs as an aggregate of large crystals may be placed with certainty in this first stage. As already stated, these crystals are frequently traversed by a band of amethystine colored quartz, and an example of this type is shown in Fig. 11. Most of the quartz of the veins that belong to this stage is, however white in color and consists of an aggregate of small, interlocking grains. It is difficult to differentiate such puartz from some quartz deposited during the next stage when the latter is free from such textural features as psuedomorphic replacements after calcite.

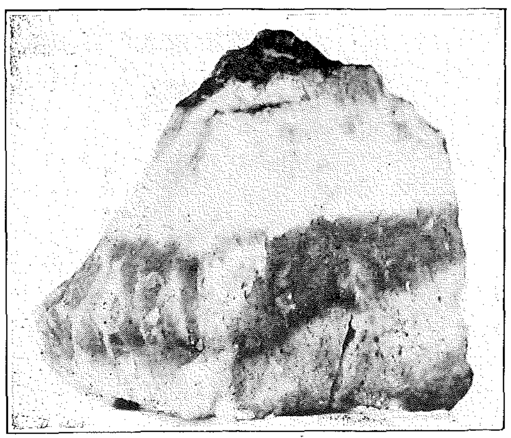


Fig. 11.—The first stage of quartz deposition. The dark band is the amethystine variety.

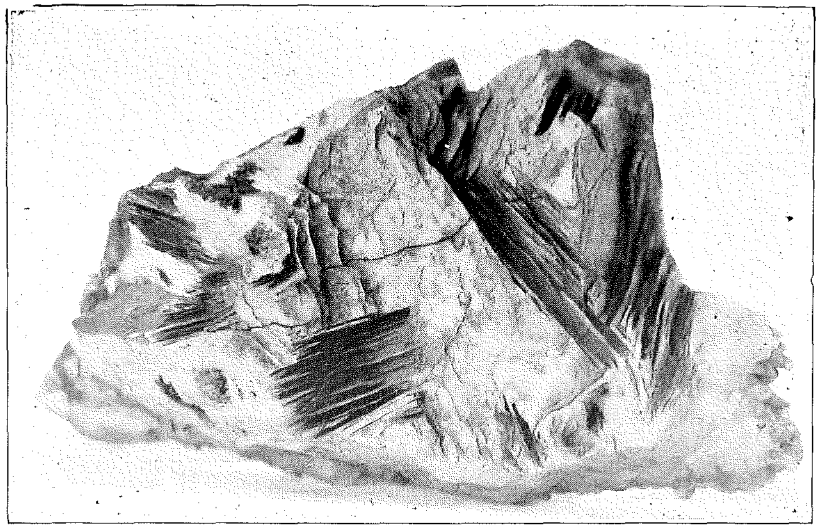


Fig. 12.—Platy quartz as a pseudomorphic replamecent of calcite. Unreplaced calcite leached out.

A microscopic examination of this quartz shows no unusual features. The individual grains of quartz are irregular in outline, but fairly uniform in size. They are crowded with minute, dust-like inclusions.

Assays reveal that this stage of quartz carries a maximum of $1.20, a minimum of $0.40, and an average of $1.00 a ton in gold and silver. The ratio of gold to silver is one to six by weight.

Calcite followed the deposition of quartz, and most of it is coarse grained with curved, rhombohedral cleavage faces. Usually, this type of calcite is of a grayish color; sometimes it is brown, and, rarely, pure white. Generally, the finer grained varieties are lighter in color. Chemical tests show a trace of magnesia and sometimes a little iron.

This calcite, in some instances, must have been deposited in open fissures, for, frequently, it formed as thin plates with crystallographic faces around the edges. This structure is important since this calcite is often replaced by the next stage of quartz deposition and the original texture retained.

Second Stage: Following the deposition of the calcite described above, the solution again began to deposit quartz. There is no way to determine the lapse of time between the two stages of mineralization. Very likely, they followed each other rather closely. In some veins, small stringers of this stage of quartz

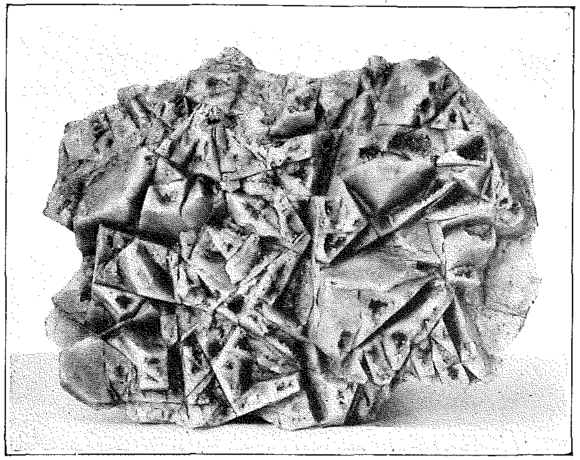


Fig. 13.—Quartz of the second stage of deposition, showing a pseudomorphic replacement of calcite plates.

may cut the earlier deposited quartz and calcite. Frequently, these veinlets are of a different texture and sometimes show slight differences in color.

An interesting feature of some of this later quartz is the texture shown in Figs. 12 and 13. From specimens studied, it was concluded that the quartz was first deposited between the thin plates of calcite, and, as deposition continued, some calcite was dissolved and carried away by these same solutions. Such calcite as remained was later dissolved, perhaps by surface waters, leaving the thin plates of quartz standing out in relief. These features are shown in Fig 12. Sometimes the thin plates of calcite grew together at acute angles, and the deposit of quartz took place on these plates. Later, when the calcite was leached out, the texture shown in Fig. 13 was developed.

Much of the quartz of this generation does not show these textures, and, when replacement is extensive, only a faint suggestion of the original texture remains. The more massive varieties of this type of quartz consist of an aggregate of small, white grains. Before deposition ceased, however, clear crystals of yellow quartz were deposited over the variety formed earlier. In places, such yellow quartz is quite massive, and examples of this variety occur at the Katherine and Arabian mines in the Katherine District. Although this mineral appears to be "live quartz," with a color and luster very much like the commercial ore from the Oatman District, an assay gave only 0.08 ounces in gold.

Microscopic examination of such quartz showed no adularia and only a few residual shreds of calcite.

Quartz of the second generation is more abundant and widespread in its distribution than any of the other stages. Assays show considerable variation with a maximum of $1.70 in gold and silver per ton. Several samples assayed only 0.02 ounces in gold. Silver, although low, exceeds gold by weight.

Calcite, deposited immediately after this quartz is relatively scarce, or else difficult to identify positively. One reason for the general absence of this calcite may be the renewed faulting and crushing along the veins which follow the deposit of this mineral. Specimens collected from the Moss and Hardy veins in the Oatman District, and from the Arabian vein in the Katherine District, show a platy variety with a pinkish color. The plates are parallel and closely spaced.

Third Stage: Faulting followed the deposition of the second stage of quartz and calcite, so the first mineral of the third stage was deposited upon this crushed material. Specimens showing the resulting features were collected from the Big Jim and Aztec mines.

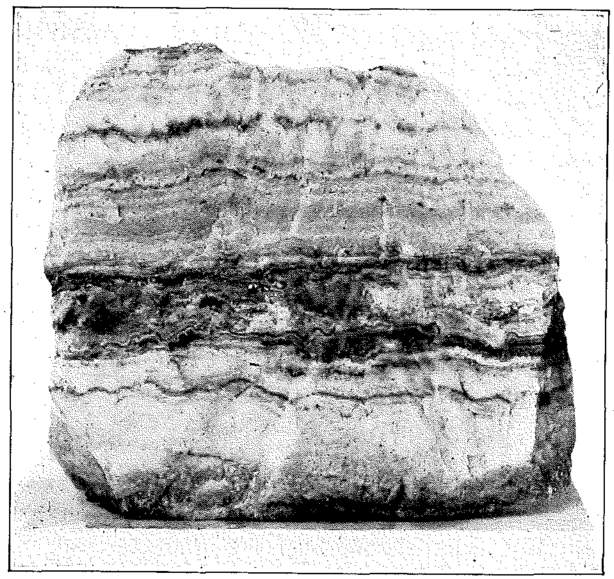


Fig. 14.—Banded quartz of the third stage of deposition. A variety commonly found at the Gold Road vein.

This variety of quartz is extremely fine grained, often chalcedonic, and consists of alternate layers of slightly different color. Usually, it is a creamy white with thin bands of pale brown. Sometimes, the broader bands are a delicate lavender between layers of white or yellow. Quartz of this generation, but of a yellow color and not particularly different in appearance from the next stage of quartz, was found at the Big Jim and Aztec mines. The quartz is rather opaque and lacks the oily luster. Very thin layers or partings of calcite may be seen in some specimens, but such calcite is rare. An illustration of this banded quartz is shown as Fig. 14. This type of quartz has a rather limited distribution. The most extensive known deposit of the third stage of quartz is in the Gold Road and Gold Ore veins where much of the vein filling is of this type. Smaller amounts may be seen at various other mines, notably at the Pioneer. The Frisco vein in the Katherine District is made up almost entirely of this type of quartz.

A microscopic examination of this stage of quartz shows considerable variation in the size of grain. Usually, the quartz first deposited is extremely fine grained, and the texture becomes increasingly coarse in later formed layers. In those bands last formed the individual crystals or grains are large enough to be distinguished with the unaided eye. With renewed deposition, a new, very fine-grained band was formed, and the process was repeated over and over again. The colliform (i.e., in layers the surfaces of which are covered with low, rounded protuberances) structure suggests that this stage of quartz was deposited in open fissures.

Values in this type of quartz range from 0.06 to 0.40 ounces in gold and 0.18 to 0.24 ounces in silver per ton. The average value of all assays was slightly over $5 per ton in gold and silver. The average ratio of gold to silver is 2 to 3. It will be noticed that there is an appreciable increase in the gold-silver ratio over the earlier stages of vein filling.

Calcite again followed the deposition of quartz and is usually flesh-colored. It occurs as thin plates, sometimes as much as six inches across and usually is less compact than the earlier stages of calcite, although this characteristic is not a reliable criterion. Occasionally, it is quite granular, and a pinkish specimen from the Pioneer vein gave a good test for manganese. Very likely this calcite contains some of the rhodochrosite molecule ($MnCO_3$). Another sample from the same mine contained some manganese oxide along fractures, and an assay gave 0.16 ounces in gold and 0.02 ounces in silver. The high ratio of gold to silver in this manganese-stained calcite suggests that this gold may be supergene in origin. In some specimens, the calcite is coated with small, colorless crystals of quartz.

Fourth Stage: Although a few small crystals of quartz were depositel on calcite, as mentioned in the preceding paragraph, they were but the forerunner of the extensive deposition of the quartz that constitutes commercial ore bodies. The quartz again shows casts of platy calcite. Fig. 15 is an illustration representative of this variety of quartz. The color is invariably yellow or greenish, but the oily luster is absent except in such specimens as have a banded structure. The banded structure is best seen where the earlier stages of mineral filling have been shattered and this later quartz introduced into the fractures.

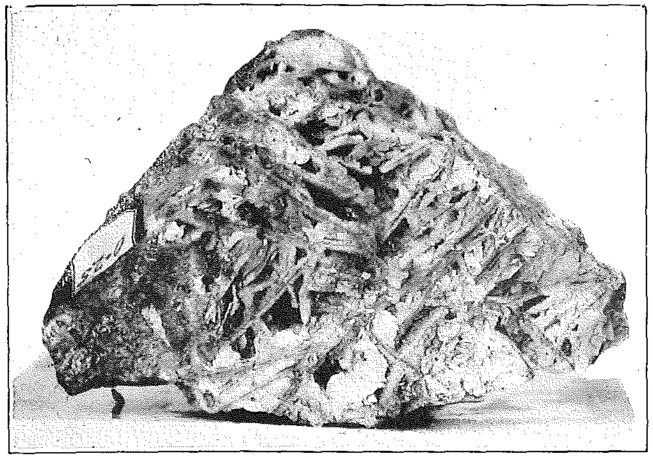


Fig. 15.—Quartz of the fourth stage of deposition. The platy structure is due to a replacement of calcite.

A microscopic examination of this quartz shows the individual crystals along definite lines which were originally thin plates of calcite. The space between the rows of crystals is lined with a granular aggregate of quartz grains together with ragged shreds of unreplaced calcite. Occasional grains and crystals of adularia may be seen in the granular quartz. This adularia is remarkably free from alteration products, and it is interesting to note here that the first appearance of the adularia coincides with the first deposition of commercial ore. Gold is rarely seen with a microscope and then only as widely scattered, thin flakes.

Quartz of this stage of deposition occurs at the Katherine Mine, but was not found at any of the other mines of the Katherine District. In the Oatman District, this variety of quartz occurs at practically all the mines that have produced gold. This period of mineralization represents the first introduction of commercial values. Assays of such quartz range from 0.20 to 1.00 ounces in gold and 0.24 to 2.34 ounces in silver per ton. The ratio of gold to silver is approximately 1 to 2.

The calcite formed upon this pseudomorphic quartz occurs as very thin lamellae which form a somewhat compact mass of curved plates. The calcite has a pearly luster and is the most distinctive variety of this mineral in all the stages of mineral deposition in these veins. A broad band of the calcite, several inches wide, may be traversed by thin layers of the yellow quartz which show a rhythmic alteration of quartz and calcite. Where the thin plates diverge, small, clear crystals of quartz rest on the calcite.

Fifth Stage: This stage of deposition brings to a close the active filling of the fissures by the mineral-bearing solutions which arose through the fractures. It is also of interest to note that the ascending solutions that deposited this last phase of mineralization also brought in the greatest concentration of gold. The vein filling of this stage of mineralization was deposited in open fissures upon the earlier stages of vein filling or upon rock fragments. Banding is well developed and crenulation in the bands is very pronounced. Such banded structures are frequently referred to as "cockade ore," [26] and represents the repeated deposition of alternate layers of somewhat different composition.

The quartz of this last stage of mineralization is yellow and, often, olive-green in color. Such quartz invariably shows an oily luster, and a well-developed banded structure. The size of the quartz grains varies from fine to coarse, and, usually, the darker-colored bands are somewhat coarser in texture. The difference in color, certainly in some specimens, appears to be due to a greater concentration of impurities, perhaps a silicate of iron. Layers of quartz are often separated by bands of snow-white adularia, and these partings of adularia vary in width from a small fraction of an inch up to two inches. Occasionally, the quartz and adularia are separated by a thin parting of calcite. The thicker bands of adularia are made up of coarser crystals and, on a fractured surface, show the cleavage characteristic of this mineral. In these broader bands, the crystals of adularia have well-developed terminal faces, and, upon the ends of these

[26] Spurr, J. E., Successive banding around rock fragments in veins: Econ. Geology, vol. 21, pp. 519-537, 1926.

crystals, the next layer of quartz was deposited. This feature clearly indicates that, during this phase of mineralization at least, the process of vein formation was due to simple deposition of minerals in open fissures, and replacement was negligible. Illustrations of this type of quartz are shown as Figs. 16 and 17.

Microscopic examination of this quartz often shows the crenulation in the banding to be developed on a minute scale. In such parts of the slide, as show this feature, the size of grain is also unusually small. A striking feature of the coarser crystals of quartz is the development of a plumose texture in them, due to

Fig. 16.—Dark greenish quartz of the fifth stage of deposition. The white bands are adularia.

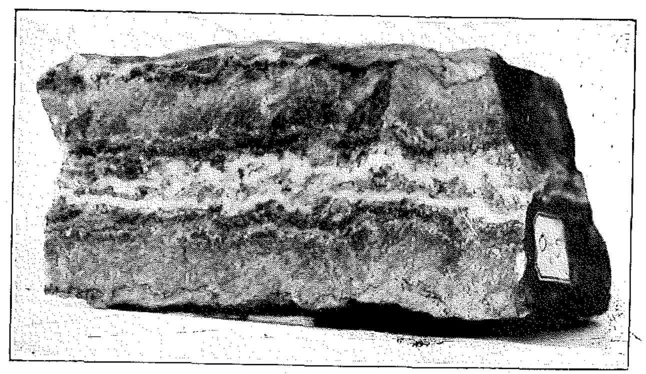


Fig. 17.—A specimen of the fifth stage of deposition. This quartz is of a dark greenish color. The white band is adularia.

the arrangement of small, opaque inclusions. A little kaolinitic dust occurs in the adularia, frequently along cleavage planes; otherwise this mineral is remarkably free from alteration products.

TABLE III.

SUMMARY OF THE CHARACTERISTIC FEATURES OF THE VARIOUS STAGES OF QUARTZ DEPOSITION.

Stage	Texture	Color	Range of values per ton.	Ratio of gold to silver.	Relative distribution in the veins.
1st	Coarse to fine grained.	Colorless, white, amethystine	Up to $1.20	1 to 5	Abundant
2nd	Fine grained. Often shows casts of calcite	White, rarely yellow	Up to $1.70	1 to 6	Abundant
3rd	Fine grained Banded	Various colors	$1.20 to $8.00	2 to 3	Relatively scarce
4th	Fine-grained Often shows casts of platy calcite	Pale green to yellow	$4.00 to $20.00	1 to 2	Abundant only in ore shoots
5th	Fine to medium grained Usually banded	Pale to deep honey-yellow	$20.00 up	4 to 1	Abundant only in ore shoots

Gold is often concentrated in certain bands as clusters of small grains. Adjoining bands of quartz may contain only isolated grains. In a few instances, the gold observed microscopically was found to have crystal boundaries, but such occurrences are rare. A specimen of the high-grade ore from the Gold Road Mine showed the clusters of gold to be associated with thin plates of adularia separated by granular quartz. A high-grade specimen shown the writer at the United Eastern had coarse gold on adularia. Usually the coarse crystals of adularia contain very little gold.

Assays of this stage of deposition always show commercial values and range from $20 per ton up. Mr. J. W. Bradley informed the writer that selected specimens would often carry more than $1,000 per ton. The average ratio of gold to silver is 4 to 1.

The calcite that followed the deposition of the fifth-stage quartz was transparent and colorless and presents no features of unusual interest. Such calcite is usually well crystallized and represents the last mineral deposited by the ascending solutions.

WALL ROCK ALTERATION

Alteration of the wall rock is more intense along some parts of the veins than elsewhere. Such alteration is particularly intense where the rock is impregnated with pyrite; and, as a rule, the more acid members of the volcanic series have undergone the least change. At many of the mines, only the workings near the surface are accessible, and here the alteration in the walls produced by ascending solutions has been masked by the changes brought about by surface waters. By examining the rock on the dumps, however, some information was obtained as to the character of the alteration at greater depth. Even in specimens collected from the mine dumps, it is often impossible to disinguish the alteration produced by mineral solutions from that which the rock has suffered prior to mineralization. This is particularly trlue of the Alcyone trachyte.

At the Katherine Mine, the effects of surface decomposition in the granite extends to the lowest level. The change most noticeable is intense kaolinization, but whether this kaolin was formed from feldspar or sericite is not known. The altered rock there is also more or less stained with iron oxide. The effect which can be attributed directly to the mineralizing solutions is a narrow zone of intense silicification in the granite. As the small stringers are abundant and closely spaced in some sections of the mine, the silicification has resulted in a local induration of the rock.

Much of the Alcyone trachyte was altered prior to the formation of the veins, and consequently, the changes produced in the rock by the mineralizing solution are not readily determinable. There appears, however, to be a bleaching of the wall rock immediately adjacent to the vein.

The Oatman andesite shows much variation in the intensity of the alteration where it forms the wall rock of the veins. Locally, it is intensely altered, and especially so where it has been impregnated with pyrite. Specimens containing finely disseminated pyrite are thoroughly bleached of their green color, and are light gray with only a slight greenish tinge. Although the rock is thoroughly altered, the outlines of original feldspar crystals remain. In thin section, such altered rock was found to consist largely of calcite, secondary quartz, and kaolin. Whatever chlorite was first formed from the original ferromagnesian minerals in the rock has been changed to a fibrous mineral resembling sericite. It is not abundant, however. Of the original constituents of the rock, only apatite and magnetite remain unaltered.

The less altered andesite wall rock that contains no disseminated pyrite is darker in color. Even this rock, when examined in thin section, is found to be composed almost entirely of calcite, secondary quartz, and chlorite. The secondary quartz was most probably formed by the decomposition of the silicates, but, to some extent, it may also represent silica introduced by the mineralizing solutions.

Changes produced in the Gold Road latite are quite similar to the alteration in the andesite. Some of the latite at the Gold Road and Gold Ore mines is impregnated with disseminated pyrite, and such rock is also bleached to a light gray color.

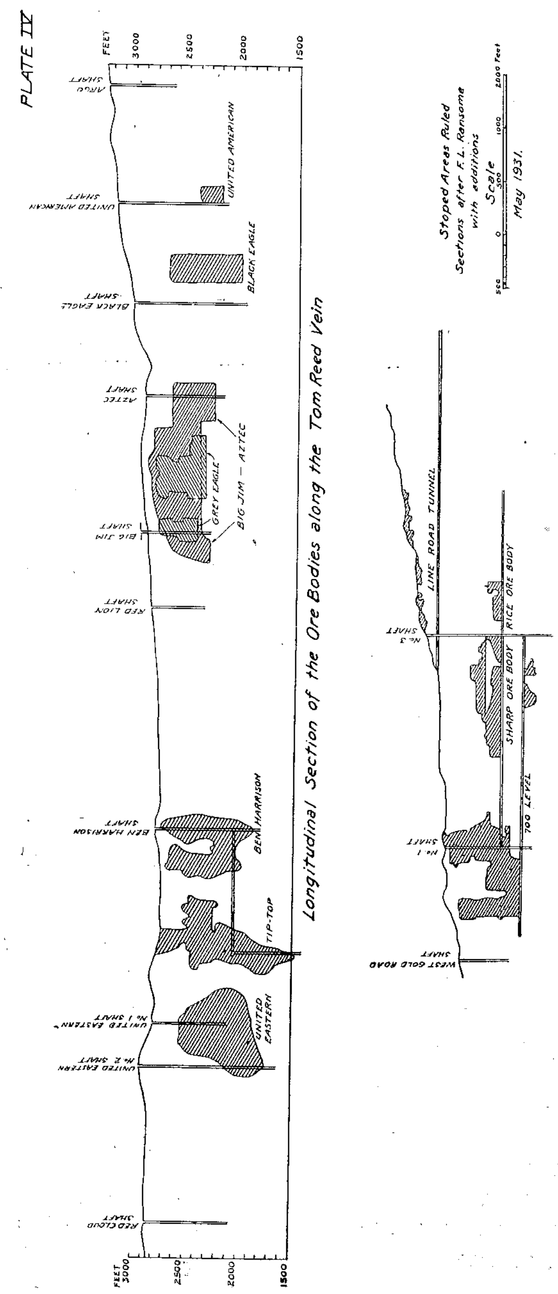
The rhyolite flows in the Oatman District are not traversed by veins, and the small stringers of chalcedony and calcite have produced only slight changes in the rock. In the Katherine District, however, the changes in the rhyolite flows are more pronounced. Calcite is only a minor constituent of the alteration products, and the rock has been changed very largely to an aggregate of kaolin and secondary quartz. Only specimens from near the surface could be obtained, and they were invariably stained with iron oxides. Silicification appears to have been the most important result of the alteration.

Attention was directed to the altered condition of the Moss porphyry when describing that rock. This intense alteration appears to be associated closely with the deposition of pyrite in the rock. At the Moss Mine, there is very little pyrite; consequently, this intensely altered condition is absent. Fragments of the porphyry enclosed in the vein have been silicified, but, in addition, small amounts of kaolin, calcite, and chlorite have also formed.

A surprising feature of the alteration of the wall rocks is the general absence of sericite. Sericite is often found in such rocks as a result of mineralization, and signifies the addition of potash from the solutions. In this case, however, the solutions may have abstracted potash from the wall rock. No analyses are available to establish this point.

ORE SHOOTS

The distribution of ore shoots along the Tom Reed vein, which are shown in elevation on Plate IV, indicates a concentration of ore bodies at certain points. For example, the three most important ore bodies, the United Eastern, the Tip Top, and the Ben Harrison, were all localized within 2,000 feet along this fracture. South of the Ben Harrison ore body, the Tom Reed fracture is barren for over 2,000 feet of its length, and some portions of the fracture are entirely devoid of vein-filling. Underground exploratory work, however, shows the fracture to be continuous,



Pate IV.—Location of ore shoots on the Tom Reed vein and the Gold Road vein.

but filled with only a heavy gouge of crushed rock. Beyond the Red Lion shaft, the important Big Jim-Aztec ore shoot with a length of over 1,500 feet was found. Here the Grey Eagle ore shoot represents a displaced segment of the Big Jim-Aztec ore body along the Mallory fault. Still farther south along this same fracture are the Black Eagle-United American ore shoots. Plate IV shows only the ground stoped; the ore developed has a greater depth than shown in the section.

Due to lack of information it is impossible at present to show an outline of the ore shoots on the Telluride, Gold Dust, Pioneer, Vivian, and Leland veins. The vertical range of ore was much less than that of the ore bodies that occur along the Tom Reed and Gold Road veins.

The outlines of the individual ore shoots, as shown in elevation, is usually quite irregular; in plan, however, they are lenticular. Nearly all of these ore bodies have been mined, the underground workings are now inaccessible and it is impossible to collect information which may give a clue to the localization of ore shoots at definite points along the main fractures. The termination of ore shoots in sharp, narrow tongues in the case of the Tip Top and Ben Harrison ore bodies suggests that, perhaps, in these areas, there was a more intense fracturing which may have controlled the circulation of the ascending, mineral-bearing solutions.

Faulting and reopening of the veins was a condition necessary for the formation of an ore shoot. This was an essential condition, for unless the veins were reopened, there was little chance for the later, higher grade stages of quartz to be deposited. This point will be discussed in connection with hypogene enrichment.

The ore shoots, broadly speaking, are lenticular in plan; sometimes they are rather long and narrow as, for example, the Big Jim-Aztec ore shoot. The portion of this ore shoot on the Big Jim claim, as mined by the United Eastern, had a maximum width of 35 [27] feet. The Black Eagle ore shoot and also the ore bodies on the Telluride vein were also narrow. The main ore body of the United Eastern which occured on the Tom Reed Extension claim had a maximum width of 48 feet. In places, this ore body consisted of massive quartz and calcite, but, in other places, it was a stringer lode with andesite between the stringers of quartz and calcite.

[27] Moore, R. W., Mining methods and records at the United Eastern Mine: Trans. A. I. M. & M. E., vol. 76, p. 56, 1928.

TABLE IV.

PRODUCTION AND METAL CONTENT OF ORE FROM THE SAN FRANCISCO DISTRICT, ARIZONA, 1908 TO 1928, INCLUSIVE.

Year	Tons treated	Av. value per ton	Ounces gold	Ounces silver	Ratio gold to silver
1908	72,737	$ 3.71	12,881	6,522	1.975
1909	18,106	16.78	14,515	7,118	2.041
1910	89,285	12.52	53,373	26,254	2.033
1911	110,699	13.34	70,568	33,834	2.086
1912	174,319	10.44	86,833	41,456	2.095
1913	159,948	11.35			
1914	160,469	11.51			
1915	132,579	11.31			
1916	95,245	9.54	43,181	23,812	1.813
1917	167.258	8.12	111,769	57,353	1.949
1918	182,824	15.55	134,155	70,432	1.905
1919	184,490	14.29	123,667	71,833	1,721
1920	197,629	14.84	136,948	72,806	1.476
1921	179,013	13.34			
1922	169,240	12.64			
1923	186,686	15.28	135,309	68,551	1.974
1924	96,788	16.98	78,239	39,097	2.001
1925	46,638	12.18			
1926	89,391	7.24			
1927	102,979	5.16			
1928	43,300	6.86			

Av. value 1908-1928—$12.368 per ton.

Gold and silver content decreased rather suddenly with depth. In the case of the ore shoot of the United Eastern on the Tom Reed Extension claim, this change took place at about the 800-foot level. Above this level, the average grade of the ore was over $20 per ton, while, below this level, the value dropped to under $10 per ton. A cross section of the Big Jim-Grey Eagle ore shoot is shown in Fig. 18. It will be noticed that the grade above the 600-foot level averaged $19 per ton, although, on the displaced segment on the Grey Eagle claim, it ran better than $20 per ton. Below the 600-foot level of the Big Jim, however, the average grade of the vein was less than $6 per ton. A similar abrupt change in values with depth was found in other mines, and appears to be characteristic of the ore bodies of these districts.

The average grade of the ore mined for each year from 1908 to 1928, inclusive, is given in Table IV for the year 1908, the grade of the ore was rather low, $3.71 per ton, and most of this ore came from the Gold Road Mine. With increased production from the Tom Reed Mine in 1909, however, the average value of the ore was increased to $16.78 per ton. From 1909 to 1917, inclusive, the grade of the ore gradually decreased; but in 1918 the

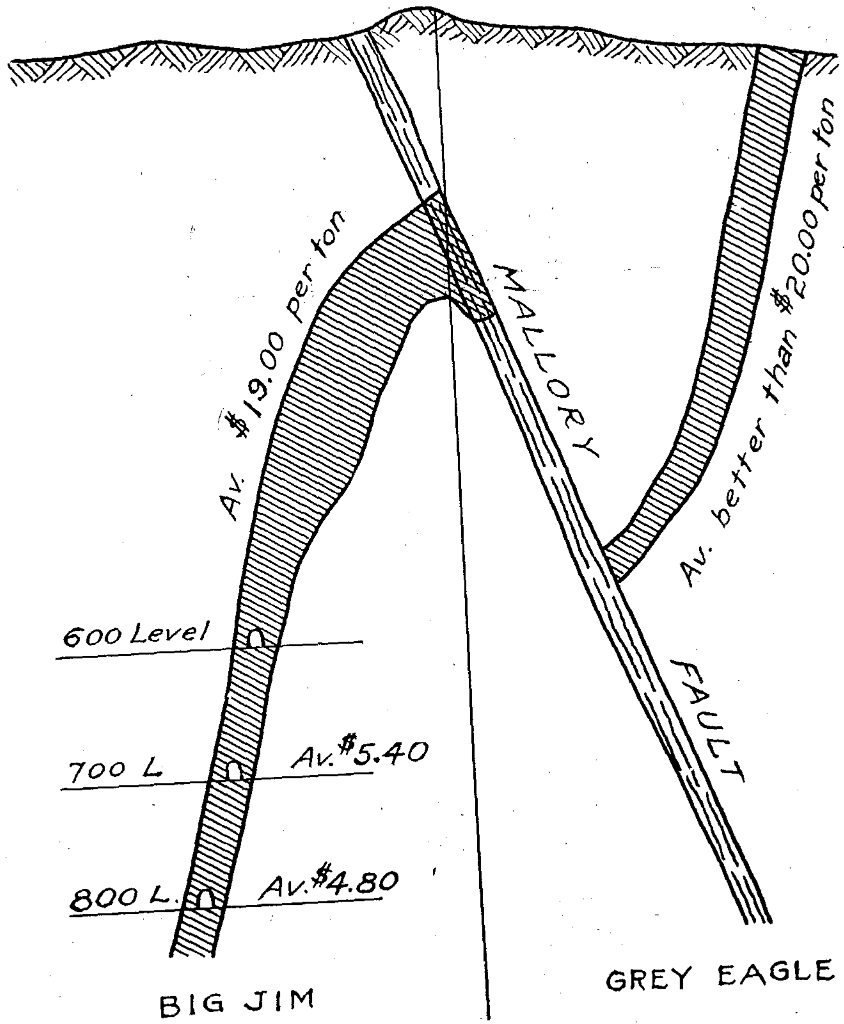


Fig. 18.—Diagrammatic section showing decrease in the value of the vein with depth at the Big Jim Mine.

United Eastern Mine became an important producer, and, with its higher grade ores, the average value per ton was raised accordingly. The low grade of the ores for the years 1926 to 1928, inclusive, was due to the inclusion of large tonnages from the Katherine Mine. The ore from the Katherine Mine during these years was of much lower grade than the ore from the Oatman District. The average grade of the ore from 1908 to 1928, inclusive, from all records available, was $12.368 per ton.

Throughout the years for which records are available, the ratio of gold to silver is remarkably constant, as is shown in the last column of Table IV. This ratio is nearly two to one; that is, the ore carried two ounces of gold to every ounce of silver. This feature of the precious metal content of the ores is significant in indicating the type of quartz mined. In a preceding section, attention was directed to the ratio of gold to silver that occurred in the various stages of mineral filling. Only the fourth and fifth stages of deposition contained commercial concentrations of the precious metals, and, of them, the latter alone carried a high ratio of gold to silver. As the earlier stages of quartz contained more silver than gold by weight, such ore bodies as were mined must have contained more or less of the later stages of mineral filling.

Gold of supergene origin carried a comparatively small amount of silver, and records show that such gold was worth $19.50 an ounce. Only a comparatively small amount of secondary gold was produced, however, and the ratio given in Table IV may be taken as indicating the respective quantities of the precious metals in the primary ores.

Veins in the Oatman and Katherine districts frequently branch and intersect; yet no ore shoots have been found at such intersections which are ordinarily favorable places to search for ore. Where the Telluride veins joined the Tom Reed, the intersection was barren; and the point at which the Tom Reed vein branched to form the United Eastern ore shoot contained vein filling, but the grade was low. Although no ore has been found at such intersections in the past, it does not mean that ore will not be found under such conditions in the future.

Ore has been found in various kinds of rocks. In the Katherine District, primary ore occurs in granite, and, in the Oatman District, primary ore shoots occur in latite at the Gold Road and Gold Ore mines and in andesite along the Tom Reed fracture. A small ore shoot at the Sunnyside Mine on the 500-foot level had trachyte for the footwall. The very rich ore shoot worked in the early days at the Moss Mine was in quartz monzonite. The general absence of ore shoots in the western part of the Oatman District will be taken up in a later paragraph.

The chemical composition of the rock, therefore, does not appear to have been an important factor in the localization of the ore shoots, and would hardly be expected to be of prime importance unless the ore bodies were formed largely by a process of replacement. A physical property of the various rocks, such as their ability to shatter and remain open rather than to form a tight gouge, may have contributed to the localization of the ore shoots where they are now found. As was stated previously, a reopening of the veins by later faulting was essential for the introduction of the later and richer stages of vein formation.

The ore of these districts is of the "bonanza type" and was deposited relatively close to the surface. Such ore bodies usually have a limited vertical range; and experience in other deposits of a similar character shows that ore stops rather abruptly. This is true of the ore bodies at Oatman. The longitudinal section of the ore bodies along the Tom Reed vein, shown in Plate III, shows that the United Eastern, Tip Top, and Ben Harrison ore shoots stopped at nearly the same depth below the present surface. Still farther south, the Big Jim-Aztec ore shoot occurs at a somewhat higher elevation, but it must be remembered that this ore occurs in the footwall of the Mallory fault, and the vertical displacement of this fault is about 500 feet. Consequently, the lower limit of ore before faulting was at about the same elevation as the bottom of the United Eastern and Ben Harrison ore bodies. The lower limit of ore on this vein is nearly at the same elevation. What the upper limit of the ore shoots was at the time of their formation, it is impossible to say, for much of the ore may have been removed by erosion. The outcrop of an ore shoot may be leached of metals, as at the United Eastern and the Grey Eagle, and at one time may have extended higher than at present.

The ore shoots in veins to the west of the Tom Reed invariably extended to lesser depth, and there must be a reason for the more limited vertical range of these ore bodies. The primary ore in the Gold Dust vein was mined to a depth of about 300 feet below the outcrop; in the Pioneer vein, about 500 feet; and, in the Leland vein approximately the same. The following suggestion is offered as a tentative explanation. Assuming that the ore shoots were formed at approximately the same distance below the surface as is shown in Fig. 19, then the lower limit of ore would occur at about the same elevation, as shown in the diagrammatic section. Although the lower limit of ore may have been at the same elevation when formed, post-mineral faulting has changed this general level. Erosion has cut deeper into the volcanic rocks in the western part of the Oatman District, and has exposed the older members of the volcanic series as well as the basement on which these flows rest. The veins have been eroded also to greater depths and the ore found in them may represent, therefore, the roots of ore shoots. Insufficint evidence is available definitely to establish this theory at the present, but such information as has been collected suggests it.

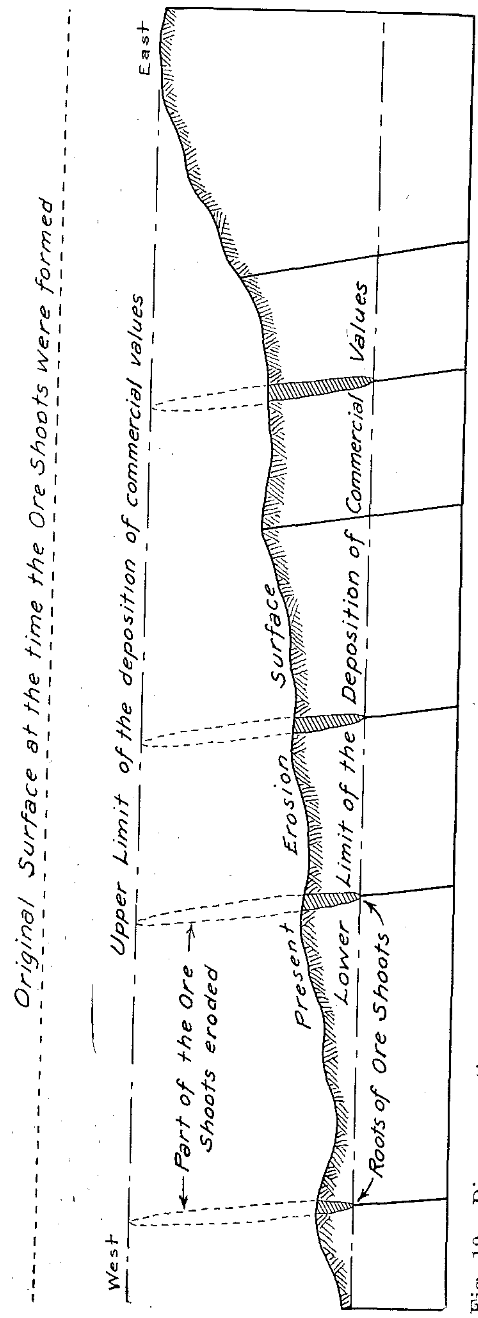


Fig. 19.—Diagrammatic section showing more extensive erosion of ore shoots in the western part of the Oatman District.

HYPOGENE ENRICHMENT

Ransome[28] proposed the term *hypogene* for minerals deposited by ascending hot solutions, and *supergene* for minerals deposited by downward moving cold solutions. Hypogene enrichment, therefore, is enrichment brought about by ascending solutions, and the term has been broadened to cover all such enrichments no matter whether they were deposited from hot or cold solutions.

In both the Oatman and Katherine districts, the earlier stages of vein filling did not contain commercial concentrations of the precious metals, but fracturing, followed by the deposition of the later stages of high-grade quartz, raised the tenor of the ores to a point where they could be extracted at a profit. An examination of assay maps for ore of the larger ores bodies of the Oatman District showed narrow zones, a few feet wide, carrying values up to $500 per ton. Such high grade streaks generally parallel the long direction of the ore shoot as shown in plan. Sometimes the high-grade streaks are near the footwall, sometimes near the hanging wall. They split into two or more branches, and, farther along, again rejoin.

Innumerable small stringers, too narrow to be sampled separately, enriched the low-grade quartz and calcite, or, traversing enclosed blocks of barren andesite, gave the entire lode a profitable grade. Schrader [29] noticed at the Gold Road Mine that the vein was locally enriched where stringers joined it. This portion of the mine is now inaccessible, but it is possible these stringers represent the later stages of vein filling.

The abrupt bottoming of the ore shoots is due to the playing out of these high-grade stringers. The lower limit of ore is also the lower limit at which this high-grade quartz was deposited. The veins continue in depth beyond this point, as has been shown by underground development work and diamond drilling, but the vein filling is too low grade to be mined and treated at a profit. The ore shoots were formed above this lowest point of deposition by a process of hypogene enrichment.

SUPERGENE ENRICHMENT

By supergene enrichment is meant the process whereby metals are dissolved near the surface in the zone of oxidation, carried downward to a lower level by descending cold water, and there precipitated. The level at which these metals are precipitated is the zone of secondary or supergene enrichment. Deposits of iron, copper, gold, and silver may show such a zone of enrichment. Many deposits originally too low grade to be workable at a profit have been enriched and made commercial by this process.

[28] Ransome, F. L.. Copper deposits near Superior, Arizona: U. S. Geol. Survey Bull. 540, pp. 152-153, 1914.

[29] Op. cit. p. 158.

The veins near the surface in both the Oatman and Katherine districts have been enriched in this way. Practically all the ore in the Katherine District resulted from supergene enrichment of the veins near the surface, and the same statement is true of some of the veins in the Oatman District, particularly those in the western and northwestern part.

The portion of the rainfall which soaks into the ground descends to the zone of saturation where the openings in the rocks are filled with water. This constitutes the upper limit of the water table or level of ground water. In a general way, it follows the contour of the surface, and it is in this zone that enrichment takes place. Above the water table is the zone of oxidation in which the veins are frequently leached of their metallic content.

An excellent summary of the enrichment of gold is given by Emmons[30] in his bulletin on enrichment, which includes all the important contributions available up to that time. As is shown in this bulletin, gold does not dissolve in sulphuric acid, but experiments by A. D. Brokaw show that gold will dissolve in the presence of manganese dioxide if the solution is acid and contains some chloride. Limestone walls or much calcite gangue will prevent the solution and downward movement of gold, however.

Manganese dioxide is widespread in its distribution in these districts and may be seen in almost any of the veins above the ground-water level. It occurs as thin, dendritic films on fractures or as pulverent black masses in cavities in the veins. Frequently this manganese dioxide is associated with fluorite.

The source of the chlorine necessary for the solution of gold may have come from the decomposition of the volcanic rocks. Such rocks contain apatite, a mineral which often contains a small percentage of chlorine, but a study of the altered rocks shows that the apatite is one of the few original constituents which has remained unaltered. Sodium chloride may occur in igneous rocks, especially as minute crystals, which occupy

[30] Emmons, W. H., The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, pp. 305-349, 1917.

microscopic cavities in other minerals. In an arid region, common salt may be concentrated in playas by evaporation of the water and the salt deposited as a thin, white crust at the surface. Later, dust storms would distribute this salt over a wide area. Penrose[31] has pointed out that chlorides occur most abundantly in undrained regions.

Gold in solution could be precipitated readily by any one of several substances occurring in the veins. Calcite is known to precipitate gold by reducing the acidity of the solution, and it is a notable fact that iron- or manganese-stained calcite will often give an assay for gold, whereas unstained calcite will not. A sample from the Pioneer vein gave, on assay, 0.16 ounces of gold and 0.02 ounces in silver, while unstained calcite at this time is barren.

Pyrite is also a precipitant of gold. Solutions containing ferric sulphate, coming in contact with pyrite, would be reduced to the ferrous state by the oxidation of the pyrite. A sample of quartz from the Moss vein which contained pyrite, some of which was oxidized, carried 10.80 ounces of gold and 30.16 ounces of silver per ton. Cavities in this sample contained visible specks of gold in limonite. It is hardly likely that the amount of gold present in the cavity could have come from the single, small grain of pyrite.

In the Katherine District, nearly all the commercial ore bodies stopped at or a short distance below the top of the water table, and such ore was invariably stained with iron oxide. Small pockets of rich ore at the Frisco vein, according to R. H. Dimmick, occurred in the footwall and were heavily stained with iron oxide. Some of this ore assayed over $1,000 per ton.

According to E. H. Dickie, who was foreman at the Moss Mine at one time, numerous small pockets of secondary gold were found occupying vugs in the mine. The gold was of a deep, brassy yellow color and occurred as rather coarse flakes and wires. This gold was present as loose particles in pulverent masses of iron and manganese oxides associated with fluorite. So constant was this association of gold with fluorite that in later prospecting for such pockets smaller stringers of fluorite were followed in the search for additional ore. Many of the veins in the vicinity of the Times porphyry contain both fluorite and manganese dioxide, and, without exception, the ore bodies mined occurred relatively close to the surface. This fact suggests that these ore bodies were probably enriched by supergene solutions.

31 Penrose, R. A. F. Jr., The superficial alteration of ore deposits: Jour. Geology, vol. 2, pp. 314-316, 1894.

The association of secondary gold with fluorite may be of more than casual interest. Chemically, fluorine is similar to chlorine in its properties, and may possibly be a solvent for gold under certain conditions. No experimental evidence bearing on this point is available so far as the writer knows. Clarke[32] states that fluorite is attacked by percolating waters which contain calcium bicarbonate or alkaline carbonates. Fluorite. however, is rare or absent in other veins in both the Oatman and Katherine districts, although some such veins show evidences of enrichment. At the southeast end of the section of the Gold Road vein, as shown in Plate IV, a number of small bodies of ore were mined near the surface. None of these ore bodies extended much over a hundred feet below the surface. The quartz was well stained with the oxides of iron, and it is possible such ores were enriched.

At the Gold Dust vein, several small pockets of secondary gold were found. Like other occurrences in the Oatman District, this gold was associated with iron and manganese oxides in cavities. Such gold contained but little silver and was worth $19.50 per ounce. At the United Eastern Mine, in the upper levels, the footwall of the vein was impregnated with iron oxides, and this iron-stained quartz carried good gold values.

OUTCROPS OF THE VEINS

Many of the outcrops of the veins consist of solid masses of quartz, an abundance of closely spaced stringers of quartz traversing country rock, or silicified wall rock. Such outcrops are the most conspicuous and stand out in relief because they are more resistant to erosion than the surrounding wall rock. Prominent outcrops of this type occur in the Gold Road, the Tom Reed, and the Moss vein in the Oatman District. In the Katherine District, the most conspicuous outcrop of this type occurs on the Black Dyke property. Such outcrops contain very little calcite except local bunches here and there, and those places in the vein where calcite is abundant weather most rapidly. Frequently such outcrops are black or red; the red stain is clearly due to iron oxides, but the dark outcrops are due to a thin film of desert varnish, and may consist of a mixture of iron and manganese oxides.

Gold is sometimes found free as visible particles in such outcrops, and the first discovery in the Oatman District, the Moss

32 Clarke. F. W., The data of geochemistry: U. S. Geol. Survey Bull, 770. p. 339. 1924.

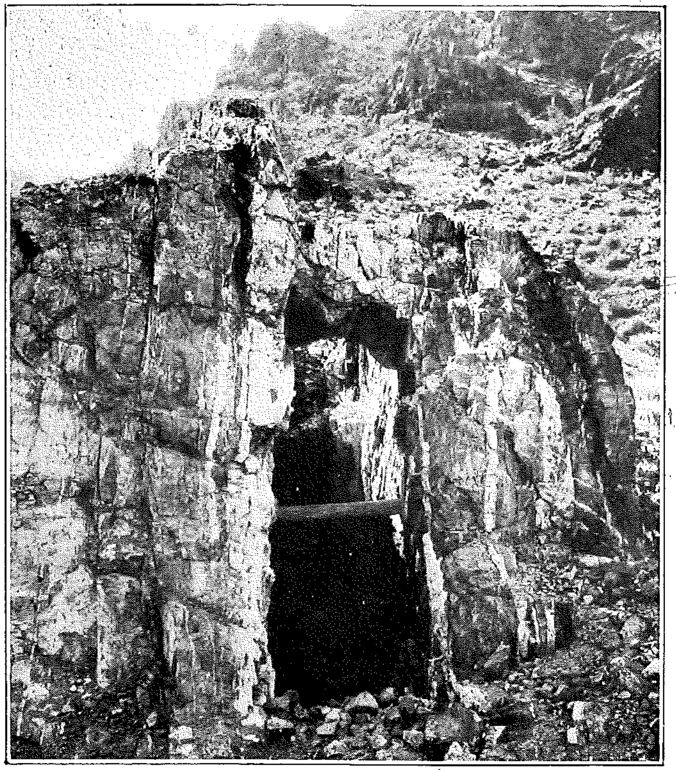


Fig. 20.—Outcrop of the Gold Road vein in the Oatman District.

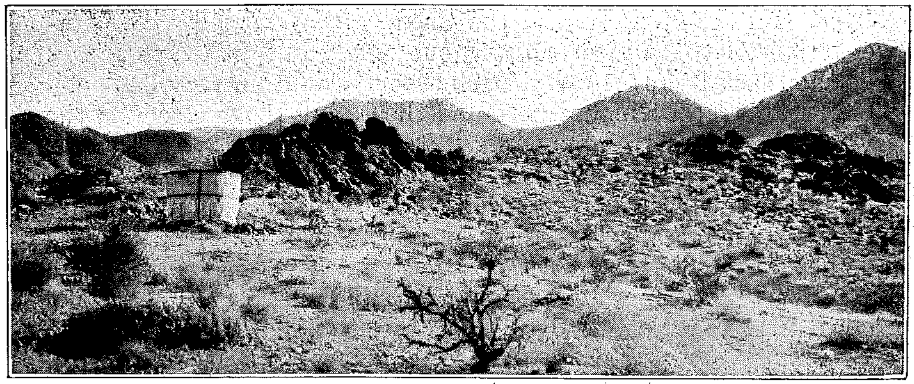


Fig. 21.—Outcrop of the Black Dyke vein in the Katherine District.

vein, was made on the finding of gold in the outcrop. In many cases, however, the gold is rather finely divided and its presence can be ascertained only by crushing and panning the sample, or by assay. Visible free gold has, however, been found in the outcrop of the Gold Road vein, but a sample taken by Joe Jeneres assayed forty ounces..

The type of outcrop most commonly found in both the Oatman and Katherine districts consists of an intergrowth of quartz and calcite. Where these two minerals are intimately mixed, the outcrop weathers down to the level of the wall rock on each side of the vein. Sometimes, such an outcrop is rather inconspicuous and may be covered by detritus at places along its strike.

Outcrops which consist entirely of calcite are relatively rare and represent a portion of the vein where this mineral was deposited in great abundance. Farther along the same vein, quartz may predominate.

The outcrop which is the least conspicuous and the most difficut to follow over the surface is one in which the vein contains more or less calcite and in which the wall rock is impregnated with pyrite. The oxidation of this pyrite generated sulphuric acid, and the acid, attacking the calcite, is neutralized and forms the hydrous calcium sulphate, gypsum. Where a vein with this type of outcrop crosses a spur or ridge, the outcrop is marked by a well defined depression. Thhe depression may be partly filled by detritus washed in from above, and a careful examination will show the wall rock to be bleached to an ocherous yellow color.

Panning of the decomposed vein material that contains gypsum will, almost invariably, yield fragments of residual quartz. The gold colors obtained in such panning, in every sample tested by the writer, were small and flaky.

Outcrops of veins which carry gypsum occur over the United Eastern, the Big Jim, a part of the United American, and the Gold Ore ore bodies. To the northwest of Oatman, gypsum is commonly found in the decomposed Moss porphyry. In many places, there is no evidence of a vein, nor is vein filling necessary for the production of gypsum. Although, in a vein, the calcite undoubtedly furnishes the lime necessary for the formation of gypsum, in the porphyry, this constituent could have been derived from the decomposition of the plagioclase feldspar.

The fact that gypsum occurred over large ore bodies at the United Eastern and the Big Jim mines has led prospectors and promoters to conclude that gypsum in the outcrop signifies ore bodies in depth. This assumption is based on incorrect premises, and actual development beneath such outcrops in some instances has failed to reveal an ore body.

To evaluate the various types of outcrops, and indicate which has the greatest merit from the economic standpoint, is not easy. The Tip Top ore body on the Tom Reed vein and some of the ore bodies on the Gold Road vein occurred beneath prominent, silicified croppings. In the case of the Tip Top outcrop, sampling showed low veins, but, within the last few years, lessees have mined small bunches of ore up to within a few feet of the surface. The occurrence of gypsum in the outcrop has no bearing on the deposition of gold. It does indicate mineralization, for the pyrite was certainly deposited by mineral-bearing solutions in the walls of the fissure prior to the deposition of quartz and calcite, but the mere existence of the veins indicates mineralization, and many of them have been shown to contain no bodies of ore.

Iron-stained outcrops, more or less porous and leached of calcite, may overlie enriched bodies of ore. Such ore may or may not be high grade, and most of such ore of supergene origin occurred as small pockets or as rather small lenses. In most cases it will prove worth while to search for them, however.

Outcrops in which the fourth and fifth stages of quartz have been deposited may be leached of the precious metals near the surface. On panning, the decomposed, gypsum-bearing outcrops of the United Eastern and the Big Jim-Aztec veins yielded fragments of the yellow quartz characteristic of the later stages of mineral deposition. Such outcrops are always worth prospecting. If an ore body is found, it may be expected to extend to a depth of a thousand feet or more in the eastern part of the Oatman District, but, in the western part of this district, it may extend down only a few hundreds of feet below the surface.

PLACERS

A small amount of placer gold has been found in the Oatman District, but no records are available of the gold production from the detrital deposits. The amount of placer gold shrinks to insignificance when compared with the large production from the lodes. No information on the occurrence of placer gold in the Katherine District is available.

Several factors are important in accounting for the general absence of placers, and perhaps, also, in limiting the amount of gold concentrated in the stream beds. Of these factors, the most important is probably the small size of most of the particles of gold originally in the veins. As was stated in a preceding section of this report, the particles of gold found when making a microscopic examination of the ores were almost invariably of small size. Such particles occurred as isolated grains or as aggregates of grains and, when liberated from the quartz, might be transported for long distances by the streams, particularly when they are in flood.

Another factor which must be considered is that of supergene enrichment. In the veins where secondary downward enrichment had taken place, the gold would be largely or even entirely abstracted from the outcrops. Such outcrops, therefore, could contribute no gold for the formation of placers.

Changes in climatic conditions may affect the rate of enrichment; and, at some time in the past, the rate of erosion may have been more rapid than enrichment. The leached portions of the veins would then be stripped and the enriched zones exposed to erosion. Under such changed conditions, gold might readily be contributed to form placers. The gold derived from the enriched zone might be coarser in grain, although part of the primary ore also contained some coarse gold.

Placer gold has been found at various places along Silver Creek, and at different times, efforts have been made to work these gravels, but up to the present, these efforts have been unsuccessful. No information is available as to the extent of the gold-bearing gravels and the value per cubic yard.

A little placer gold was washed from the small side streams tributary to Silver Creek, which headed in the area of Times porphyry near Mt. Hardy. A sample of this placer gold was shown the writer by Mrs. Le Clair of Oatman. This small vial contained gold of two different colors; one was pale yellow and the other much darker yellow in color. It is not certain that all this gold was panned from the same stream. This gold varied in the size of grain from small, flat flakes to hackly particles up to the size of a grain of wheat.

The small stream below the Pioneer Mine was panned at different points along its course and some flake gold was obtained. Nearly all of this gold was in fine particles and occurred within three feet of bedrock. Only a small amount of gold was obtained, however, and the ground was abandoned. Some placer gold is said to have been found a short distance below the Moss vein, but only meager information is available. Coarse gold occurred in the one important ore shoot on this vein and it is possible that the gold in the placer was also coarse.

The placers that occur to the northwest of the Katherine District and in the high benches bordering the Colorado River were not derived from the veins in the districts covered by this report. They are not properly a part of these districts and will not be considered further in this report.

As a whole, the placers of these districts are unimportant; they have contributed very little gold in the past and are not likely to yield much in the future. Undoubtedly, the total value of gold in the gravels of these streams would amount to many thousands of dollars, but test pits show the value per yard to be low. In this arid region, a sufficient quantity of water is not available for sluicing, and dry-washing machines are not successful on finely divided gold.

ORIGIN OF THE ORES

The ores of the Oatman and Katherine districts belong to the general group of deposits sometimes referred to as the "bonanza type." In such types, gold is often concentrated to form exceptionally high-grade ores. The gold may occur free or combined with other constituents, such as tellurium. Deposits of this kind are classed as epithermal by Lindgren.[33]

Such deposits have been formed relatively close to the surface, at depths measured in hundreds rather than thousands of feet. They appear to have formed at relatively low temperatures, that is, not over 175°C. In many cases they are closely associated with Tertiary volcanism, and the ores may occur in the lavas or in the rocks upon which the lavas rest.

In the Oatman and Katherine districts, the ores are believed to have been deposited by hot, ascending solutions which originated at considerable depth below the surface. The exact source of the solutions, however, cannot be determined. They were, however, derived from a cooling magma. The more volatile constituents, including water vapor, were concentrated by differentiation of the magma. Slow cooling and contraction would force these volatile constituents upward through cracks in the earth's crust. Such heated vapor on rising would reach a cooler environment; and would condense with a decrease in temperature, and, under the pressure existing at that depth, form aqueous solutions.

The solutions would issue from the surface as springs, and the temperature of the flowing water would depend on the quantity of heat lost in transit. Hot springs are rather common and the temperature of the water is quite variable. Mineral substances are often deposited around the orifices, and careful analyses of these deposits show traces of various metals, including gold and silver.

The veins in the Oatman and Katherine districts consist

33 Lindgren, W., Mineral Deposits: 3rd ed. 1928.

largely of quartz and calcite together with smaller amounts of adularia and fluorite. These substances may have been concentrated with the vapors in the magma basin and, therefore, were once an integral part of the original magma. If so, they were transported by the solutions and later deposited in the fissures to form veins. In addition to water vapor, the gaseous emanations from the cooling magma would contain much carbon dioxide and smaller amounts of fluorine, boron, and perhaps, other constituents. Solutions charged with such substances would be powerful mineralizers, and would be likely to react with the walls of the fissure and produce various mineralogical changes. Among them, would be the formation of hydrous silicates such as chlorite and sericite. The solvent action of such solutions in some cases might be quite strong, and they are known to be capable of dissolving silica, iron, lime, and soda from the wall rock of the fissures which they traverse. No analyses of the altered wall rock of the Oatman veins are available, and the quantitive chemical changes that have occurred are not definitely known.

The rising, hot solutions, therefore, could have derived their mineral matter from the wall rock in depth, and, on ascending to a region of lower temperature and lower pressure, could have deposited this mineral matter as veins in the fissures. If this hypothesis is correct, the magma need only furnish the water and carbon dioxide, and perhaps also the fluorine. The remaining constituents, including the precious metals, could have been abstracted from the wall of the channel traversed by the rising thermal water. Even a part of the water may have been furnished by the underground circulation.

According to these two views, the gangue minerals, as well as the gold, could have been derived from some magma in depth as a result of slow cooling and differentiation, or, these constituents could have been abstracted by the hot solutions from the rocks traversed on rising to the surface.

It is certain that the gold was not abstracted from the lavas in which the ore bodies occur in the Oatman District, for the veins extend into the rock beneath the lavas. At such depths, the later stages of quartz deposition do not occur at Oatman, but, at the Katherine Mine, these ores occur in the pre-Cambrian granite. If they were deposited by ascending waters, the gold must have been derived from some source beneath the lavas.

In a preceding section of this report, it was shown that the time of injection of the Times porphyry corresponded closely with the outpouring of the rhyolitic flows. Attention was also called to the absence of veins in the basalt, although these basic flows are traversed by faults. The period of ore deposition consequently, followed the rhyolite flows and was earlier than the basalts. Vein formation, therefore, probably took place in the latter half of Tertiary time.

The depth below the original surface at which ores of this type were formed has been determined indirectly with some degree of certainty in several districts. At Cripple Creek, Lindgren and Ransome [34] have shown, on reconstructing the cone of the old crater, that the deposits were formed within 1,500 feet of the original surface. At Goldfield, Ransome[35] found that the principal ore bodies were formed at comparatively shallow depth, perhaps less than 1,000 feet below the original surface.

In the Oatman District, there is some evidence suggesting that commercial ore was formed relatively close to the surface, but the evidence is far from conclusive. Veins are rarely found in the rhyolite in this district, largely because of the limited distribution of the rhyolite in the mineralized areas. The Gold Road vein can, however, be traced from the latite to where it passes into the overlying tuffs and flows of rhyolite. The general trend of this vein is southeast, and, towards this end, the vein becomes narrow, averaging less than thirty inches in width. On following this vein in a southeasterly direction up Gold Road Gulch, one passes from lower to higher levels, both geographically and geologically. The last prospect pit is still in the latite, and there the quartz is of the greenish yellow variety and well banded. An assay of a sample of this quartz gave an assay of $8 per ton in gold and silver. This pit is less than 200 feet vertically below the base of the rhyolitic tuff. Farther along the vein, the quartz is still of a yellowish color and shows both the banded and platy texture. Immediately below the base of the tuff, the quartz is banded and grayish white in color and contains numerous small and irregular cavities lined with quartz crystals. A sample taken here assayed only a trace in gold and silver. Where the vein enters the tuff, it splits into a number of small stringers, and consists of quartz and chalcedony. Only a trace of the precious metals was obtained on assay. In the rhyolite flows over the tuffs, the stringers are made up entirely of chalcedony and calcite. Above the rhyolite are tuffs and flows of basalt with no evidence of the vein.

The sample from which an assay of $8 per ton was obtained

[34] Lindgren, W. and Ransome, F. L., Geology and gold deposits of the Cripple Creek District, Colorado: U. S. Geol. Survey, Prof. Paper 54, p. 226, 1906.

[35] Ransome. F. L., The geology and ore deposits at Goldfield, Nevada: U. S. Geol. Survey Prof. Paper 66, p. 174, 1909.

is not over 700 feet vertically below the base of the basalt. At this point, the flows of ryolite may have been largely removed by erosion, for only a few miles to the north they have an estimated thickness of nearly 1,000 feet. Even here, however, they may have been eroded to a certain extent. It is possible, therefore, that ore may have been deposited in the Oatman District within 1,500 feet of the original surface.

A sequence in the deposition of the ores, such as has been described in a preceding section of this report, has been noted also in other districts. In the Tonopah District, Spurr[36] describes a definite sequence in the formation of the ores, but Locke[37] concluded that, although several periods of mineralization did exist, the assignment of a vein to a particular period was impossible. Bastin and Laney,[38] as a result of microscopic study of the ores, concluded that "the primary or hypogene mineralization was not a simple, brief event, but was a process of considerable duration accomplished by solutions whose composition was not at all times the same." Ransome[39] found three main stages in the deposition of the ores at Goldfield, and, as at Oatman, the richest ore was deposited last. Here, also, fracturing was followed by renewed deposition of the vein filling.

In the Oatman and Katherine districts, the first of the mineralizing solutions deposited pyrite and produced an intense alteration in the wall rock of the fissure. An assay of this pyrite shows it to contain but a trace of the precious metals. The deposition of pyrite was followed by the introduction of the first stage quartz and then calcite. Probably the composition of the solutions changed from time to time, for we find the earlier stages of calcite partly replaced by quartz. What brought about the changing composition of the solutions is unknown. It appears to be a rather common phenomenon in ores of this kind.[40]

No information is available to indicate whether the solutions that deposited the ores were acid or alkaline. Primary sulphates

[36] Spurr, J. E., Geology of the Tonopah mining district, Nevada: U. S. Geol. Survey Prof. Paper 42, pp. 71-72, 1905.

[37] Locke, Augustus, The geology of the Tonopah mining district: Trans. Am. Inst. Mining Eng., vol. 43, p. 164, 1913.

[38] Bastin, E. S., and Laney, F. B., The genesis of the ores at Tonopah, Nevada: U. S. Geol. Survey Prof. Paper 104. p. 12, 1918.

[39] Ransome, F. L., The geology and ore deposits of Goldfield, Nevada: U. S. Geol. Survey Prof. Paper 66, pp. 195-196, 1909.

[40] Lindgren, W., Mineral deposits, 3rd ed., pp. 523-524, 1928.

were absent from these solutions, although they probably contained an abundance of carbon dioxide. It is conceivable that calcite might be deposited from slightly acid solutions due to a greater concentration of carbonic acid gas over the concentration of lime. As there is no chance for escape of the carbon dioxide, and if the law of mass action applied, one would expect the equilibrium to be shifted in a direction which would precipitate $CaCO_3$.

Within recent years, more evidence has become available suggesting that the particles were transported as colloids by the solutions. The delicate banding in ores such as are found in these districts is often interpreted as indicative of deposition in the colloidal state. If so, there has been a dehydration and crystallization of the gel after its introduction into the fissure. Open spaces must have existed, for otherwise the growth of the thin plates of calcite would have been interrupted.

COMPARISON WITH DISTRICTS HAVING SIMILAR TYPES OF ORE

Epithermal deposits containing gold and silver as the principal metals are widespread in their distribution throughout the world. They occur almost invariably in regions where Tertiary volcanoes have been active; but similar types of deposits are are known from areas characterized by pre-Tertiary volcanism. It is possible that ores of this kind may be in process of formation today at the Yellowstone National Park and at the Katmai volcanic province in Alaska.

The gold and silver deposits of epithermal origin (formed near the surface) often bear resemblances to each other, but may diverge widely in mineral composition. A brief description of some of the better known deposits of the western part of the United States is given below for comparison with the ores of the Oatman and Katherine districts.

Jarbridge District, Nevada: The Jarbridge District is situated in northern Nevada, within fifteen miles of the Idaho state line. The gold veins of this district were described by Schrader[41] in 1912. Here Tertiary rhyolite flows rest upon older sedimentary and granitic rocks. The general trend of these gold-bearing quartz veins is north-south, and they occur chiefly in the older rhyolite flows. They range in width from one to twenty feet, and in length from 1,000 feet to several miles.

The veins are composed essentially of quartz and adularia, and the quartz often has a laminated structure, showing a pseudomorphic replacement of platy calcite. Some of the veins contain as much as 60 percent adularia. Associated with the quartz and adularia, is more or less fluorite, and both pyrite and marcasite are listed as occurring in this district. At the surface the veins are stained with the oxides of iron and manganese. Plate VIII of Schrader's report on this district illustrates two specimens of ore which bear a remarkable resemblance to the Oatman ores. The color of the ore, however, is "milk-white" rather than the yellow color so common in the Oatman District.

Most of the gold is finely divided, and the particles range in size from that of a pin head to minute specks. Some of the gold is quite coarse along fractures in the specimen. The specks of gold are often associated with argentite and hematite. The range in the value of the ore was from a few cents to $1,000 per ton. The gold occurs both in quartz and adularia.

De Lamar District, Idaho: The country rock in which the veins occur in the De Lamar District is rhyolite, and a description of the district was published by Lindgren[42] in 1898-99. The general trend of the veins is to the northwest, and the dip is usually to the southwest, but sometimes they are vertical. The veins may consist of stringer lodes or narrow fissure fillings. Angular inclusions of the country rock are common, and such fragments, as well as the wall rock, may be kaolinized.

The gold-silver veins, as represented by the De Lamar vein, carry extremely fine gold. Associated with this gold is a little pyrite, marcasite, and silver sulphides. Quartz is the chief gangue mineral and has a platy structure, suggesting that it replace biotite or calcite. Adularia is abundant in the ores, and sometimes it is well crystallized. Pyrite and marcasite occur in the district, but the former is practically confined to the wall rock adjoining the veins. In this respect, the occurrence of pyrite is similar to that in the Oatman District. Lindgren states that the ratio of gold to silver by weight, based on production records over a period of years, is 1 to 20. A small amount of gold occurs in the pyrite and in the silver sulphide.

The ore shoots at the De Lamar Mine were large, rich, and

[41] Schrader, F. C., A reconnaisance of the Jarbridge, Contact, and Elk Mountains mining districts, Elko County, Nevada: U. S. Geol. Curvey, Bull. 497, 1912.

[42] Lindgren, W., The gold and silver veins of Silver City, De Lamar and other mining districts in Idaho: U. S. Geol. Survey Twentieth Annual Rept. part 3, 1898-99.

continuous to the 10th level. They were about 200 feet long and were ordinarily one to six feet thick, although ore bodies thirty feet thick have been found. Below the 10th level, the average grade of the vein was less than $10 per ton. All the quartz contained some gold and silver, but some of it ran as low as $1.20 per ton.

Gold Springs District, Utah: The Gold Springs District occurs in the southeast corner of Utah and has been described by B. S. Butler.[43] The prevailing rocks are volcanic in origin and comprise such types as latite, rhyolite, and rhyolite tuff. These flows are essentially horizontal and have been disturbed but little by folding and faulting, although fissuring is extensive.

The ores occur in veins with a general north-south trend and with an easterly dip and have been deposited in open fissures. Banded and crustified structures are common, and lamellar structure has been noted. Quartz is the most abundant mineral and is usually fine grained; it is sometimes chalcedonic in texture. Calcite, perhaps containing some iron and manganese, is also a common constituent of the veins. Next in abundance after the calcite is adularia, the vein-forming feldspar. Locally, this mineral forms 50 percent of the vein filling. Fluorite occurs in small amounts, and is variable in its occurrence. A little pyrite is usually associated with the wall rock or with included fragments of rock in the veins. The mineralogy of the veins is remarkably similar to that of the Oatman District. Even the yellow quartz so common at Oatman occurs there.

The gold, as observed in a thin section with the microscope, is rather pale, suggesting the presence of considerable silver. This gold is associated with a dark-gray, metallic mineral that may be a telluride of gold and silver. Most of the gold occurs in the yellow quartz, while the finely crystalline white quartz contains but little of the precious metals. The coarsely crystalline calcite is almost barren. Most of the bullion shows silver to predominate over gold by weight.

The ore occurs in distinct shoots in the vein. Several shoots decrease in size and metal content with increase of depth, but this may not be general. A common characteristic of the veins is to break up into a series of stringers in a zone of altered rock.

Tonopah District, Nevada: The rich silver ores, containing more or less gold, were discovered in 1900, and the total value of the precious and base metals produced is now well over $100,-

[43] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 563-568, 1920.

000,000. The geology and ores have been described by several writers.[44]

The prevailing rocks are practically all of igneous origin and are essentially flows with associated tuffs. These flows comprise such diverse rock types as rhyolite, trachyte, dacite, andesite, and basalt. Some intrusive dacite and rhyolite are present as volcanic rocks and sheets. The lavas are traversed by a number of faults which divided the area into a series of irregular blocks. The general trend of the veins is to the northeast, and they have been offset by a series of closely spaced fractures which trend more nearly north-south. Usually the offset along these fractures is small. More recent work on the district has shown that the ore shoots are related to a flat fault.[45]

The veins are usually quite narrow and vary considerably in length; many of them are between 500 and 1,000 feet long and are about equally persistent in depth. The wall rock in most cases is intensely altered adjacent to the veins. Spurr believes that the ores were formed, in the main, as replacement deposits along closely spaced zones of fracturing rather than a simple filling of fissures.

The content of the veins is essentially quartz with smaller amounts of other minerals, among which adularia and sulphides are the most important. Locally, the adularia is very abundant. A carbonate, probably calcite, occurs as microscopic particles in the ores. The sulphides most commonly found are complex salts of silver, chalcopyrite, pyrite, galena, and blende. The texture most often observed is a colliform banding.

As a result of microscopic study, Bastin and Laney divide the hypogene mineralization into two stages known as alpha hypogene and beta hypogene. The earlier minerals formed are of the alpha hypogene stage and are essentially base metal sulphides with complex silver minerals. The minerals of the second stage replace the first and consist of silver sulphide with a little chalcopyrite. Associated in both stages is some electrum, an alloy of gold and silver. The ratio of gold to silver in these ores is 1 to 98 by weight.

[44] Spurr, J. E. Geology of the Tonopah mining district, Nevada: U. S. Geol. Survey Prof. Paper 42, 1905.
Burgess. J. A.. The geology of the producing part of the Tonopah mining district: Econ. Geology, vol. 4, pp. 681-712, 1909.
Locke. Augustus, The geology of the Tonopah mining district: Trans. Am. Inst. Mining Eng., vol. 43, pp. 157-166. 1912.

[45] Nolan, T. B., The underground geology of the western part of the Tonopah mining district, Nevada: Bull. 4, vol. 24, Univ. of Nevada Publications, 1930.

The points of similarity of the Tonopah ores to those of Oatman are the occurrence in veins or vein-like bodies in volcanic rocks; the association of quartz and adularia as gangue; and the banded textures. The two occurrences are dissimilar in other respects. The ores at Tonopah are essentially ores of silver while those at Oatman and Katherine are valuable principally for their gold content. Replacement was important at Tonopah and does not appear to have been important at Oatman.

Manhattan District, Nevada: In the Manhattan District, Tertiary volcanic rocks rest upon Paleozoic formations and on Mesozoic granitic intrusions. The district has been described by Ferguson.[46] The distribution of the ore bodies in different kinds of rock has resulted in various types of deposits.

The veins that occur in the volcanic rocks occupy joints in the rocks or minor faults. Quartz with some calcite, and locally a little fluorite, are the gangue minerals. Sometimes the quartz shows a tabular structure and is a pseudomorphic replacement of calcite. These quartz veins, however, are not important and the principal yield of gold has been from the oxidized portions near the surface.

Veins also occur in the older rocks, and consist principally of comb quartz and platy calcite, but in places adularia is plentiful. The gold is of a pale yellow color and is finely divided. It is found embedded in both quartz and adularia. Near the surface, much of the ore is manganiferous, and the gold is believed to be largely supergene in origin.

The principal deposits at Manhattan occur in the Paleozoic sediments; principally the White Caps limestone. The ore bodies in this limestone are of the replacement type and the mineralogy of the ores is quite complex. The gangue minerals at the White Caps Mine are chiefly calcite and quartz, less commonly dolomite and fluorite. The principal sulphides are pyrite, stibnite, realgar, and orpiment. Pyrite occurs throughout the deposit, but is less abundant than the other sulphides. Both the realgar and the orpiment are auriferous, but the stibnite is practically barren, and the calcite is everywhere barren. Gold is more abundant than silver in the ores.

The ore deposits of Manhattan and of the Oatman and Katherine districts show few similarities. They are all, however, of the bonanza type, and the principal metals are gold and silver. Some of the ore at Manhattan was of rather high grade.

[46] Ferguson, H. G., Geology and ore deposits of the Manhattan District, Nevada: U. S. Geol. Survey Bull. 723, 1924.

Goldfield District, Nevada: The Goldfield District is located about 28 miles south of Tonopah. Ransome[47] published a complete account of the geology and ore occurrences in 1909. At Goldfield the country rocks are a series of volcanic flows, associated tuffs, and some lake bed deposits. The flows comprise such rock types as rhyolite, latite, dacite, andesite, and basalt. These volcanic rocks were arched into a domical uplift through which erosion has cut and exposed the underlying formations upon which the lavas rest.

A few major faults traverse these rocks, and there are a great number of minor fractures. The ore bodies are closely related to these minor fractures. Ransome prefers to use the noncommital term "ledges" rather than veins because of the lack of persistancy along the strike and in depth. As shown in Fig. 12 of his report, the ledges may be divided into two groups; those with a north-south trend, and those with a northwest-southeast trend. The strike of others not included in these two major groupings, may be northeast or east. As a rule, the ledges are quite irregular in shape, and there have been local concentrations of the valuable metals within them. The ore shoots are rather limited in size and quite irregular in outline. The ledges represent areas of replacement and silicification of highly altered country rock.

The mineralogy of the ores is more complex than in any of the other districts reviewed in this report. The gangue is chiefly cryptocrystalline quartz. Embedded in this fine-grained, flinty quartz are sulphides of the base metals, such as galena, sphalerite, chalcopyrite, and pyrite, and complex sulpho-salts of silver, such as proustite and polybasite. Famatinite, enargite, and goldfieldite have been found in this district.

Over 95 percent of the gold in the district occurs free. The particles of gold are small, but are usually visible except in the lower grades of ore. Sometimes the particles of gold are clustered together in the quartz and are so abundant as to impart a yellowish color to the ore. The gold is remarkably pure; the average of 34 assays of rich ore gave 330 ounces gold and 46.5 ounces in silver. The gold is not uniformly distributed throughout the ores, but appears to be concentrated around the grains of sulphides.

Ransome recognizes three types of alteration; a silicification associated with the formation of the ledges, an intense altera-

[47] Ransome, F. L., The geology and ore deposits of Goldfield, Nevada: U. S. Geol. Survey, Prof. Paper 66, 1909.

tion of some of the flows with the development of alunite, and a propylitic alteration. The development of alunite appears to be closely associated with the deposition of the rich ores. As a result of this alteration, the rocks affected have been changed to light-colored masses of quartz, kaolin, alunite, and pyrite. This type of alteration is not confined to the immediate vicinity of ore bodies, but extends for some distance away from the limits of ore. The propylitic type does not appear to be related to the deposition of ore.

Comstock Lode, Nevada: These remarkable concentrations of silver ores are in the western part of Nevada, near the California line. These deposits have been described by Becker and by others.[48] In 1923 a microscopic study of the ores was published by Bastin.[50] The ores on the Comstock lode were discovered in 1859, and, since then, the value of the production of gold and silver exceeds $400,000,000.

The lode is a fault fissure which can be traced for over two miles, with the veins that contain the ore bodies occurring in the hanging wall. At the surface are flows of andesite and they rest upon intrusive rocks variously classified as diorite, diabase, and augite andesite.

The ore bodies occurred along nearly vertical fissures, and consisted largely of crushed quartz in which the sulphides, including the rich silver salts, were deposited. Although mining has been carried on to a depth of 3,000 feet below the outcrops, the rich bonanza ores were not found at depths of over 2,000 feet. The wall rock of the ores shows intense alteration with an abundant development of sericite where the ore solutions have traversed the fissures.

Quartz is the principal gangue mineral, although some calcite is also present. Banding is pronounced in some of the ores, due to the deposition of the sulphides in layers. The principal sulphides are pyrite, galena, chalcopyrite, and zinc blende. Replacing the quartz and sulphides, are gold, argentite, and polybasite. The gold is pale in color and contains considerable silver. The quartz is rather fine grained in texture, and the lamellar variety so common at Oatman does not occur in the

[48] Becker, G. F., Geology of the Comstock lode and Washoe district, Nevada: U. S. Geol. Survey Monograph 3. 1882.
Reid, John A., The structure and genesis of the Comstock lode: Univ. of California, Dept. of Geology, Bull. 4, pp. 177-199, 1905.

[50] Bastin, E. S. Bonanza ores of the Comstock lode, Virginia City, Nevada: U. S. Geol. Survey Bull. 735, pp. 41-63, 1923.

ores of the Comstock lode. Bastin recognizes two stages of quartz deposition, some of which probably replaces the country rock. The various sulphides are intergrown in a fashion suggesting contemporaneous deposition. Enrichment, apparently, did not extend to depths greater than 500 feet below the surface.

MINES OF THE OATMAN DISTRICT

The brief description of the various mines in this district is based partly on original observations and partly on the published accounts in the bulletins issued by Ransome and Schrader. Much information was obtained from Schrader's report, particularly on the ores mined at the time of his study. Ransome examined the district when some of the large ore bodies were mined, such as the United Eastern main ore body and the Big Jim-Aztec ore shoot.

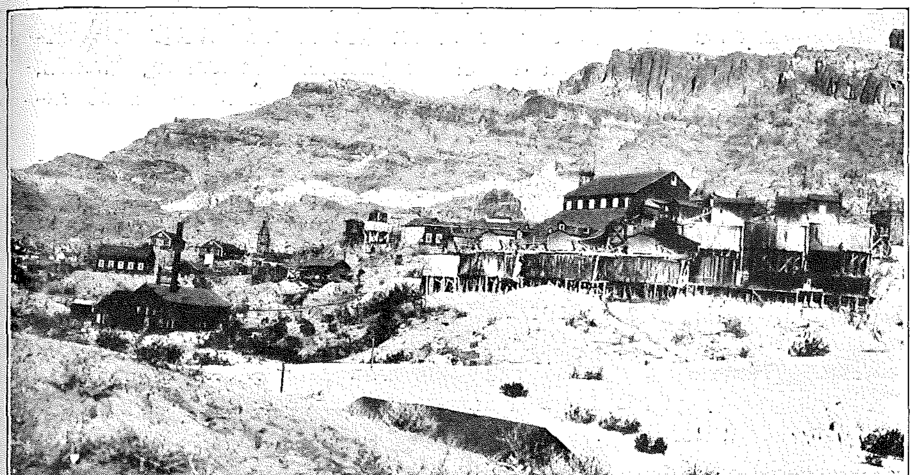


Fig. 22.—A general view of the Tom Reed plant at Oatman.

TOM REED MINE

The first locations on the Tom Reed vein were made about 1900 by a group of individuals, and their holdings were purchased in 1904 by the Blue Ridge Gold Mines Company. The original discovery appears to have been made on the Ben Harrison claim. In 1906 the holdings were taken over by the present company, the Tom Reed Gold Mines Company.[51]

[51] Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs Mohave County, Arizona: U. S. Geol. Survey Bull. 397, p. 192, 1909.

This company's claims extend for a length of over three miles along the Tom Reed fracture; at the northwest end is, what was originally, the Pasadena Mine, and, at the southeast end is the Black Eagle Mine.

The vein takes a sinuous course and has an average strike of about N.50° W. Throughout its entire length, with the exception of a small section on the Black Eagle claim, both walls of the vein are Oatman andesite. Along most of its course, the croppings are inconspicuous and the vein is difficult to trace; numerous prospect pits are, however, located along what appears to be the main vein.

The Ben Harrison was the first important ore shoot discovered on this vein. According to Schrader,[52] this ore shoot had a width of sixteen to twenty feet in the Ben Harrison shaft. The first thirty feet in depth averaged $25 per ton, and below that point, $12 per ton. The outline of the ore shoot, as shown in elevation in Plate IV, is rather irregular. It takes the form of two separate tongues connected on the lower levels. No information is available as to the maximum and average width, nor is the grade of the ore mined known. The ore shoot extended to a depth of about 800 feet below the outcrop.

Approximately 1,000 feet to the northwest of the Ben Harrison shaft is the prominent outcrop of the Tip Top ore body. About 1901, the Gold Road Company sank a shaft on this outcrop to a depth of 100 feet, but apparently the results obtained were not sufficiently promising to justify a continuation of the shaft to greater depth. Within recent years, lessees have taken out considerable ore within 100 feet of the surface. The Tip Top extended to below the 1,400-foot level where it ended in a rather sharp point. According to Victor Light, it is possible that this lower portion is a segment of the ore shoot displaced by normal faulting.

To the northwest of the Tip Top ore body, the vein is not of commercial grade. This section of the vein was explored from the Olla Oatman shaft on the 300-foot and 500-foot levels. Some good assays were obtained, but no body of ore was found. The vein filling consists of an abundance of calcite with some quartz, and, where examined, appears to belong to one of the earlier stages of deposition.

Prior to Schrader's visit to the district, work on the Pasadena claim, at the northwest end of the Tom Reed fracture, disclosed a good grade of ore to a depth of 55 feet below the surface. This group of claims was later taken over by the Tom Reed Company, and additional work was done in depth, but the grade of the vein filling was too low to be worked at a profit. It is possible that the better values found nearer the surface may have been due to supergene enrichment.

[52] Op. cit. p. 193.

To the southeast of the Ben Harrison shaft, there is a section of the Tom Reed vein that is barren. A part of this section is devoid of vein filling and only a heavy gouge, indicating the position of the fault, exists here. The ground was explored by a long drift on the 500-foot level from the Ben Harrison shaft and also by a drift and crosscut from the Aztec shaft.

That portion of the Big Jim-Aztec ore shoot that occurred on the Aztec Center claim had a length of 900 feet. The width of the ore shoot varied from place to place and averaged between ten and twenty feet; it was widest at the northwest end. The upper part of the ore shoot is cut off by the Mallory fault with a displacement along the dip of the fault of about 500 feet. The horizontal component of this faulting is not known. The upper limit of the ore shoot, where it is cut by the Mallory fault, is near the 300-foot level and extended below the 600-foot level. Much of the ore consisted of the fourth and fifth stages of quartz deposition, and the grade of the ore mined is said to have been better than $12 per ton. A part of this same ore shoot which occurred on the Grey Eagle-Bald Eagle claims, which is generally considered as the down-faulted segment of the Big Jim ore body, averaged more than $20 per ton.

South of the Aztec shaft, is the Black Eagle ore body. During the past few years, this ore shoot has been developed under direction of Mr. Victor Light to the 1,100-foot level. On the 900-foot level, it has a length of over 500 feet with an average width of seven feet. Much of the ore is relatively high grade, and free gold is often visible in a specimen. The daily mill heads on this ore often run better than $60 per ton. Some of the ore is oxidized, and small flakes of gold in hematite are common. Such gold may be supergene in origin, but primary gold also occurs as visible particles embedded in quartz, and, as yet, there is no evidence of a material decrease in grade with depth. It is possible that the ore may extend an additional 300 feet below the 1,100-foot level.

The Telluride vein joins the Tom Reed in the general vicinity of the Red Lion shaft. The junction was barren, but, a short distance to the south, a part of the Telluride ore shoot occurred on Tom Reed ground. According to Victor Light, ore never occurred within less than 200 feet of the surface and played out at about the 500-foot level. The vein was only three feet wide, but the grade was exceptionally good. Only a small tonnage was mined from this vein.

The total number of tons mined from the various ore bodies by the Tom Reed Company from 1911 to 1928, inclusive, was 876,639, and, to date—May, 1931—this tonnage probably has been increased so that it now totals 1,000,000. The total value of the bullion produced from 1908 to 1928 inclusive was $11,740,158. Included in the amount is the gold from ore produced by other mines in the district and from lessees, but it will hardly amount to one percent of the total. At the time of writing this report, the Black Eagle ore body was producing ore with a gross value of $100,000 per month.

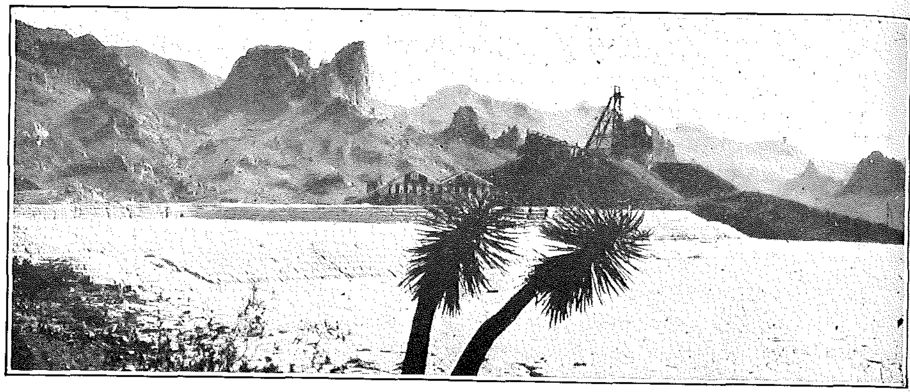


Fig. 23.—View across the tailing pond to the No. 2 shaft of the United Eastern Mine.

UNITED EASTERN MINE

The main ore shoot of the United Eastern occurred on the northeast branch of the Tom Reed fracture and was discovered in 1915. During the following year, a considerable tonnage of ore was blocked out, and, in February, 1917, the mine was producing bullion.

The junction of this branch with the Tom Reed was still accessible in 1921, and Ransome described it as follows:

"The main vein, consisting here chiefly of many irregular stringers of calcite accompanied by a strong gouge-filled fissure, plainly divides into two branches, each similar to the main vein and each accompanied by a gouge-filled fissure. Nothing was seen to indicate that one branch was older than the other. The angle of divergence is about 50°, and, as this angle is nearly bisected by the strike of the vein south of the point of branching, one branch is as much to be regarded as the direct continuation of the main vein as the other."[53]

The main ore shoot of the United Eastern occurred on the Tom Reed Extension claim, just south of the No. 2 shaft. According to Roy Moore,[54] this ore shoot had the following maximum dimensions: height, 750 ft.; length, 950 ft.; thickness, 48 ft. A vertical elevation of the ore body is shown in Plate IV. Ore extended from the 3rd level down to the 8th level, and only a small amount was extracted below the 8th level. Here, an abrupt change in grade occurred. The vein continues in depth, but the grade of the quartz and calcite is too low to permit mining at a profit. Above the 3rd level, what gold was originally present has been largely leached out. The outcrop, as was stated in a preceding section, contains gypsum.

This ore body produced over 500,000 tons with an average value of $21 per ton. In places, the ore consisted of massive quartz and calcite, but, elsewhere, it was made up of stringers separated by barren andesite. Quartz and adularia were abundant in the ore shoot, and such streaks often contained exceptionally good values. On the footwall of this ore body and extending from the 300-foot to the 500-foot level was a streak of ore heavily stained with iron oxides. This ore contained high gold values, and the gold may have been of supergene origin.

The other ore body mined by this company occurred on the Big Jim claim. The ore extended from a short distance below the 1st level down to the 6th level. Its height was 450 feet, its length was 850 feet; and its maximum thickness was 35 feet. This ore body produced somewhat over 220,000 tons of ore with a gross value of $19 per ton.

The upper part of the ore shoot was displaced by faulting and was mined on the Grey Eagle and Bald Eagle claims by the Tom Reed Company.

The total production of the United Eastern Gold Mining Company, from the year 1917 to 1925 inclusive, was $14,726,895. Before closing the mine, extensive diamond drilling was done underground chiefly on the 800-foot level, but also on the 1,100-foot level. All the ore mined came from the Tom Reed Extension claim and the Big Jim claim. In addition to the claims

[53] Ransome, F. L., Geology of the Oatman Gold District, Arizona: U. S. Geol. Survey Bull. 743, p. 44, 1923.

[54] Moore, Roy W., Mining method and records at the United Eastern Mine: Trans. Am. Inst. Mining and Met. Eng., vol. 76, pp. 56-90, 1928,

mentioned, the company owns three fractional claims and important water rights on Silver Creek.

GOLD ROAD MINE

The Gold Road vein is located in the eastern part of the Oatman District, and has a northwest trend. The dip of the vein is at steep angles to the northeast. This company owns four full claims along the length of the vein. Located in 1900, the ground changed hands several times before it was sold to a French syndicate. In 1911, the mine was purchased by the United States Smelting and Refining Company.

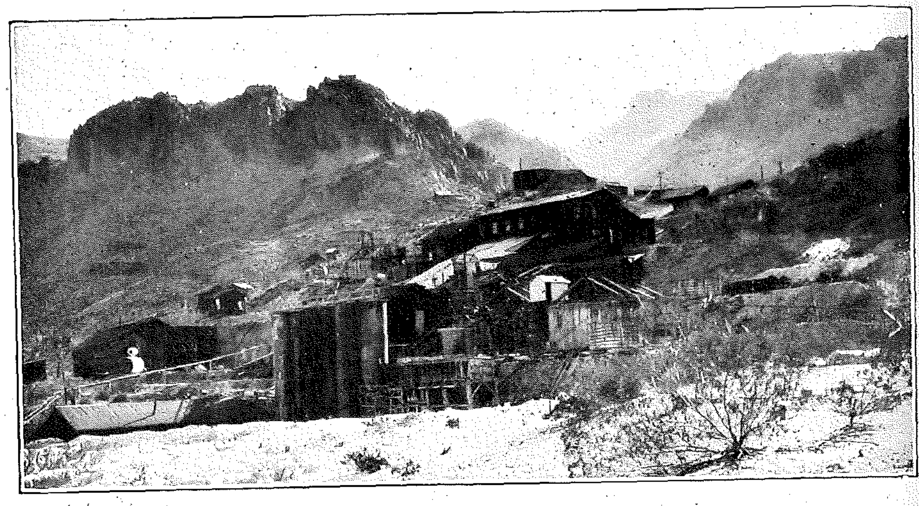


Fig. 24.—A view up Gold Road Gulch. Remains of the old mill in the foreground.

The deepest development along the vein is from the No. 3 shaft which extends to the 900-foot level. The Line Road tunnel followed the vein for over 3,000 feet to the southeast end of the Railroad claim, the limits of the property. No ore body was found in driving this tunnel, although ore was taken out at the surface above the tunnel. On the Railroad claim is the No. 5 shaft with a depth of slightly over 200 feet. Practically all the ore mined along this vein was taken out through the No. 1 and No. 3 shafts.

At the surface, the wall rock for almost the entire length of the vein latite. Not far below the surface, the Oatman andesite forms the footwall of the vein and the latite the hanging wall. The vein parallels a dike of rhyolite porphyry which is about 600 feet to the southwest. At the southeast end, the dike

turns towards the vein and probably joins it, but not at the surface. Vein quartz occurs along the dike, and some of this quartz has been mined as ore, but the grade of most of this material was rather low. The vertical displacement on the fault appears to be greater at the northwest end, and the average throughout its entire length is probably between 300 and 400 feet. At the extreme southeast end, the rhyolite tuff is not offset more than 250 feet.

The outcrop of the vein is quite prominent and is formed of well banded quartz as stringers in silicified latite. In reality, the vein is a stringer lode which in places attains a width of nearly 100 feet. The quartz filling was concentrated in two zones, which formed the north and the south veins, and the country rock between these two veins was barren. Stringers of quartz branched away from both the north and south veins into the barren portion of the lode, but the grade was too low to constitute ore. Such stringers rarely continued from one vein to the other, but played out at a relatively short distance beyond the point of divergence. Nearly all the ore mined came from the north vein.

Three important ore shoots occurred on the north vein; the largest was at the northwest end and was mined from the No. 1 shaft. This ore shoot had a length of 900 feet and extended from the surface down to the 700-foot level. The maximum width was 22 feet. About 600 feet to the southeast is the Sharp ore body. The ore shoot did not crop out at the surface, although the vein is marked by conspicuous croppings at this point. Ore extended from a short distance above the 300-foot level down to the 500-foot level, and what appears to be a continuation of the ore shoot was mined between the 700-foot and 800-foot levels. Apparently, most of the veins between the 500-foot level and the 700-foot level on this ore shoot was too low grade to be mined at a profit. Less than 200 feet to the south of the No. 3 shaft is a small ore shoot known as the Rice ore body. It occurred between the 300-foot level and the 500-foot level, and had a length of about 400 feet. Southeast of the No. 3 shaft, the bold outcrops of the Gold Road vein are more or less stained with iron oxides and some manganese dioxide. Small pockets of ore were mined along a length of 1,500 feet of the vein, but none of this ore extended to a depth of much over 100 feet below the surface. The tonnage mined from along the outcrop was small. Supergene enrichment may have played a prominent part in raising the grade of this portion of the vein and made the mining of these small ore bodies profitable. At this end, the southeastern, the vein narrows down to less than five feet.

Most of the vein filling in the outcrops is of the third stage of quartz deposition. This quartz is chalcedonic and is very fine grained. A striking feature is the well-developed wavy banding in several colors. As this type of quartz rarely carries over $5 per ton in the precious metals, it is not ore. In the ore shoots, the 4th and 5th stages of quartz were deposited. The texture of this ore is the same as in other parts of the district. Some of the richer ore contained an abundance of thin plates of adularia intergrown with granular quartz. The quartz was always of a deep yellow color. Free gold occurred in this adularia-quartz intergrowth as an aggregate of minute particles. As some of the quartz in the vein is the coarse-grained, glassy variety it represents the first stage of mineral deposition. Calcite does not appear to have been an important constituent of the ore shoots, and certainly forms but a minor part of the vein which can now be examined. Pyrite occurred in the altered wall rock at a number of places along the vein, but appears to have been barren.

The total value of the bullion from the Gold Road Mine from 1904 to 1915, inclusive, was $6,504,050. The earlier records of production, however, are incomplete, but it is hardly likely that the entire value of the gold and silver produced exceeds eight million dollars.

TELLURIDE MINE

The Telluride vein takes a rather sinuous course, but, in general, parallels the Tom Reed vein. It joins the Tom Reed vein near the Red Lion shaft, and, at its southern extremity, joins the Lucky Boy vein. It has a known length of about 3,000 feet, and the general strike is southeast-northwest. The country rock in both walls of the vein is Oatman andesite. Outcrops of the vein are rather inconspicuous and are difficult to trace over the surface.

Development work on this vein has been at relatively shallow depths. According to Victor Light, the ore extended from the 500-foot level to a short distance above the 300-foot level. A part of this ore shoot occurred on Tom Reed ground and was mined by that company. The vein varied in width from a few inches up to five feet, and for most of its length averaged only three feet in width.

An examination of the dump showed the vein filling to have consisted largely of quartz of the first and second periods of deposition, accompanied by calcite. Faulting reopened the vein and the high-grade quartz of the last stage of deposition filled the available openings. This high-grade quartz occurred as a narrow streak rarely more than six inches in width, but samples frequently assayed as high as $200 per ton in gold and silver. A surprising feature of this vein was the rather limited vertical extent of the ore shoot. The grade of the ore is said to have changed abruptly at about the 500-foot level.

No records of the production of gold and silver from this mine are available, but estimates furnished the writer indicate that the gross value of all the ore mined was approximately $200,000. Although this is a comparatively small production, it is interesting to note that this amount of bullion came from a relatively small tonnage of ore. The grade of the ore per ton was, therefore, higher than the average in most of the ore bodies of the district. Information obtained from the publications on the mineral resources of the United States by the Department of the Interior indicates that the Telluride Mine was producing bullion from 1922 to 1925.

PIONEER MINE

The Pioneer Mine, originally known as the German-American, is located about one and one-half miles to the southwest of Oatman. The property has been developed by three shafts the deepest of which is the Pioneer shaft with a depth of 420 feet. Drifts connect these three shafts on several levels.

The Pioneer vein strikes N.13°W. and dips to the east at 80°. This trend is across the strike of the broad zone of fissuring in the vicinity of the Gold Dust-Boundary Cone zone of faulting where the general trend is about N.55°W. The two vein systems intersect at 40°, but neither vein appears to have been offset by the other. The hanging wall of the Pioneer vein is the Oatman andesite, and the footwall, for 2,000 feet is the Alcyone trachyte. The maximum width of the vein is near the Pioneer shaft, and there it is eighteen feet. At that place, the vein consists of coarse-grained, gray calcite and quartz, and the gold-silver content is rather low except along iron-stained streaks. These iron-stained streaks represent zones of crushing in the vein filling produced by post-mineral faulting.

Several small ore bodies were mined towards the south end of the Pioneer vein; the largest occurred near the Treadwell shaft. This ore shoot had a length of about 400 feet and an average width of 3.5 feet. The lower workings are now inaccessible, but small bunches of ore left near the surface and ore left in the bins indicate that the ore shoot contained quartz of the 4th stage of deposition. The ore consists of quartz with some unreplaced calcite, but no adularia was noted in any of the specimens studied.

The color of the best grade of ore is pale greenish rather than yellow, and it assayed up to $35 per ton in gold and silver. The ore shoot stopped rather abruptly a short distance above the 400-foot level.

A small ore shoot was mined just north of the Thirty-fifth Parallel shaft. The length of this ore shoot was less than 200 feet, and the width was about three feet. The best ore occurred near the surface where the vein was heavily stained with iron oxides. Some of this surface ore is said to have been high grade

A third important ore shoot was developed from the Pioneer shaft at the north end of the property. Only narrow portions of the vein there assay better than $10 per ton. Very little ore was mined from this section of the vein except near the surface where some samples assayed over $100 per ton.

The mine was located in 1896, and, up to 1907, produced 2,700 tons of ore. Much of the ore mined in the early days was from near the surface and was of a good grade. No record of the bullion produced is available, however. The last production recorded was in 1925 and was mined by lessees.

GOLD DUST MINE

This mine is about one mile to the southwest of the Ben Harrison shaft. Originally, this mine was known as the Victor-Virgin and was located about 1900. The general trend of the vein is northwest, and, on the Virgin Lode claim, the vein branches. The southern branch, striking nearly east-west, intersects the Pioneer vein a few hundred feet south of the Pioneer shaft. The north branch continues northwest and appears to be continuous with the southern extremity of the Midnight vein. The country rock throughout the entire length of this vein is the Oatman andesite.

At some places, the vein consists of solid quartz and calcite with a width up to seven feet. To the northwest, the vein splits up into a series of small stringers which ramify through a zone of somewhat altered andesite over twenty feet wide. According to Ransome, [55] two ore shoots were mined, the largest having a length of 200 feet and extending from the surface to a depth of 160 feet. A small ore shoot, mined near the No. 2 shaft, extended only from the surface to the 100-foot level. This ore shoot occurs up the hill to the northwest of the main shaft and at a higher elevation. The vertical range of the ore shoots as mined is approximately 500 feet. Development work from the 500-foot

[55] Op. cit. p. 49.

level of the main shaft failed to find ore bodies in depth on this vein. The ore mined consisted of greenish quartz with unreplaced remnants of calcite. Adularia is present in the specimens collected only as a microscopic constituent.

Most of the production from this mine came from ore produced from 1923 to 1925, inclusive. Records of the amount or value of gold and silver produced are not available.

LELAND MINE

The Leland Mine is situated on the east slope of a prominent hill, about two miles to the west of Oatman. The Oatman andesite forms the top of the hill and the long slope to the east, but, on the west side of the hill, is the Alcyone trachyte. Some of the andesite flow contains an abundance of unusually large crystals of feldspar. The contact between the two types of rock is a short distance below the top of the hill and dips to the east at 15°. The strike of the vein for most of its length is N.65°W., but, at the west end, after crossing Leland Hill, it turns and takes a more westerly course. The southeast end of the fault continues to where it joins the Pioneer vein near the Treadwell shaft. The dip of the vein on Leland Hill is 70° to the southwest.

Some of the development work on this vein was done by tunnels, but a shaft was sunk to a depth of 700 feet and levels run. The lower levels are now under water, and some of the tunnels are badly caved.

According to Schrader,[56] who examined the mine when it was in operation, 4,500 tons of ore with an average grade of $15 per ton were milled. Some ore is reported to have assayed $50 to $60 per ton. Only the richer portions of the vein were mined. Specimens obtained from near the old ore bins consist of greenish quartz and calcite. No adularia is visible in a hand specimen, but may occur as a microscopic constituent.

The outcrop of the vein is ten feet wide in places and consists of a nearly solid mass of quartz and calcite. As it is more resistant to erosion than the wall rock, it stands out in relief. To the west the vein splits into a number of stringers spread over a width of forty feet. As these diverge, they also tend to play out. and the course of the vein is then more difficult to trace, particularly in the Alcyone trachyte. About 400 feet to the south of the Leland vein is the Mitchell vein. These two veins take a parallel course, but the Mitchell vein dips steeply to the north.

[56] Op. cit. pp. 183-186.

It is much narrower than the Leland vein, and its greatest width is seven feet. A little ore was mined on this vein from the upper levels.

Near the surface on both the Leland and Mitchell veins, small cavities, lined with quartz crystals and more or less filled with manganese dioxide containing wire gold, were found. Such gold was undoubtedly supergene in origin.

All the ore found at this mine occurred above the contact of the andesite and trachyte, and, from this relation, it was assumed that the trachyte was an unfavorable rock for the deposition of ore. The Alcyone trachyte, however, is traversed by veins, and a small body of ore was mined on the Midnight vein where one wall was trachyte.

From Schrader's figures of 4,500 tons with an average value of $15 per ton, the gross production in the early days was $67,500. Some ore was mined after Schrader examined the district, but no records of this production are available.

SUNNYSIDE MINE

The Sunnyside Mine is situated in the southeastern part of the district, near the center of Section 25. The fault on which this mine is located has a known length of about one mile. At the north end of it offset one hundred feet by an east-west fault, and beyond this fault, it is difficult to trace. At the south end, it joins the Mallory fault. The vein is well exposed at several places along the fault and appears to be continuous, but it is difficult to trace. The wall rock at the surface is andesite.

Much of the vein consists of coarse-grained quartz and calcite and is low grade. The vein is quite variable in width along the strike, and, at one place, it contains five feet of solid quartz and calcite. Small stringers occur in the adjacent wall rock.

The main shaft was sunk to a depth of somewhat over 500 feet. On the 500-foot level, the footwall of the vein, which at this point dips steeply to the northeast, is the Esperanza trachyte, while the hanging wall is Oatman andesite.

In the spring of 1928, a small ore shoot was found in a winze sunk from the 500-foot level. The ore shoot had a rather limited extent, both horizontally and vertically. The ore consisted of quartz and very little calcite, and specimens showed visible specks of coarse gold. To the east of this ore shoot, is a lode forty feet wide, which consists of quartz stringers in andesite. The ore is too low in grade to be mined. The small ore shoot was later mined by lessees.

GOLD ORE MINE

The Gold Ore shaft is about one mile to the northeast of the Gold Road Mine. The vein occurs in a fault fissure which strikes N.68°W. and dips 82° to the southwest. The country rock is all latite, and, along parts of the vein, is intensely altered. At the surface, the altered rock is kaolinized and stained yellow to brown by iron oxides. Although the altered rock is the same in appearance as the altered andesites, the presence of abundant flakes of bleached biotite suggests that the rock was originally latite.

The shaft is down to a depth of 800 feet and various levels were run at 100-foot intervals. Most of the ore mined occurred between the 300-foot level and the 600-foot level. Only a small amount was found above the 300-foot level, and little mining was done below the 600-foot level. According to Victor Light, the ore shoot was approximately 100 feet long and had a width of four to five feet.

Several stages of quartz deposition occurred in the vein. Specimens of glassy quartz, coarse grained and stained with copper, were found. There appeared to have been an abundance of the well-banded, chalcedonic quartz of the third generation, and such material was traversed by yellow stringers of quartz with adularia. Some of this yellow quartz contained visible clusters of free gold and undoubtedly was high grade. Pyrite was common in the walls of the vein, but near the surface it was oxidized.

This mine produced bullion at various times from 1918 to 1926, but no information is available on the total value of the output.

MOSS MINE

The Moss vein was located in 1863 or 1864, by John Moss. The mine is situated in some low hills, about seven miles to the northwest of Oatman and about two miles to the north of Silver Creek. One prominent hill to the northwest of the shaft rises 700 feet above the general level of the surrounding country. The Moss vein follows the crest of a ridge to the summit of the hill.

The country rock in which the vein occurs is a quartz monzonite-porphyry. To the west of the prominent hill described above, are flows of Alcyone trachyte with a westward dip. At the east and in the same general line of strike are some veins of porphyry with a north-south trend.

The vein, which strikes N.80°W., consists of a mineralized lode from twenty to over 100 feet wide. The widest portion is at the west end. Where the ore shoot was found, the vein is 22

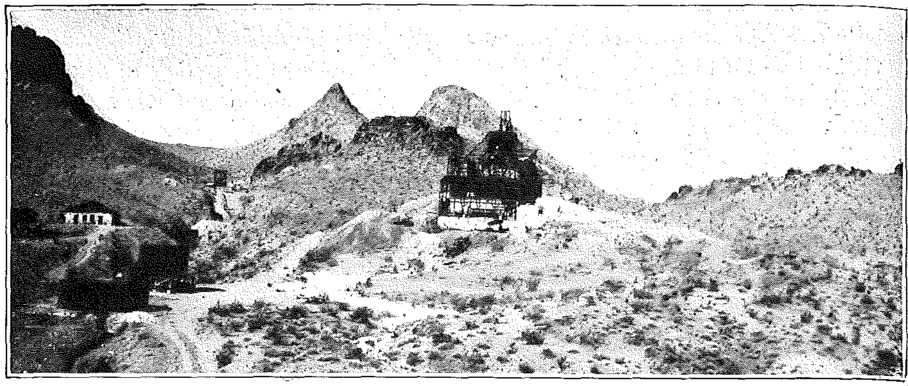


Fig. 25.—General view of the Moss Mine. The dark outcrop of the vein may be seen behind the mill.

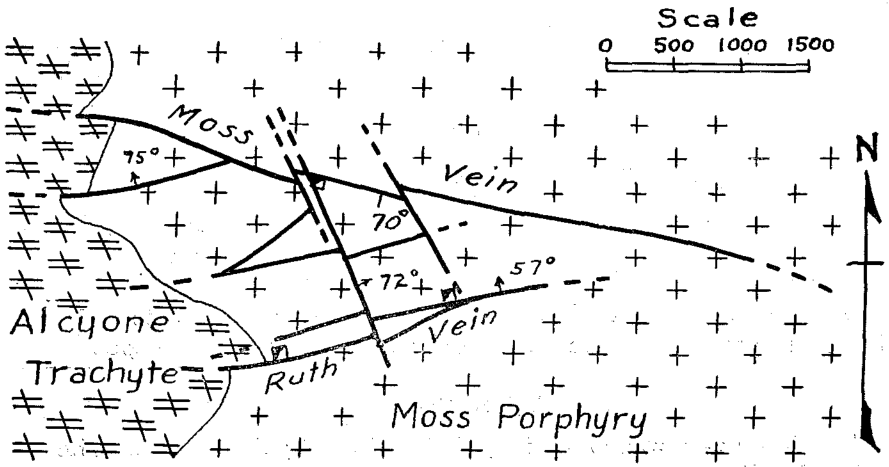


Fig. 26.—A map of the veins and faults at the Moss Mine.

feet wide and dips to the south at 70°. The vein is traceable to the east on the surface for somewhat over a mile. Farther to the east and in the same general line of strike are some veins of quartz which may occur in the same fracture. The vein is offset by several northwest faults and these relations are shown in Fig. 26.

The vein consists chiefly of fine-grained, white quartz and a small amount of calcite, but here and there are small stringers of pale green fluorite. At several places in the vein, these stringers led to vugs in the vein which were lined with fluorite and contained free gold with pulverent manganese oxide. A short distance to the east of the shaft, a little pyrite and marcasite were found in the quartz. One specimen, in which the sulphides were oxidized, contained small particles of free gold in the cavities.

The one important ore shoot found contained free gold in iron-stained quartz, at the surface. This was exceptionally rich ore, but extended to a depth of only 65 feet below the surface. According to Schrader,[57] two tons of ore netted $114,000. From a hole only ten feet in diameter, $240,000 is said to have been taken out. Several smaller bodies of ore were mined at various places along the vein, but none extended more than a few feet in depth.

The mine has been developed by a shaft, 230 feet deep, and a level run at 225 feet below the surface. One long tunnel was driven under the vein from the south, and several other short tunnels have been driven into the vein.

MINES OF THE KATHERINE DISTRICT

The Katherine District extends from the Pyramid Mine on the Colorado River eastward to Union Pass. The more important deposits are all located in the ten-mile strip from the Frisco Mine westward and are shown on Plate II. The elevations range from somewhat over 500 feet at the Colorado River to 3,200 feet at the Frisco Mine. It is a region of low hills and ridges of granite with occasional knobs of rhyolite. In the general vicinity of the Katherine Mine are extensive deposits of gravel and sand which slope gently towards the Colorado River.

The district has had a checkered history. The earliest locations were probably made on veins in knobs of granite along the Colorado River, such as at the Pyramid Mine. The dates of these early locations are unknown.

Only the Katherine Mine was operating at the time this study of the district was made, and the underground workings of other mines were generally inaccessible except in the surface levels. Much information concerning these mines was obtained from R. H. Dimmick, formerly the manager of the Katherine Mine, the individual who is best informed concerning the district.

KATHERINE MINE

The Katherine Mine is about two miles to the east of the Colorado River and is located on a small knob of granite which protrudes slightly above the general level of the surrounding re-

[57] Op. cit. p. 170.

gion. The exposure is hardly more than 150 feet across and is surrounded by gravel. The elevation of the collar of the shaft is 990 feet above sea level and about 450 above the level of the Colorado River. The top of the water table at this mine is 350 feet below the surface. Coarse-grained granite forms the walls of the vein. It is highly sheared and altered even at some distance away from the vein. Near the vein, the granite is kaolinized and iron stained, and, locally, it is silicified.

The Katherine vein is a stringer lode with a width of over sixty feet at the surface. In the lower levels, the vein narrows down considerably. The vein has been explored underground for a distance of 1,700 feet. A continuation of the vein occurs at the Katherine Extension Mine, approximately one-half mile to the northeast. Nothing is known of its extension in a southwesterly direction, for here the granite is covered by recent detritus. It has been thought by some individuals that the Katherine vein continues its southwesterly course and joins the Pyramid vein near the Colorado River. The two veins have approximately the same strike, and, if they were originally continuous, have been offset by cross faulting. The strike of the Katherine vein is N.62°E., and the dip is about vertical.

The vein and the ore shoots have been cut by a large number of north-south faults which have been interpreted by Dimmick as low angle thrusts from the southwest. The displacements of each of these faults is small; the maximum offsetting of an ore body in the plane of the vein is sixty feet. Later movements on the vein cut the thrust planes. The relation of these various faults to each other, and the levels on which they have been mapped, are shown in elevation as Fig. 27.

Vein filling at the Katherine Mine usually consisted of a series of closely spaced stringers in the granite. At some places, however, the vein filling was solid quartz and calcite up to ten or more feet wide. Much of the vein filling consisted of quartz, but here and there calcite was abundant. Various stages of quartz deposition are represented at this mine, but the first and second are the most abundant although of least importance from an economic standpoint as the grade of such quartz is low. An intergrowth of quartz and adularia also occurred here and formed some of the important ore shoots. It was very similar in appearance to that occurring at Oatman. Sometimes the adularia was rather coarse grained, and the associated quartz was of a deep greenish yellow color. Platy quartz, white in color, with a well-developed laminated structure, also occurred in the Katherine vein. Some of the smaller stringers frequently show-

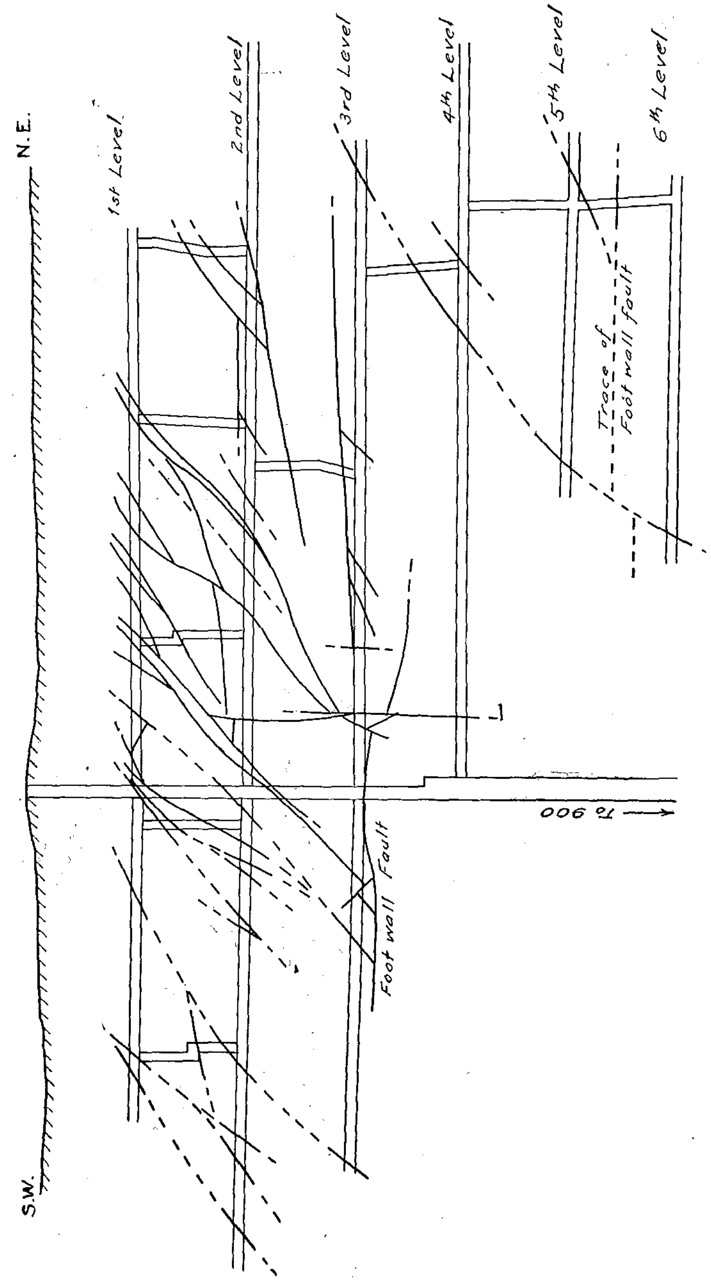


Fig. 27.—Vertical section through the Katherine Mine. Based on maps furnished by R. H. Dimmick.

ed a fine banding and were usually frozen to the somewhat silicified granite walls.

At the west end of the 200-foot level, some rich silver ore was mined, and, on the 900-foot level, a small stringer, from two to six inches wide, assayed 65 ounces in silver, and ten ounces in gold. Copper stain was abundant in this rich stringer, associated with chalcocite. It is possible that this high-grade quartz was locally enriched by supergene processes. Similarly enriched ore was found on the 300-foot level in reddish, silicified granite.

The mine has been developed by a vertical shaft to the 900-foot level. Levels have been run at 100-foot intervals. The 5th and 6th levels are not connected with the shaft, however, but were run from a winze sunk from the east end of the 4th level.

According to R. H. Dimmick, the gross production of the Katherine Mine has been about $2,000,000, and, from July, 1925, to 1930, when the mine was closed, the production was slightly over $1,000,000. Records show the bullion to contain 344.59 parts gold to 637.62 parts silver.

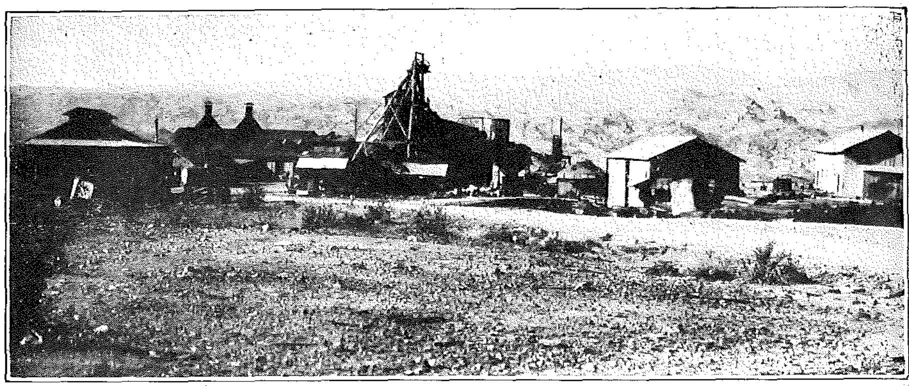


Fig. 28.—A general view of the plant of the Katherine Mine.

PYRAMID MINE

The Pyramid Mine is probably the oldest location in the Katherine District. It is situated near the Colorado River in some low hills of granite. The vein, which consists of a large number of small stringers in reddish granite, strikes N.65°E. and the dip is vertical. The vein has been prospected by a number of small pits and a shaft at the west end, which is said to have been sunk to a depth of seventy feet. Some rich ore is said to have been stoped from this shaft, but the workings are now caved. No record of production is available.

GOLDEN CYCLE MINE

About 2,000 feet to the northwest of the Pyramid Mine is the Golden Cycle. The vein there also occurs in the coarse-grained granite. The vein takes a more easterly course than the Pyramid vein, and appears to join this vein somewhat less than a mile to the east. The vein consists of a series of quartz stringers occupying a shear zone in the granite. The general dip of this zone is 82° to the north, and the width is from ten to eighteen feet.

At the west end of the property, a shaft was sunk to a depth of 115 feet, and some lateral work has been done at this level. Near the surface, samples assay from $1 to $3 per ton, but, underground some samples have assayed $14 per ton.

BLACK DYKE GROUP

The Black Dyke group of claims is three miles to the east of the Katherine Mine. This large vein is composed principally of calcite, cut by a great number of small stringers of quartz. The vein takes a curved course, trending northwest, and with a length of one-half mile. About midway between the ends it swells to a width of 150 feet. A general view of the outcrop is shown as Fig. 21. The dark color is confined to a thin film at the surface, usually termed "desert varnish." The vein appears to occur in a shattered rhyolite which may have been replaced to a certain extent by both the calcite and quartz.

This vein is said to have been thoroughly sampled and found to average $3 per ton, but the highest assay obtained by the writer was $2.40. A small inclined shaft has been put down at the west end, and numerous small tunnels have been run beneath the outcrop. According to Dimmick, small, iron-stained streaks have been found to assay as much as $50 per ton. Some diamond drilling is said to have been done on this vein, but the records of this work are not available.

SHEEPTRAIL-BOULEVARD MINE

The Sheeptrail Mine was one of the earlier locations in the Katherine District, and, according to Dimmick, was discovered in 1887. The mine was operated for a number of years and was finally closed down in 1902. The property was later unwatered and sampled by R. H. Dimmick. Originally, the Sheeptrail and Boulevard were separately located, but were later combined by one operating company. The mine is situated approximately five miles in an easterly direction from the Katherine Mine, in a group of low hills of granite and rhyolite.

The vein occurs near the contact of granite with a dike of rhyolite-porphyry which forms the hanging wall at the west end of the mine. Small stringers occur both in the granite and in the dike, but most of the ore mined appears to have come from the rhyolite. The vein strikes northwest, dips south, and takes a curved course, trending more nearly east-west towards the northwestern end. At the west end, it is cut by a northeast fault. A number of minor faults which trend northeast cut the vein, but, in each case, the offset is small.

Mineralization consists of a number of small stringers of quartz over a width of from three feet to seven feet. This quartz is not everywhere ore, and only certain portions of the vein stained with iron oxides were mined. Much of the quartz is fine grained, and some of it shows a platy structure. The specimen illustrated in Fig. 12 came from this mine, and represents the second stage of quartz deposition. The average width of the stopes was four feet. The best ore was found where pulverent manganese oxide occurred in the porous quartz, and such ore would carry $100 per ton or more in gold. The best ore was found at the water table or else a short distance below. This occurrence strongly suggests that secondary enrichment concentrated the gold. In the lower parts of the mine, the grade of the ore is too low to be mined at a profit.

The mine was developed to a depth of 450 feet by an inclined shaft, and considerable drifting was done from this shaft. At the surface, numerous tunnels have been driven into the vein. The water table occurs forty feet below the collar of the shaft, and no ore was mined below the 350-foot level.

Dimmick states that the total production from this mine was 15,000 tons of ore. This ore was hauled to a mill located on the banks of the Colorado River. The total production of bullion is unknown.

TYRO MINE

The Tyro shaft is located about one-half mile to the northeast of the Sheeptrail-Boulevard Mine. The country rock is gneissic granite, coarse grained in texture. Numerous narrow dikes of rhyolite-porphyry occur in the vicinity of the mine. The vein, which consists of a large number of stringers in granite, varies in width from a few feet up to sixty feet. The strike is northeast, and the dip is 85° to the southeast.

The vein consists of granular white quartz and platy calcite; some of the plates of calcite are quite large. A later stage of quartz, glassy and with a yellow color, occurs here, but the grade is rather low. Very likely this yellow quartz represents the second stage of deposition. This vein is a strong one, but the grade as a whole is low; locally, some small pockets of rich ore were found in association with iron and manganese oxides.

The shaft on the Tyro vein is down to a depth of 500 feet, and some drifting on the vein was done at the 200-foot level. The vein has not been found in the deeper levels, and Dimmick believes that it has been displaced by thrust faulting. This mine has had no production other than that from a few small pockets of ore found near the surface.

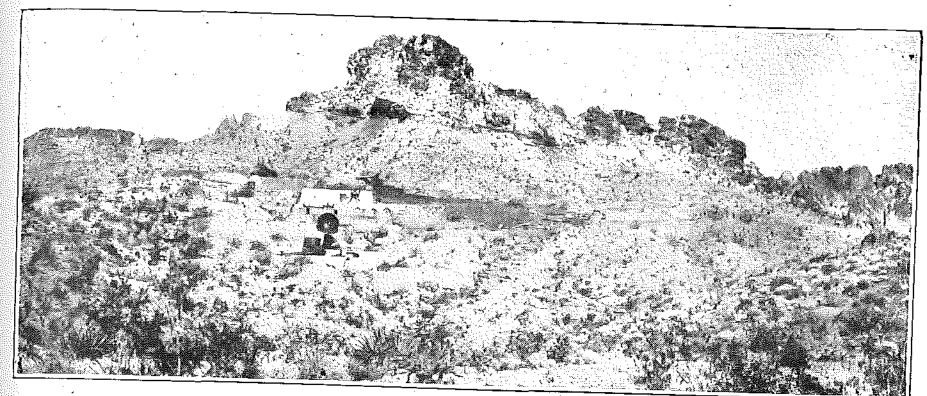


Fig. 29.—View of the Frisco Mine showing the vein at the contact of the rhyolite and granite.

FRISCO MINE

The Frisco Mine is situated in the eastern part of the Katherine District, about eight miles in an easterly direction from the Katherine Mine. The vein occurs in a low hill the base of which is granite, and above the granite is a flow of rhyolite and some rhyolitic tuff. The Frisco vein was located in 1894 and the mine closed in 1914.

The vein occurs at the contact of granite and rhyolite. It strikes N.55°E. and dips to the southeast at 12°. A number of small faults cut the vein, and, in nearly all cases, the offset is only a few feet. At the south end, however, one fault displaces the vein about 100 feet. A fault with a northwest trend drops the west side of the mineralized zone about 35 feet. A vertical section through the mine is shown as Fig. 30. The outcrop of the vein is quite conspicuous because of the abundance of iron oxide which occurs at the contact of the granite and the rhyolite.

Banding is a characteristic feature of the quartz that occurs in this vein. The color is from creamy white to light brown, and

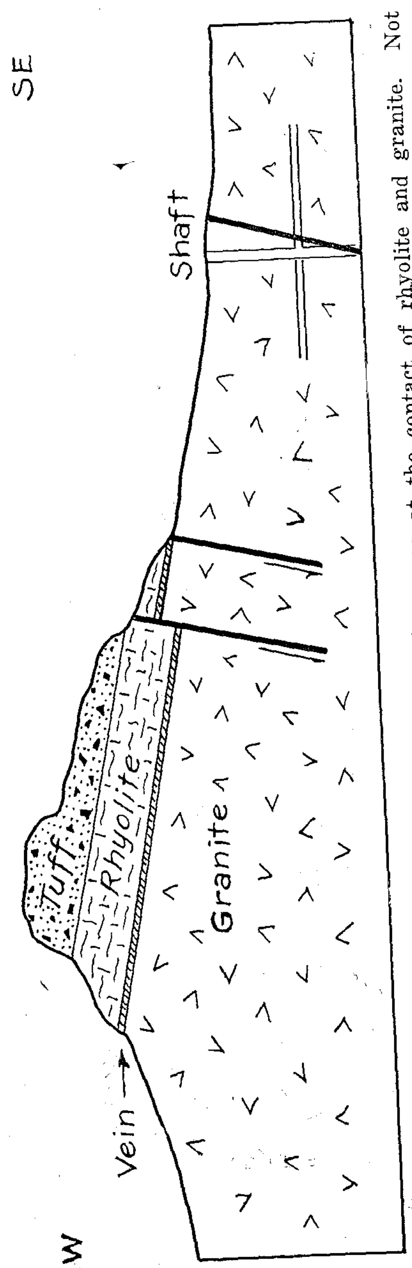


Fig. 30.—Vertical section through the Frisco vein. The vein occurs at the contact of rhyolite and granite. Not drawn to scale.

the texture is chalcedonic. The vein consists of many small stringers which cut the rhyolite. The appearance of much of the ore suggests that the lower portion of the flow was shattered by faulting prior to the introduction of the quartz. Banding occurs around these fragments of rhyolite, and the space between them is not always entirely filled with quartz, but may be a vug lined with quartz crystals. In places, the vein was eighteen feet thick, but most of it was narrower. In the lower portion of the vein, some sections were heavily stained with iron oxides, and these portions of the vein constituted the ore shoots. Iron oxide also occurred in the granite, and some of the iron-stained granite was mined for ore. Frequently it carried high concentrations of gold. Some of this enriched ore, according to R. H. Dimmick, carried $3 per pound in gold.

A second vein, which strikes northeast and dips to the northwest at 65°, occurs in the flat to the southeast of the hill. A shaft was sunk to a depth of 300 feet to explore this vein. All the lateral work was done on the 200-foot level. The vein, which here consists of a mineralized lode with a width up to 59 feet, occurs in granite. The ore is, however, too low grade to mine.

Dimmick estimates the production of the Frisco Mine at 44,000 tons with an average value of $14 per ton.

ARABIAN MINE

The Arabian Mine is located about one mile to the southwest of the Frisco Mine. At this mine, a rhyolite-porphyry dike intrudes granite, and, along the hanging wall of this dike, the rhyolite tuffs have been faulted against the dike. The vein occurs in the dike, close to the fault, and it strikes northwest while the dip is 82° to the southeast.

A mineralized zone, thirty feet wide and consisting of a number of quartz stringers, occurs in the rhyolite dike and, to a certain extent, in the granite footwall. The individual veinlets of this zone vary in width from a fraction of an inch up to twelve inches or more. The veinlets are chiefly quartz, but, in some places, consists of coarse-grained gray calcite. A comb structure is common in the smaller stringers where the quartz crystals are large. The central portion may be vuggy, and the vugs often contain manganese dioxide; occasionally, however, the central part of a veinlet is filled with calcite. Near the hanging wall portion of the lode, a small stringer of fluorite was found. Near the portal of the tunnel is some waxy yellow quartz, a part of which had replaced calcite. No adularia was found in this quartz, but, the best values occur in this portion of the lode. Assays of this tunnel indicate a grade averaging between $5 and $6 per ton, but some assays run as high as $14 per ton.

At the north end of the property, on the Rising Fawn claim, a shaft was put down and exploratory work was done by drifts and crosscuts. Some rich silver ore is said to have been found at this place. A small mill on the property was run on this ore, but no information as to the amount of the bullion produced is available.

FUTURE POSSIBILITIES

While examining a mining district, many data are usually gathered which have an important bearing on future prospecting in the area. In fact, the chief aims of this study of the Oatman and Katherine districts have not been to describe the mines and prospects in great detail and to write a complete history of operations there, but (1) to discover geological facts which may be helpful to operators in the search for additional ore shoots, (2) to indicate in which sections of the districts new ore shoots should be sought, and (3) to determine the possibilities of these districts as future producers of gold and silver. The information that has been obtained, bearing on these points, may be summarized thus:

FACTS APPLICABLE TO THE SEARCH FOR ORE SHOOTS

Outcrops which consist only of stringers of chalcedony and calcite may be worth prospecting in the eastern part of the Oatman District where ore shoots which have not been exposed by erosion may exist.

Excepting in that part of the Oatman District just mentioned, it is useless to prospect veins unless they contain quartz of the 4th or 5th stage of deposition, as described in this report, or unless they show evidence of having been subjected to leaching and supergene enrichment.

Mineralization has been connected with faulting, and veins which contain crushed zones through which run small stringers of 4th- or 5th-stage quartz and associated minerals offer particularly attractive possibilities.

Outcrops which show black manganese stains, no calcite, more or less iron stain in the veins or wall rocks, and occasional low gold values should be prospected in the hope of striking a supergene enrichment of gold.

There is apparently no reason why ore shoots should not be found in any of the igneous rocks that occur in these districts. The wall rocks have suffered little or no replacement, and their effect upon ore deposits has probably been physical rather than chemical. They promoted ore deposition when brittle enough to shatter and provide openings for the passage of solutions and the deposition of minerals.

MOST PROMISING AREAS

Speaking generally, the eastern part of the Oatman District appears to offer greater promise than the western portion because it is believed that ore shoots not yet exposed by erosion may exist there. It may be difficult or impossible, however, to locate veins in the upper latite flows, because they are either very inconspicuous or else differ materially in mineral content from veins which outcrop to the west.

In the western part of the Oatman District, good ore or material that has been leached and enriched below may outcrop. It is, therefore, easier to prospect there than farther east. There, it is not necessary to speculate as to what changes sinking on a barren outcrop will reveal. If 4th- or 5th-stage quartz is present or evidences of supergene enrichment are seen, development should be undertaken. It should be remembered however, that ore shoots in the western part of this district have probably suffered more erosion than to the east, and, once found, may be expected to bottom within a few hundred feet.

POSSIBILITY OF FUTURE PRODUCTION

There is little probability that additional large ore bodies will be found in the Katherine District. Only in the Katherine Mine. there was 4th- or 5th-stage quartz found, and the existence of large bodies of rich primary ore elsewhere in the district is doubtful. Supergene enriched ore, like that in the Sheeptrail-Boulevard and Frisco mines, may be found elsewhere, but such ore bodies are not likely to be important.

Although many veins in the Oatman District have been explored by shafts or drifts at depths of from one to six hundred feet, such exploration has rarely been continuous for the full known lengths of the veins. The portions still unexplored have some potential value, especially if 4th- or 5th-stage quartz was found in the parts already mined.

In spite of the fact that good primary ore has been found at a depth of 1,100 feet below the surface in the Black Eagle Mine of the Tom Reed Company, it is not believed that the chance of finding other ore shoots beneath ore already mined and apparently bottomed is good enough to jusitfy deeper exploration.

It is likely that further prospecting will result in the location of new veins or of new ore shoots in well-known veins that have been previously unproductive, providing that prospectors and miners keep in mind the significant facts about the types of quartz that carry good values, which are set forth in this report. Although the peak production in these districts will probably never again be reached, it is hoped that this report will help extend for several years the period during which the Oatman and Katherine districts are the principal producers of precious metal ore, free from base metals, in Arizona.

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G. M. BUTLER, *Director*

ARIZONA GOLD PLACERS AND PLACERING

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